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Engenharia de Segurança e Higiene Ocupacionais
Faculdade de Engenharia da Universidade do Porto

MANUAL DE RISCOS ELÉTRICOS
INTRODUÇÃO ÀS REDES DE PROTEÇÃO

Gisela Sofia Caridade

Orientador: Professor Doutor António Carlos Sepúlveda Machado e Moura
Faculdade de Engenharia da Universidade do Porto

Arguente: Professor Doutor João Manuel Ribeiro Baptista
Universidade de Trás-os-Montes e Alto Douro

Presidente do Júri: Professor Doutor João Manuel Abreu dos Santos Baptista
Faculdade de Engenharia da Universidade do Porto

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Faculdade de Engenharia da Universidade do Porto
Rua Dr. Roberto Frias, s/n 4200-465 Porto PORTUGAL

VoIP/SIP: feup@fe.up.pt **ISN:** 3599*654
Telefone: +351 22 508 14 00 **Fax:** +351 22 508 14 40
URL: http://www.fe.up.pt **Correio Electrónico:** feup@fe.up.pt

AGRADECIMENTOS

"Nem sempre muitas palavras indicam muita sabedoria." Tales de Mileto

Não se pretende com este trabalho a elaboração de um tratado, mas de um simples manual que funcione como um guia para os Técnicos de Segurança durante a execução de trabalhos na presença da corrente elétrica.

Espera-se que as palavras aqui utilizadas não sejam poucas ou muitas, espera-se que apenas e somente, sejam as adequadas ao estudo em questão e que consigam esclarecer o propósito do trabalho.

Existem alturas na vida em que é preciso muita força de vontade para concretizar os nossos sonhos, esta tese é o concretizar de um sonho. Acontece que no decorrer da busca dos nossos sonhos passamos por um processo de aprendizagem, que vai muito além do conhecimento científico, descobrem-se novos amigos, mas principalmente descobre-se que ainda existem amigos com vontade de ajudar e de nos apoiar.

Uma referência muito especial ao meu Orientador, Professor Doutor Machado E Moura, pela sua disponibilidade e por me facultar caminhos para a obtenção de material para o estudo.

Quero também agradecer à Refinaria de Matosinhos, à minha entidade empregadora ISQ (Instituto de Soldadura e Qualidade), ao IEP (Instituto Eletrótenico Português), ao Francisco Silva, aos Funcionários do laboratório de alta tensão do Departamento de Eletrotécnica e Computadores da FEUP.

Este trabalho é dedicado a todos aqueles que acreditam em mim.

RESUMO

Este documento é realizado no âmbito das disciplinas de Estudo de Caso e da Dissertação do Mestrado de Segurança e Saúde Ocupacionais (MESHO). A realização de dois trabalhos num só documento foi implementada uma vez que se considera que o estudo de caso “Manual para a realização de trabalhos em baixa tensão (BT)” é fundamental para a perfeita compreensão do trabalho a realizar na Dissertação. No estudo é realizada uma primeira abordagem à utilização da energia elétrica, com a introdução das definições e conceitos, passando pela identificação e descrição dos locais de trabalho, finalizando com a implementação de medidas preventivas, definindo um conjunto de preceitos fundamentais para a realização da Dissertação, “ Introdução ao estudo das linhas de terra pelo IEEE Std 80-2000” (IEEE - Institute of Electrical and Electronics Engineers 2000).

O estudo de caso elaborado na forma de manual pretende dar resposta às dúvidas que frequentemente os técnicos de segurança enfrentam durante as operações de manutenção corretiva e preventiva em instalações industriais relativamente aos riscos elétricos. Abrange uma abordagem sucinta aos principais diplomas legais aplicáveis à unidade industrial onde foi realizado o estudo, particularizando depois para as normas jurídicas e para as normas técnicas específicas dos riscos elétricos. Tem por guia da sua estrutura, as Regras Técnicas das Instalações Elétricas de Baixa Tensão (RTIEBT) (Assembleia da República Nº 175 -11 de Setembro de 2006), o Decreto-Lei nº 226/2005, de 28 de Dezembro (Assembleia da República Nº 248 - 28 de Dezembro de 2005), a Declaração de Retificação nº. 11/2006, de 23 de Fevereiro (Assembleia da República Nº 36 - 23 de Fevereiro 2006) e a Portaria nº. 949-A/2006, de 11 de Setembro (Assembleia da República Nº 175 -11 de Setembro de 2006) e o seu objectivo consiste:

- Na abordagem aos conceitos aplicáveis às instalações elétricas;
- Na identificação das instalações elétricas;
- Na identificação dos factores de risco para a execução dos trabalhos;
- Na identificação das medidas preventivas aplicáveis aos trabalhos a desenvolver nas instalações elétricas.

A Dissertação, como desenvolvimento do manual, procede à exemplificação do ponto de vista teórico-prático da utilização da norma IEEE Std 80-2000 (IEEE - Institute of Electrical and Electronics Engineers 2000) para o estudo dos condutores de proteção, nomeadamente o das linhas de terra. O estudo engloba a medição, recolha e análise dos dados recolhidos através de um equipamento.

Palavras-chave: Manual, baixa tensão (BT), Energia elétrica, medidas preventivas, linhas de terra, IEEE Std 80-2000, Regras Técnicas

ABSTRACT

This document has been created in order to fulfil "Estudo de Caso" e a "Dissertação" of MESHO. The combination of the two documents concerns the relation between them, the definitions and specifications of "safety manual in low voltage works" (Estudo de Caso) are fundamental for the development of "Dissertação". The first document introduces definitions and specifications for electrical equipments and places of work and also preventive safety practices for electrical works, essential fundamentals for the study of the application of IEEE Std 80-2000 (IEEE - Institute of Electrical and Electronics Engineers 2000).

As a practical guidance, attempt to achieve safety officers questions, during maintenance tasks on industrial sites (corrective maintenance, preventive maintenance) when workers are in contact with electrical hazards during maintenance activities in industrial zones.

It will be establish an approach to the principal legal documents related to industrial activities, nevertheless, the studied will be concerned in terms of safety standards related to electrical safety. The principal aim regulation standard, for, the execution of this document it will be, the "Decreto-Lei nº 226/2005, de 28 de Dezembro" (Assembleia da República Nº 248 - 28 de Dezembro de 2005), the "Declaração de Retificação nº. 11/2006 de 23 de Fevereiro" (Assembleia da República Nº 36 - 23 de Fevereiro 2006) and the "Portaria nº. 949-A/2006, de 11de Setembro"(Assembleia da República Nº 175 -11 de Setembro de 2006) intended to accomplish:

- An overview of electrical systems concepts;
- The identification and classification of the electrical equipments on site;
- The identification of the hazards works;
- The identification of preventive safety rules according to the hazards works.

The development on this guidance it will be done in the discipline of dissertation, it will consist on a study for grounding grids of substations according to IEEE Std 80-2000 (IEEE - Institute of Electrical and Electronics Engineers 2000) regulations. The analysis includes the measuring and treatment of the values obtained.

Keywords: Guidance, low voltage, electrical energy, safety preventive measures, grounding grids, IEEE Std 80-2000, technical rules

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GLOSSÁRIO/SIGLAS/ABREVIATURAS/

ISQ – Instituto de Soldadura e Qualidade

IEP – Instituto Electrotécnico Português

DEEC – Departamento de Engenharia Electrotecnica e de Computadores

FEUP - Faculdade de Engenharia do Porto

RTIEBT – Regras Técnicas Das Instalações Elétricas de Baixa Tensão

MESHO – Mestrado de Segurança e Saúde Ocupacionais

IEEE - Institute of Electrical and Electronics Engineers

OSH - Occupational Safety and Health Network

OSHA - Occupational Safety & Health Administration

CERN – Centro Europeu de Pesquisa Nuclear

IST – Instituto Superior Técnico, Lisboa.

EPI – Equipamento de Proteção Individual

OIT – Organização Internacional do Trabalho

REAI – Regime de Exercício da Actividade Industrial

IPQ - Instituto Português da Qualidade

SPQ – Sistema Português da Qualidade

CEN - European Committee for Standardization

NIOSH - National Institute for Occupational Safety and Health

CENELEC - European Committee for Electrotechnical Standardization

CGPM - Conference General des Poids et Mésures

OIML - International Organization for Legal Metrology

ISO - International Organization for Standardization

ESFI - Electrical Safety Foundation International

BlS - U.S.Labor Statistic´s

SOII – Survey of Occupational Injuries

IEC – Comissão Electrotécnica Internacional

VEI – Vocabulário Electrotécnico Internacional

BT – Baixa Tensão

MT – Média Tensão

TRS – Tensão Reduzida de Segurança

TRP – Tensão Reduzida de Proteção

1 INTRODUÇÃO

No âmbito Do Mestrado de Engenharia de Segurança e Higiene Ocupacionais, este trabalho foi realizado tendo por base uma intervenção numa pequena unidade de transformação de energia, numa unidade industrial de atividade petroquímica e pretende compilar soluções orientadoras para as dúvidas que surgem aos técnicos de segurança, durante a implementação dos princípios gerais de prevenção em meio laboral tendo por base os principais fatores que contribuem para a ocorrência dos acidentes elétricos e fornecer um estudo teórico-prático de aplicação da norma IEEE Std 80-2000 (IEEE - Institute of Electrical and Electronics Engineers 2000).

A energia elétrica está presente no nosso quotidiano em quase tudo o que fazemos. Embora tenha ocorrido uma alteração nas fontes energéticas de produção de eletricidade, ao nível da utilização das chamadas fontes limpas, os riscos inerentes à utilização da energia elétrica continuam a imperar.

Atualmente, ao nível do território nacional, tem-se assistido à reconversão das unidades de produção, transformação e distribuição de energia elétrica em muito motivada pela política nacional de utilização de fontes mais limpas, "Portugal Eficiência 2015" de acordo com a Resolução do Conselho de Ministros nº 80/2008 (Assembleia da República Nº 97- 20 de Maio de 2008). Nas unidades industriais, é aplicável o programa Sistema de Eficiência Energética na Indústria, que engloba várias medidas dirigidas a quatro grupos tecnológicos, motores elétricos, produção de calor e frio, iluminação e outras medidas para a eficiência no processo industrial.

A maioria das unidades industriais, tem acompanhado esta evolução e tem efetuado alterações nas unidades de produção, transformação e distribuição. Habitualmente estas operações de alteração dos equipamentos existentes desenvolvem-se de acordo com trabalhos planeados de manutenção.

Apresenta-se um excerto relativo à definição das operações de manutenção retirado do relatório "Maintenance and OSH – A statistical Picture" (Agência Europeia para a Segurança e Saúde no Trabalho ISSN 1681-2166 2010-2011):

"Maintenance concerns the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function. A maintenance function is critical to:

- Ensure continuous productivity;
- Produce products of high quality;
- Maintain a company's competitiveness "

Perante as novas formas de gestão, as unidades industriais deixaram de realizar este tipo de trabalhos, sendo que estes passam a ser executados por entidades externas, o que não deixa de ser outro fator importante a considerar pelo técnico de segurança durante a implementação das medidas de prevenção.

De acordo com um estudo efectuado pela Occupational Safety and Health Network (OSH), através do relatório "Maintenance and OSH – A statistical Picture"(European Agency for Safety and Health at Work ISSN 1681-2166 2010), a maioria dos riscos a que os trabalhadores estão sujeitos estão relacionados com:

- As condições do local de trabalho;

- Os equipamentos utilizados;

- O tipo de energia utilizada (elétrica, pneumática, hidráulica);

- O ambiente de trabalho;

- Os agentes químicos e biológicos a que os trabalhadores estão sujeitos.

Neste estudo os riscos que vão ser alvo do estudo, serão os riscos elétricos, uma vez que estes são aqueles sobre os quais considero que existe uma lacuna relativamente à informação existente (Miguel 2006).

Com este manual pretende-se responder a algumas perguntas tais como:

- Quais são os principais riscos elétricos?
- Qual a melhor e mais adequada proteção contra os riscos elétricos?
- Quais são os equipamentos de proteção para os riscos elétricos?
- Como identificar os equipamentos de proteção?
- Que tipo de proteção é garantida pelos vários tipos de isolamento?
- Quais os tipos de isolamentos existentes?
- Quais as melhores práticas de trabalho para as atividades com exposição ao riscos elétrico?
- Como utilizar uma norma técnica e jurídica para a realização de ensaios?

Neste estudo não serão considerados os equipamentos de proteção individual (EPI'S). Os EPI'S requerem um processo de criteriosa seleção de forma a poderem garantir uma proteção adequada para além da sua simples utilização. Este estudo é fundamentalmente baseado nas medidas que têm de ser implementadas ao nível dos equipamentos elétricos.

2 ESTADO DA ARTE

2.1 Breve perspetiva histórica dos riscos da eletricidade

A descoberta da eletricidade é atribuída a Thales de Mileto (634 A.C.- 548 A.C.), filósofo, astrónomo, e matemático. Thales de Mileto ao esfregar um pedaço de âmbar numa pele de carneiro, observa que este atrai pedaços de palha, testemunhando uma manifestação de eletricidade estática. A palavra eletricidade tem as suas raízes na palavra grega para o âmbar, elektro (Infopedia 2012).

Ao longo do tempo a eletricidade tem vindo a ser alvo de vários avanços tecnológicos, sendo considerada um ramo da física que estuda os fenómenos que resultam da existência de partículas com carga elétrica. Está sujeita à lei de conservação da energia e é uma das formas que esta pode adotar, originando vários fenómenos caloríficos, mecânicos, luminosos entre outros (Infopedia 2012).

Dependendo do sinal das cargas elétricas, estas desencadeiam forças elétricas de atração e repulsão. Estas forças possuem uma intensidade que é maior que a das forças gravíticas, sendo originadas mediante distribuições adequadas das cargas, o que provoca o aparecimento de campos elétricos (Infopedia 2012).

Para além de Thales de Mileto, muitas outras descobertas relativas à utilização da carga elétrica foram efectuadas aos longos dos tempos(Infopedia 2012):

- Em 1620, Niccolo Cabeo descobriu que a eletricidade estática pode ser atrativa e repulsiva;

- Em 1745, Pieter Van Musschenbroek inventou a garrafa de Leyden, ou condensador;

- Em 1747, Benjamin Franklin propôs a teoria da eletricidade com um só fluido, segundo a qual só existe, na realidade, um dos fluidos de Nollet, sendo o outro fluido apenas a ausência do primeiro. Propôs o princípio da conservação da carga elétrica e chamou ″positivo″ ao fluido que existe. Franklin descobriu ainda que a eletricidade pode atuar a uma distância em situações em que a teoria como um só fluido não faz sentido. Bemjamin Franklin inventou o pára-raios;

- Em 1748, Sir William Watson utilizou uma máquina eletrostática e uma bomba de vácuo para fazer a primeira descarga luminosa, construindo a primeira lâmpada de luz florescente;

- Em 1785, Charles Augustin de Coulomb publica os estudos sobre medição das forças de atração e repulsão entre dois corpos eletrizados (Lei de Coulomb), inventando aquilo que veio a ficar conhecido por balança de Coulomb;

- Em Março de 1800, o físico italiano Alessandro Giuseppe Antonio Anastasio Volta apresentou à Sociedade Real de Londres a descrição da primeira pilha geradora de corrente elétrica;

- Em 1820, Hans **C**hristian Oersted descobriu o eletromagnetismo;

- Em 1830, Michael Faraday, expõe as leis fundamentais do eletromagnetismo, após a realização de enumeras experiências;

- Em 1832, James Clerk Maxwell através do seu trabalho consegue reproduzir as leis fundamentais de Faraday através de uma expressão matemática, que significa que a *"quantidade de eletricidade" produzida pelo magnetismo era igual à taxa de variação da força causadora*. Através das fórmulas de Maxmell é possível estabelecer a relação entre a eletricidade e o eletromagnetismo;

- Em outubro de 1879, após anos de pesquisas custeadas pela Edison Eletric Light Company, Thomas Edison conseguiu a patente da lâmpada dotada de um filamento de carvão muito fino, mantido no interior de um bulbo de vidro submetido a vácuo. Em 1883 patenteou a chamada válvula de Edison, precursora da válvula de rádio, formada por uma lâmpada incandescente com uma placa metálica no interior, em volta do filamento. Denomina-se efeito Edison a emissão de elétrons e consequente aparecimento de corrente do filamento para a placa;

- Em 1897, Joseph John Thomson descobriu o eletrão, como consequência de várias experiências que tinha realizado com raios catódicos. Esta descoberta contribuiu para que em 1906 lhe tivesse sido atribuído o Prémio Nobel da Física;

- Em 1905, Albert Einstein, publicou, na revista Annalen der Physik, um artigo intitulado *Zur Electrodynamik Bewegter Korper* (sobre a Eletrodinâmica de Corpos em Movimento), que constitui a essência do que é hoje conhecido sob a designação da Teoria da Relatividade Restrita;

- Em 1930, H. Freiberger e L.P. Ferris iniciaram as pesquisas relativas ao efeito da passagem da corrente elétrica no corpo humano às quais se seguirem os de C. E Dalziel, W.B. Kouwenhoven, W.R. Lee, P. Osypka, H. Antoni entre outros;

- Em 1947, foi inventada nos laboratórios Beel Telephone o primeiro transistor;

-Em 1959,Jack Kilby, da Texas Instruments, e Robert Noyce, da Fairchild Semicondutor deram início à revolução da microeletrônica ao desenvolver o primeiro circuito integrado;

-Em 1973, Jonh Bardeen, Leon Cooper, Robert Schrieffer implementam o desenvolvimento da teoria microscópica da supercondutividade, hoje conhecida como Teoria BCS;

- Em 1974 é publicada a norma internacional relativa à proteção contra os choques elétricos em instalações elétricas, publicação nº479 da IEC (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994)*"Effects of current passing through the human body";*

-Em 1983 Karl Muller, Georg Bednorz descobrem a supercondutividade a altas temperaturas num cuprato de lantânio e bário;

- Em 2003 Vitaly Ginzburg e Alexei Abricosov desenvolvem a teoria fenomenológica da supercondutividade e ajudaram a elucidar fenómenos quânticos com consequências observáveis no mundo macroscópico: a supercondutividade e a superfluidez;

- Em 2012, o físico teórico Eef van Bevere utilizou os resultados de experiências realizadas nos aceleradores de partículas de Bona (Alemanha) e do CERN (Centro Europeu de Pesquisa Nuclear), na Suíça, através de um modelo, desenvolvido em conjunto com o cientista George Rupp, do Instituto Superior Técnico, Lisboa. O modelo, que permite prever um infinito de ressonâncias de combinações quark-antiquark (mesões), varreu todos os eventos registados nas experiências, mesmo os considerados irrelevantes, e num determinado espaço, um ínfimo espaço, registou uma quantidade de 45 mil eventos com 13 sigma significância, o que é considerado mais que suficiente para a existência de uma partícula, o bosão, esta nova partícula é 25 vezes mais leve do que um protão e, apesar de ainda serem necessários muitos estudos para avaliar as suas propriedades e o seu armazenamento, as implicações desta descoberta são de longo alcance, não apenas para física hadrónica (física das partículas que estuda as interacções fortes), mas também para física das altas energias e cosmologia;

Não se pretende com a descrição anterior expor todas as experiências e descobertas relativas à carga elétrica, pretende-se sim, tentar demonstrar a evolução desta ciência, tão fundamental e imprescindível para o mundo.

Inicialmente as descobertas limitavam-se às observações dos fenómenos da natureza, muitas das vezes atribuídos a manifestações pagãs. Com o evoluir das constatações surge a necessidade de estabelecer um conhecimento mais profundo dos fenómenos observados. São então criados laboratórios e equipamentos onde seja possível reproduzir os fenómenos naturais.

Quando é finalmente possível reproduzir, explicar e controlar os fenómenos naturais da actividade das cargas elétricas, esta nova forma de energia passa a ser utilizada para os mais diversos fins (iluminação pública, utilização em máquinas industriais, aquecimento).

A 17 de Dezembro de 1909 é publicado por Elihu Thomson na revista "Science"(Thomson 1909), um artigo sobre o início, o desenvolvimento e utilização da carga elétrica, neste documento é atribuído ao ano 1879 o início da utilização da eletricidade na indústria.

No entanto com o decorrer da utilização da carga elétrica, verifica-se que o seu controlo não é tão eficiente como se julgava e que para além das vantagens existem também desvantagens. São inúmeros os acidentes provenientes dos riscos relativos à utilização desta nova fonte, George Westinghouse, Jr. No seu artigo "A Reply to Mr. Edison (Westinghouse 1889) alerta para os perigos que advêm dessa utilização:

*"**The use of electricity for supplying light and power has now become as much a part of our every-day life as the railway, the steamship, the street-car, or the gas supply. In fact, we live in a time when power is made in every way subservient to the comfort of the people. It is employed in nearly every useful industry, with a full knowledge that such employment has been and always must be attended with an appreciable degree of danger. Electricity is one manifestation of power"*** (Westinghouse 1889).

Com a constatação de que os equipamentos elétricos utilizados no período acima referido necessitam de ser melhorados e sujeitos a um controlo mais eficaz, passa-se a transcrever uma das resoluções imanadas pela convenção anual da "Edison Illumination Companies at Niagara, de Agosto de 1889, que constam do artigo referido (Westinghouse 1889):

"The address of Sir William Thomson, as president of the physical section of the British Association in 1882, contained this memorable passage: ' Nothing above 200 volts, on any account, ever should be admitted into a ship or house or other place where safeguards cannot be made absolutely and forever trustworthy against all possible accident.' This opinion accords with what Mr. Edison has always maintained - that in the long run every system will fail which does not (for domestic service) use a low-pressure curren"(Westinghouse 1889***).***

2.2 Enquadramento Legal e Normativo

As fontes de direito internacional, a Declaração Universal dos Direitos do Homem (1948), a Convenção Europeia dos Direitos do Homem (1950), a Carta Social Europeia (1961) e a Directiva nº89/391/CEE, de 12 de Junho de 1989, foram as precursoras do actual regime jurídico da promoção e prevenção da segurança e saúde no trabalho (Quintas 2006).

A Carta Social Europeia concerne todas as normas contidas nas convenções da Organização Internacional do Trabalho (OIT) (Quintas 2006).

A Convenção nº 155, de 22 de Junho de 1981, regula a segurança e a saúde dos trabalhadores e o ambiente de trabalho, e é considerada assim como a Directiva nº89/391/CEE, de 12 de Junho de 1989, uma Convenção Quadro (Quintas 2006).

A Directiva nº89/391/CEE, de 12 de Junho de 1989, tem por objectivo “ a execução de medidas destinadas a promover o melhoramento da segurança e da saúde dos trabalhadores no trabalho (art.1º, n.º 1). Segundo Fernando Cabral e Manuel Roxo “ O quadro preexistente à (presente) Directiva era caracterizado por um conjunto de regras de conformidade técnica dos locais e dos equipamentos de trabalho quanto a determinados riscos específicos, daí resultando uma abordagem preventiva da natureza corretiva. Aquela Directiva veio introduzir uma nova ótica, configurada numa obrigação de resultado, que consiste na responsabilidade transferível de o empregador assegurar a segurança e saúde dos trabalhadores em todos os aspetos relacionados com o trabalho (vd. Artigo 5º da Directiva) (Quintas 2006).

2.2.1 Legislação

O início do planeamento deste manual teve por base os normativos jurídicos definidos pela legislação portuguesa, de forma a implementar medidas de prevenção e limitação da exposição dos trabalhadores e de toda a envolvente da instalação industrial aos acidentes graves envolvendo substâncias perigosas e os riscos elétricos. Tendo em consideração o enquadramento legal descrevem-se os principais diplomas legais aplicáveis:

O atual regime jurídico da promoção e prevenção da segurança e saúde no trabalho, Lei 102/2009 de 10 de Setembro, introduz uma nova referência no âmbito da prevenção dos riscos profissionais nomeadamente ao nível do regime de licenciamento, artigo 12º, Licenciamento e autorização de laboração**:** **“** *A legislação sobre licenciamento e autorização de laboração contém as especificações adequadas à prevenção de riscos profissionais e à proteção da saúde”* (Assembleia da República Nº 176 - 10 de Setembro de 2009)*;*

O Regime de Exercício da Atividade Industrial (REAI). O REAI encontra-se legislado através do Decreto-lei nº 209/2008 de 29 de Outubro. Assim como no diploma anteriormente mencionado, procede à implementação dos princípios gerais de prevenção na fase de projecto, no artigo 21º, ponto 2, onde nos elementos instrutórios definidos na secção 1 do anexo IV, ponto 9 alínea c), passam a ser incluídos os princípios de Segurança e saúde no trabalho e segurança industrial (Assembleia da República Nº 209 - 29 de Outubro de 2008);

O Regulamento Geral de Segurança e Higiene do Trabalho nos Estabelecimentos Industriais, aprovado pela Portaria nº 53/71, de 3 de Fevereiro, posteriormente alterado pela Portaria nº 702/80, de 22 de Setembro (Assembleia da República Nº 219 - 22 de Setembro de 1980);

O Regulamento de Segurança de Instalações de Utilização de Energia Elétrica e o Regulamento de Segurança de Instalações Coletivas de Edifícios e Entradas, aprovadas pelo Decreto-Lei nº 226/2005, de 28 de Dezembro com a respetiva declaração de Retificação nº11/2006, de 23 de Fevereiro e pela Portaria nº 949-A/2006 de 11 de Setembro(Assembleia da República Nº 175 -11 de Setembro de 2006);

As Regras Técnicas das Instalações Elétricas de Baixa Tensão foram objecto dos procedimentos de notificação à Comissão Europeia previstos no Decreto-Lei n.º 58/2000, de 18 de Abril, que transpôs para o direito interno a Directiva n.º 98/34/CE, do Parlamento Europeu e do Conselho, de 20 de Julho (Assembleia da República Nº 175 -11 de Setembro de 2006).

Figura 1 – Exemplo de um quadro de gavetas

2.2.2 Normas

De acordo com o artigo 11º da Lei 102/2009 de 2009:

"1 — As normas e especificações técnicas na área da segurança e da saúde no trabalho relativas, nomeadamente, a metodologias e a procedimentos, a critérios de amostragem, a certificação de produtos e equipamentos são aprovadas no âmbito do SPQ.

2 — As directrizes práticas desenvolvidas pela Organização Internacional do Trabalho e Organização Mundial de Saúde, bem como as normas e especificações técnicas nacionais a que se refere o número anterior, constituem referências indispensáveis a ser tidas em conta nos procedimentos e medidas adoptados em cumprimento da legislação sobre segurança e saúde no trabalho, bem como na produção de bens e equipamentos de trabalho"(Assembleia da República Nº 176 - 10 de Setembro de 2009).

Do ponto de vista das especificações técnicas no âmbito deste guia devem ser consideradas duas vertentes sendo ambas tuteladas em Portugal pelo Instituto Português da Qualidade (IPQ).

A primeira do ponto de vista da orientação para os fundamentos da implementação do sistema de prevenção de Riscos Profissionais, a segunda na vertente da implementação das regras técnicas aplicáveis aos equipamentos elétricos (componentes materiais do trabalho).

" O Instituto Português da Qualidade (IPQ) é um instituto público que, nos termos da sua lei orgânica aprovada pelo Decreto-Lei n.º 71/2012, de 21 de Março, tem por missão a coordenação do Sistema Português da Qualidade (SPQ) e de outros sistemas de qualificação regulamentar que lhe forem conferidos por lei, a promoção e a coordenação de atividades que visem contribuir para demonstrar a credibilidade da ação dos agentes económicos, bem como o desenvolvimento das atividades inerentes à sua função de laboratório nacional de metrologia (IPQ - Instituto Português da Qualidade 2012).

No que concerne à participação ao nível internacional, o IPQ assegura a representação de Portugal em inúmeras estruturas europeias e internacionais relevantes para a sua missão, designadamente, no European Committee for Standardization (CEN), no European Committee for Electrotechnical Standardization (CENELEC), na International Electrotechnical Commission (IEC), na Conference General des Poids et Mésures (CGPM), na International Organization for Legal Metrology (OIML), e na International Organization for Standardization (ISO)" (IPQ - Instituto Português da Qualidade 2012).

2.3 Conhecimento Científico

Desde a fase inicial de aplicação da eletricidade à industria que se coloca a problemática da segurança dos equipamentos e das instalações. A carga elétrica não é visível, os seus efeitos nefastos só são percetíveis após a ocorrência de incidentes, perante esta problemática é necessário formar e sensibilizar os trabalhadores para os riscos associados à exposição à corrente elétrica. De acordo com o definido na regulamentação, este tipo de trabalho só deve ser realizado por profissionais qualificados e instruídos, no entanto ficam por definir os limites de atuação do técnico de segurança, profissional que procede à implementação das actividades no domínio da segurança (INTECHOPEN).

De acordo com estudos recentes as principais lacunas associadas aos incidentes elétricos estão relacionadas com a falta de conhecimento dos reais perigos e riscos a que os trabalhadores estão sujeitos em ambiente elétrico. Todos os profissionais com atividades nesta área devem ter formação adequada para que sejam capazes de identificar e avaliar os riscos elétricos de forma a poderem implementar estratégias de controlo e reconhecimento dos reais perigos e riscos (Cadick , Schellpeffer et al. 2006).

De acordo com Alberto Sérgio Miguel no livro “Manual de Higiene E Segurança Do Trabalho”, existe uma significativa insuficiência de dados estatísticos (Miguel 2006).

Através de um estudo efectuado pela Electrical Safety Foundation International (ESFI) que teve por base um estudo estatístico realizado pela U.S.Labor Statistic´s (BlS) aos incidentes de trabalhos (mortais e não mortais), ocorridos no sector elétrico em função do tipo de fonte de dano, nos Estados Unidos entre 2003-2010, foi possível ter uma perspetiva da distribuição do número de acidentes mortais por tipo de contato: contato com a corrente elétrica, contato com as linhas áreas de alta tensão, contato por arco elétrico, contato com equipamentos elétricos, contato com cabos elétricos e transformadores.

Os acidentes não mortais englobam os choques elétricos e queimaduras, numa população de 230000 trabalhadores por ano. Os acidentes mortais foram contabilizados através de certidões de óbito, relatórios policiais e artigos de jornais tendo em consideração os trabalhadores com mais de 16 anos de idade. Durante o estudo foi determinado que seria relevante a obtenção de mais informação nomeadamente ao nível do setor industrial, assim como é notória a redução dos incidentes, num período de 15 anos, resultante de uma cultura de segurança (Bureau of Labor Statistics 2010).

Através do gráfico (figura 2) apresentado é possível ter uma perceção da distribuição dos acidentes elétricos por atividade. O principal setor de atividade onde ocorre a maior percentagem de mortes é o das linhas aéreas de alta tensão, cerca de 44%, com um registo de 2% em acidentes não mortais. O segundo setor é relativo ao contato com cablagem, transformadores e componentes elétricos, com 27% relativo a acidentes mortais e 37% acidentes não mortais. O terceiro setor abrange o contato com máquinas, ferramentas e sistemas de iluminação, atividades relacionadas com manutenção elétrica com 17% de acidentes mortais e 35% de acidentes não mortais. A restante distribuição de acidentes está relacionada com o contato com redes elétricas enterradas. Foi ainda regista a morte de 45 trabalhadores por descargas elétricas atmosféricas e 27 trabalhadores morreram por circunstâncias não determinadas (Bureau of Labor Statistics 2010).

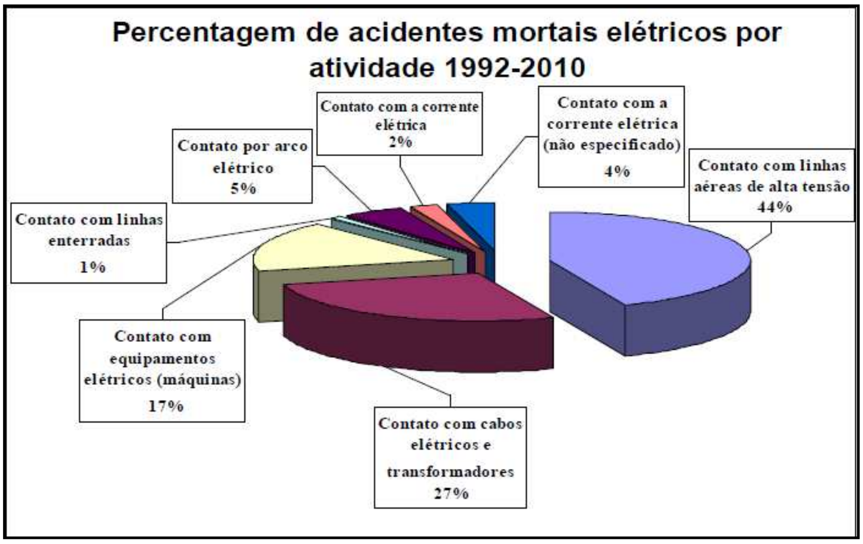


Figura 2 – Gráfico de acidentes mortais elétricos (Bureau of Labor Statistics 2010)

De acordo com o Regime jurídico da promoção da segurança e saúde no trabalho, a entidade empregadora deve focalizar a sua acção na prevenção de acordo com os princípios gerais de prevenção. A Lei 102/2009 refere que a entidade empregadora deve proceder à identificação dos riscos previsíveis em todas as atividades da empresa, estabelecimento ou serviço, na conceção ou construção de instalações, de locais e processos de trabalho, assim como na seleção de equipamentos, substâncias e produtos, com vista à eliminação dos mesmos ou, quando esta seja inviável, à redução dos seus efeitos (Assembleia da República Nº 176 - 10 de Setembro de 2009).

Deve ainda na aplicação das medidas de prevenção, organizar os serviços adequados, internos ou externos à empresa, estabelecimento ou serviço, mobilizando os meios necessários, nomeadamente nos domínios das atividades técnicas de prevenção, da formação e da informação, bem como o equipamento de proteção que se torne necessário utilizar.

Para que o técnico de segurança possa avaliar as condições de trabalho nos equipamentos e nas instalações elétricas deve estar familiarizado com os referenciais técnicos (2.4) que deve aplicar, neste contexto surge este trabalho com o intuito de contribuir para a aquisição de informação sobre como identificar os perigos e riscos nas atividades que envolvem a interação com a energia elétrica.

2.4 Referenciais Técnicos

"As Regras Técnicas definem um conjunto de normas de instalação e de segurança a observar nas instalações elétricas de utilização em baixa tensão (Assembleia da República Nº 175 -11 de Setembro de 2006)."

A Directiva 2006/95/CE do Parlamento Europeu e do Conselho, de 12 de Dezembro de 2006, relativa à harmonização das legislações dos Estados-Membros no domínio do material elétrico destinado a ser utilizado dentro de certos limites de tensão determina que em virtude da livre circulação e comércio de equipamentos elétricos, assim como de forma a atingir o objetivo de segurança, através da implementação de medidas preventivas e repressivas e de forma a uniformizar os critérios de conceção dos equipamentos elétricos (Parlamento Europeu do Conselho 2006):

- As normas são consideradas harmonizadas quando, tendo sido elaboradas de comum acordo pelos organismos notificados pelos Estados-Membros nos termos da alínea a) do primeiro parágrafo do artigo 11º, forem publicadas de acordo com as legislações nacionais. As normas devem ser atualizadas em função do progresso tecnológico e da evolução das regras da arte em matéria de segurança (artigo 5º) (Parlamento Europeu do Conselho 2006);

- Sempre que não existam, elaboradas e publicadas, normas harmonizadas nos termos do artigo 5º, e tendo em vista a colocação no mercado referida no artigo 2º ou a livre circulação referida no artigo 3º, os Estados-Membros devem tomar todas as medidas necessárias para que as respetivas entidades administrativas competentes considerem que um material elétrico está de acordo com o disposto no artigo 2º desde que satisfaça as regras de segurança da Comissão Internacional das Regulamentações para a Aprovação de Equipamento Eléctrico (CEE-el), ou da "International Electrotechnical Commission" (IEC — Comissão Electrotécnica Internacional) que respeitem o processo de publicação previsto nos n.^{os} 2 e 3 (artigo 6º) (Parlamento Europeu do Conselho 2006).

Tendo por referência a Directiva 2006/95/CE, segue-se a transcrição de um excerto das regras técnicas das instalações de baixa tensão:

"Na elaboração deste documento são considerados os documentos de harmonização relevantes do Comité Europeu de Normalização Electrotécnica (CENELEC) e da Comissão Electrotécnica Internacional (IEC), bem como utilizados termos contidos no Vocabulário Electrotécnico Internacional (VEI), que se reputam importantes para a compreensão daqueles textos. Por esta razão, a ordenação das oito partes em que se subdividem as Regras Técnicas respeita a estrutura seguida pela IEC e adotada pelo CENELEC, de forma a facilitar futuras atualizações decorrentes daqueles documentos de harmonização."(Parlamento Europeu do Conselho 2006)

As tabelas e figuras que se apresentam são o resultado da aplicação do norma internacional relativa à proteção contra os choques elétricos em instalações elétricas, publicação nº479 da IEC "*Effects of current passing through the human body*", que consolida os estudos realizados sobre a segurança em instalações elétricas. Os resultados da ação da corrente elétrica sobre o homem em função da intensidade da corrente, da frequência e variação brusca da corrente, da duração do efeito, do percurso e da impedância do corpo humano são apresentadas nas seguintes tabelas e gráficos (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994). Optou-se pela colocação das tabelas e figuras neste subcapítulo uma vez que funcionam como referencias de consulta, sendo mais fácil a sua consulta num subcapítulo do que nos vários capítulos do manual.

Tabela 1 – Tabela de impedância total do corpo humano válida para adultos vivos, para um circuito de corrente mão-mão ou mão-pé, para áreas de contato de 50 a 100cm^2 e em condições secas (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994)

Tensão de contato (Volts)	**Impedância total em ohms do corpo humano que não são excedidos por**		
	5% da população	50% da população	95% da população
25	1750	3250	6100
50	1450	2625	4375
75	1250	2200	3500
100	1200	1875	3200
125	1125	1625	2875
220	1000	1350	2125
700	750	1100	1550
1000	700	1050	1500
Valor assimptótico	650	750	850

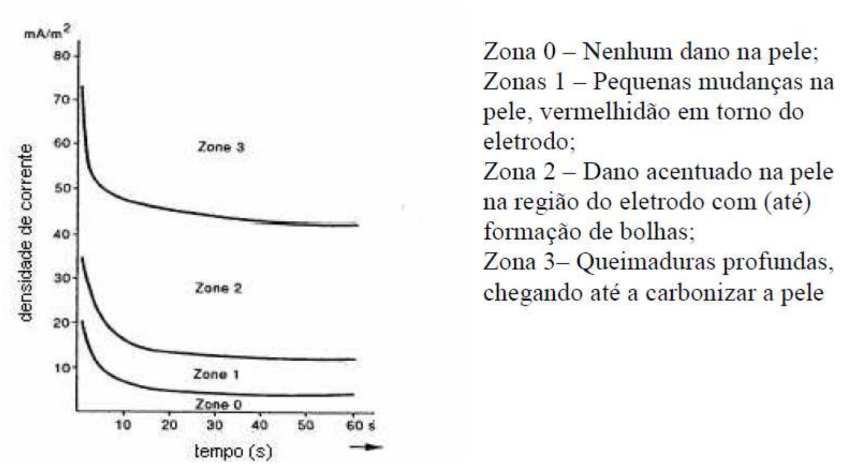
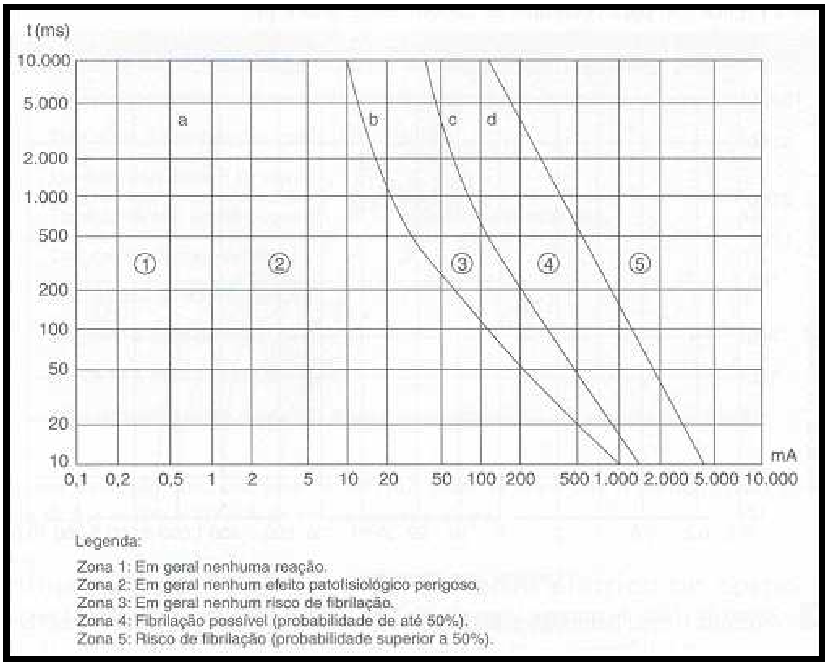


Figura 3 – Danos na pele humana (fonte Kindermann, 2000)

Tabela 2 – Principais valores de intensidade com efeitos notórios sobre o corpo humano (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994)

I(A)	Efeitos sobre o corpo humano
20 a 100.10^{-6}	Fibrilação ventricular para sinais elétricos aplicados diretamente ao nível do miocárdio ou do encéfalo e de f <1000Hz
$0,02.10^{-3}$	Perceção sensorial ao nível da retina: fosfeno
$0,045.\ 10^{-3}$	Perceção sensorial da língua (Dalziel)
$0,1.\ 10^{-3}$	Ligeiras contrações musculares dos dedos (Weber)
$0,8.\ 10^{-3}$	Perceção cutânea na mulher (Dalziel)
$1.\ 10^{-3}$	Perceção cutânea para o homem
$6.\ 10^{-3}$	Perceção cutânea dolorosa e de não largar (valor de disparo de certos dispositivos diferenciais a muito alta sensibilidade)
$8,8.\ 10^{-3}$	Impossibilidade de autolibertação (não largar) para 0,5% dos indivíduos (Dalziel)
$10.\ 10^{-3}$	Limiar de não largar definido pela CEI
$15,5.\ 10^{-3}$	Impossibilidade de autolibertação para 100% dos indivíduos
$20.\ 10^{-3}$	Possibilidade de asfixiar se t >3 minutos e se o trajeto da corrente atinge o diafragma (ex.: contacto mão-mão)
$25.\ 10^{-3}$	Limite da categoria I de Koeppen (não há repercussão no ritmo cardíaco nem sobre o sistema nervoso)
$30.\ 10^{-3}$	Possibilidade de fibrilação ventricular (probabilidade >50% se t>1,5 do ciclo cardíaco) (Biegelmeier)
$70.\ 10^{-3}$	Fibrilação ventricular para $t \geq 1$ segundo (Koeppen)
$80.\ 10^{-3}$	Fibrilação ventricular quase certa se $t \geq 1$ segundo (Koeppen, Dalziel,…)
2 a 3	Inibição dos centros nervosos no ser humano
20	Queimaduras muito importantes, mutilações

Figura 4 – Zonas de efeito de corrente alternada (de 50 e 60 Hz) sobre adultos (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994)



Através da figura 4 são definidas 5 zonas de efeitos para correntes alternadas de 50 a 60 Hz, tendo em consideração pessoas que pesam 50kg, num trajeto de corrente entre as extremidades do corpo (mão/mão ou mão/pé).

Zona 1 – Nesta zona a corrente elétrica não produz reação alguma no corpo humano. Situa-se abaixo do chamado limiar de perceção (0,5 mA) e é representada pela reta a da Figura 4;

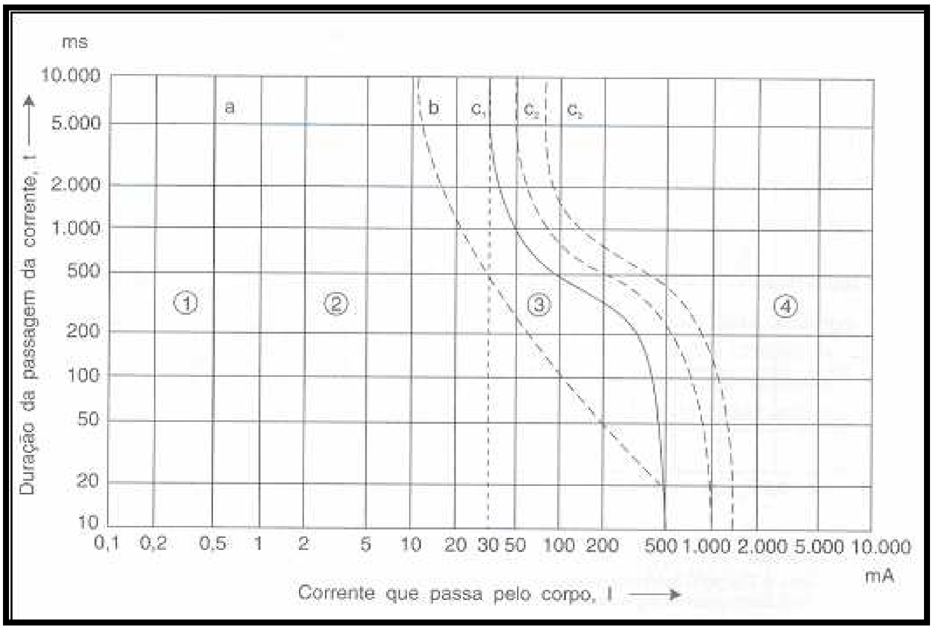
Zona 2 – Nesta zona a corrente não produz nenhum efeito patofisiológico perigoso. Está entre o limiar de perceção e a curva limite de corrente patofisiologicamente perigoso (curva b);

Zona 3 – Esta zona é compreendida entre a curva b e a curva c, não há risco de fibrilação ventricular, mas a corrente pode provocar outros inconvenientes, tais como: paragem cardíaca, paragem respiratória e contrações musculares, geralmente reversíveis;

Zona 4 – Nesta zona a corrente do choque elétrico pode provocar fibrilação ventricular, com uma probabilidade que vai de 0,5% (curva c) a 50% (curva d);

Zona 5 – Esta zona encontra-se situada após a curva d, existe o perigo efetivo da ocorrência de fibrilação ventricular.

Figura 5 – Zonas de efeito de corrente alternada (de 15 a 100 Hz) entre mão e pé sobre as pessoas (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994)



Através da figura 5, para a corrente alternada com frequência de 15 a 100Hz, é possível caracterizar 4 zonas, para correntes de choque entre mão e pé:

Zona 1 – Nesta zona não ocorre nenhuma reação;

Zona 2 – Nesta zona não ocorre nenhum efeito fisiológico perigoso;

Zona 3 – Nesta zona não acontece, em geral, nenhum dano orgânico. Para tempos longos ocorrem contrações musculares, dificuldade de respiração e perturbações reversíveis no coração. Sendo limitada pelas curvas b e c_1;

Zona 4 – Nesta zona acorrem os efeitos referidos na zona 3, no entanto a probabilidade de fibrilação ventricular aumenta cerca de 5% (curva C_2) a 50% (curva C_3) e acima de 50% além da curva C_4.

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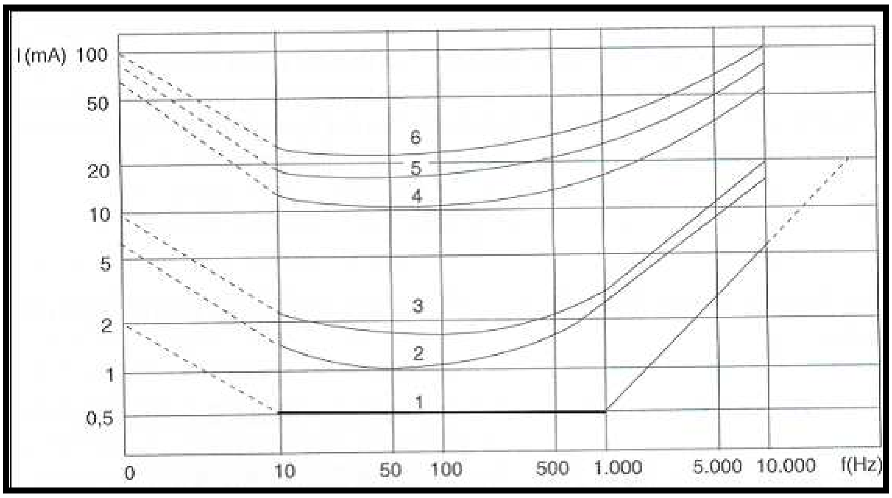
Figura 6 – Corrente elétrica *versus* frequência (IEC - Comissão Electrotécnica Internacional CEI/IEC 479-1 1994)



Através da análise da curvas da figura 6 apresentado para a corrente elétrica versus frequência verifica-se que:

- A curva 1 apresenta o limite convencional das intensidades da corrente elétrica do choque que não resulta em nenhuma percepção;

- A curva 2 apresenta o início da percepção para 50% das pessoas;

- A curva 3 apresenta o início da percepção para 99,5% das pessoas;

- A curva 4 apresenta a corrente de largar para 99,5% das pessoas;

- A curva 5 apresenta a corrente de largar para 50% das pessoas;

- A curva 6 apresenta a corrente de largar para 99,5% das pessoas.

De acordo com o estipulado pelas normas técnicas são definidos os limites impostos em termos de segurança, quer para os trabalhos em baixa tensão, quer para os limites de segurança das redes de proteção, apresentados sob a forma de tabelas:

Tabela 3 – Domínios das tensões em corrente alternada (valores eficazes)Quadro 22 A das RTIEBT (Assembleia da República Nº 175 -11 de Setembro de 2006)

Domínios	**Sistemas ligados directamente à terra**		**Sistemas não ligados diretamente à terra (*)**
	Entre fase e terra	Entre fases	Entre fases
I	U ≤ 50	U ≤ 50	U ≤ 50
II	50 <U≤ 600	50 <U≤ 1000	50 <U≤ 1000

U – Tensão nominal da instalação, em volts

(*) – Se o neutro for distribuído, os equipamentos alimentados entre fase e neutro devem ser selecionados por forma a que o seu isolamento corresponda à tensão entre fases

Tabela 4 – Domínios das tensões em corrente contínua (valores eficazes) Quadro 22B das RTIEBT (Assembleia da República Nº 175 -11 de Setembro de 2006)

Domínios	**Sistemas ligados diretamente à terra**		**Sistemas não ligados diretamente à terra (*)**
	Entre pólo e terra	Entre pólos	Entre pólos
I	U ≤ 120	U ≤ 120	U ≤ 120
II	120 <U≤ 900	120 <U≤ 1500	120 <U≤ 1500

U – Tensão nominal da instalação, em volts

(*) - Se o condutor for distribuído, os equipamentos alimentados entre um pólo e aquele condutor devem ser seleccionados por forma a que o seu isolamento corresponda à tensão entre pólos.

Tabela 5 – Valores mínimos da resistência de isolamento e valores da tensão de ensaio Quadro 61 A das RTIEBT (Assembleia da República Nº 175 -11 de Setembro de 2006)

Tensão nominal do circuito (V)	**Tensão de ensaio em corrente continua (v)**	**Resistência de isolamento(MΩ)**
TRS e TRP	250	≥ 0,25
U≤ 500 V ([1])	500	≥ 0,5
U > 500 V	1000	≥ 1,0

[1]Exceto para os casos referidos na alínea anterior

TRS – Tensão Reduzida de Segurança

TRP – Tensão Reduzida de Proteção

Tabela 6 – Domínios de tensão (EDP CGC Anexo VI PEC 2006)

Domínios De tensão	**Níveis de tensão**	**Valor da tensão nominal**	
Baixa tensão I	Tensão Reduzida	U ≤ 50V	U≤120 V
Baixa tensão II	Baixa Tensão	U ≤ 1000 V	120V < U ≤ 1500 V
Alta Tensão	Média Tensão Alta Tensão Muito Alta Tensão	1 kV < U ≤ 45 kV 45 kV < U ≤ 110kV U > 110 kV	U> 1500 V

3 OBJETIVOS E METODOLOGIA

3.1 Objetivos da Tese

Para a maioria das pessoas que trabalha na implementação dos princípios gerais de prevenção no trabalho, a área elétrica significa um mundo desconhecido em que muitas vezes não se sabe muito bem como intervir. A área elétrica comporta riscos elevados, sendo que muitas das vezes não existe uma formação especializada nesta área.

Neste âmbito foi elaborado este pequeno manual para o esclarecimento de algumas dúvidas de carácter geral. A sua estrutura é baseada principalmente no Regulamento de Segurança de Subestações e Postos de Transformação e de Secionamento, nas Regras Técnicas das instalações elétricas de baixa tensão e na parte do Regulamento de Segurança de Instalações de Utilização de Energia Elétrica (RTIEBT), de referir que na parte 8 das RTIEBT estão algumas regras definidas pelo Decreto-Lei nº 740/74, de 26 de Dezembro, estas não foram alteradas pelas partes 1 a 7 das Regras Técnicas, por não existirem, quer no CENELEC quer na IEC, regras correspondentes. Para além deste documento chave, de carácter legislativo são aplicados os documentos emanados pelos organismos internacionais que se ocupam da normalização e regulamentação de segurança no domínio da electrotecnia, nomeadamente a Comissão Electrotécnica Internacional (CEI), a comissão Europeia de Normalização Electrotécnica (CENELEC). Este trabalho está focalizado para a identificação dos perigos e dos riscos e a implementação das medidas de prevenção, não estando no seu âmbito o processo de majoração do risco, nem a elaboração de documentos como planos de segurança e saúde ou procedimentos específicos de trabalho.

A abordagem elétrica é realizada somente para a baixa tensão (BT) e média tensão (MT) (ver tabela 6), com este documento pretende-se:

- Identificar e descrever os riscos elétricos;
- Identificar e descrever uma instalação elétrica;
- Identificar os condicionalismos da envolvente;
- Identificar as atividades a realizar;
- Verificar a compatibilidade da instalação com as atividades e o meio envolvente;
- Identificar os principais perigos e riscos;
- Identificar os intervenientes (empresas, equipamentos, trabalhadores);
- Identificar as medidas preventivas a implementar,
- Identificar, implementar e realizar um método de ensaio de forma a exemplificar a medição a um equipamento de proteção elétrica.

3.2 Metodologia Global de Abordagem

A metodologia a aplicar será a metodologia idêntica à de um relatório cientifico, este documento descreve as várias fases de um trabalho de implementação dos princípios gerais de prevenção, tendo por base os princípios legais e normativos aplicáveis aos principais fatores que contribuem para a ocorrência de acidentes durante trabalhos em eletricidade. Como em todos os trabalhos de investigação terá de existir um propósito, neste trabalho o propósito será a elaboração de um manual (ver capítulo 4), que pretende responder de uma forma rápida e eficaz, às dúvidas que os técnicos de segurança apresentam perante a execução de trabalhos com riscos elétricos.

A fase inicial consiste na procura e análise de documentos legais que identifiquem e expliquem a dinâmica da eletricidade. Logo após a posse destes documentos estes devem ser relacionados com o locais de trabalhos e os trabalhos a realizar, por forma a identificar a maioria dos riscos existentes e assim definir as medidas de prevenção a implementar. Por fim, com recurso a uma norma técnica, descrever e identificar as linhas orientadoras para a análise e tratamento de dados obtidos, após as ações de inspeção e da realização de ensaios a equipamentos de proteção elétricos, nomeadamente redes de proteção, avaliando desta forma a sua eficácia.

Este documento tem a sua estrutura definida pelas (RTIEBT) sob a forma das seguintes linhas orientadoras (LO):

- Identificar descrever os riscos elétricos – LO1;
- Identificar descrever uma instalação elétrica – LO2;
- Identificar os condicionalismos da envolvente – LO3;
- Identificar as atividades a realizar – LO4;
- Verificar a compatibilidade da instalação com as atividades e o meio envolvente –LO5;
- Identificar os intervenientes (empresas, equipamentos, trabalhadores) – LO6;
- Identificar as medidas preventivas que devem ser implementadas – LO7.

De forma a auxiliar a sua análise são elaboradas tabelas e lista de verificação que se encontram no Anexo 1.

A segunda fase deste trabalho, tem a sua estrutura definida pelas linhas orientadoras emanadas pela "Norma IEEE Guide for Safety in AC Substantion Grounding" (IEEE Std 80-2000). Consiste na aplicação da norma acima referida e pela utilização de um equipamento de medição. A escolha para o estudo mais pormenorizado das redes de proteção foi atribuída pela sua importância, nomeadamente ao nível da dissipação das correntes de defeito.

3.3 Materiais e Métodos

Os materiais utilizados neste documento constam da utilização de:

- Fontes de direito de sentido técnico-jurídico, normas jurídicas;
- Normas técnicas;
- Documentos históricos, artigos científicos, com referências a atividades cientificas que demonstram e comprovam a vantagens e desvantagens da utilização da energia elétrica;
- Documentos académicos, teses de mestrado;
- Livros sobre o tema;
- Equipamentos de medição de terras;
- Listas de verificação.

O manual de riscos elétricos é realizado de acordo com sete linhas orientadoras (ver capítulo 4), em que a cada uma das linhas orientadoras é efetuada uma correlação com a respetiva(s) parte(s) das regras técnicas. A primeira linha orientadora pretende ainda definir os principais conceitos existentes assim como identificar os efeitos da exposição aos riscos elétricos. Implementa-se uma nova abordagem de análise das regras técnicas com uma consulta mais rápida e objetiva complementada com listas de verificação.

Numa das linhas orientadoras é realizada a abordagem aos ensaios que devem ser realizados. Na parte 6 das RTIEBT são apresentados os vários ensaios que devem ser realizados nas instalações elétricas, com objetivo de verificar a sua conformidade. Os ensaios a realizar nas linhas de terra vão ser alvo de estudo neste manual, no caso prático de aplicação da norma IEEE Std 80-2000.

A introdução ao caso prático para a análise das redes de proteção pretende definir os métodos de ensaios existentes para a medição de redes de terra. Esta segunda fase pretende evidenciar a correlação entre as regras técnicas das instalações elétricas de baixa tensão e a norma do IEEE Std 80-2000 aplicável a subestações. No Anexo 1 encontra-se um exemplo de aplicação da norma IEEE Std 80-2000, de acordo com o caso prático apresentado no anexo B da referida norma e do método apresentado neste subcapítulo.

No anexo C das RTIEBT é apresentado o método de medição da resistência de um elétrodo de terra (figura 7).

Este método, consiste em fazer circular uma corrente alternada de intensidade constante entre o elétrodo a medir T e um outro elétrodo auxiliar T1, colocado a uma distância tal que as superfícies de influência dos dois elétrodos não se intercetem.

O elétrodo auxiliar T2, que pode ser feito a partir de uma vareta metálica espetada no solo, deve ser colocado a meio caminho entre T e T1, medindo-se a queda de tensão entre T e T2.

Desde que exista garantia de que não há influência entre os três elétrodos de terra, o quociente entre a corrente aplicada entre T e T1 e a queda de tensão medida entre T e T2 é igual à resistência de terra do elétrodo T.

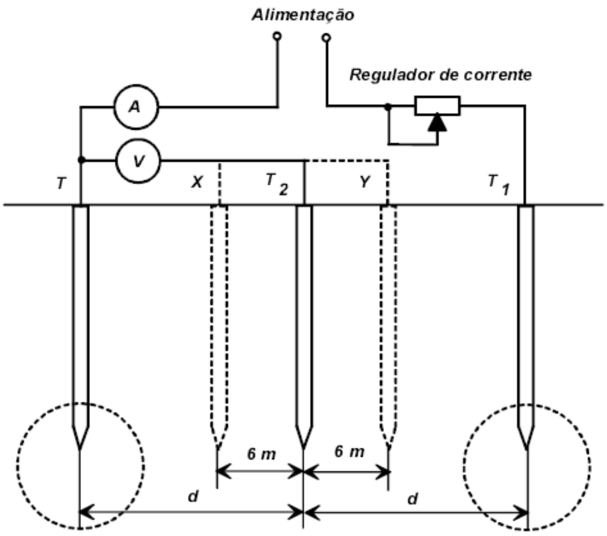


Figura 7 – Medição da resistência de um elétrodo de terra (RTIEBT)

T — Elétrodo de terra a medir, desligado de quaisquer fontes de alimentação.
T1 e T2 — Elétrodos de terra auxiliares.
X — Posição inicial de T2 para a medição de controlo.
Y — Posições de T2 para as medições de confirmação.

Atualmente existem várias normas técnicas utilizadas para a medição de linhas de terra em subestações, no entanto para este estudo foi aplicada a norma IEEE Std 80-2000. De acordo com o estudo realizado por Tiago Castelhano "Projecto de Terras em Subestações" no qual é efetuada uma comparação entre as linhas gerais das metodologias de dimensionamento presentes nas normas do IEEE, CEI, CENELEC é concluído que as normas da CEI e da CENELEC aplicam métodos complexos, e que a norma IEEE apresenta um método de dimensionamento simplificado e que este não compromete a segurança no dimensionamento das linhas de terra (Castelhano 2011).

O método de ensaio que tem como guia a norma IEEE Std 80-2000 para a verificação das condições das subestações perante a exposição ao choque elétrico, no que concerne aos ensaios para medição e dimensionamento das redes de proteção consiste na determinação dos seguintes parâmetros (IEEE - Institute of Electrical and Electronics Engineers 2000):

- Fator de divisão da corrente S_f :

$$S_f = \frac{Z_{eq}}{z_{eq} + R_g} \qquad (1)$$

Z_{eq} - Impedância equivalente dos caminhos alternativos da corrente elétrica em relação à malha de terra

R_g - Resistência da malha de terra da subestação

- Efeito assimétrico da corrente de defeito D_f

$$D_f = \sqrt{1 + \frac{T_a}{t_f}\left(1 - e^{\left(\frac{-2t_f}{T_a}\right)}\right)} \qquad (2)$$

T_a - Constante de tempo continua

t_f - Tempo de duração do defeito (s)

$$T_a = \frac{X}{2\pi f R} \qquad (3)$$

- Corrente de defeito máxima na malha de terra I_G

$$I_G = D_f \times S_f \times I_f \qquad (4)$$

Como se sabe a tensão de toque terá de ser determinada pela seguinte equação:

$$U_{toque} = U_{malha} - U_{pé} \quad (5)$$

U_{toque} - Tensão de toque (V)

U_{malha} - Potencial do sistema de terra (V)

$U_{pé}$ - Potencial no local onde os pés da pessoa estão em contato com solo (V)

$$U_{malha} = R_g \times I_G \quad (6)$$

A tensão de passo é determinada pela equação:

$$U_{passo} = U_{pé1} - U_{pé2} \quad (7)$$

U_{passo} - Tensão de passo (V)

$U_{pé1}$ - Potencial à superfície do solo no local do pé (V)

$U_{pé2}$ - Potencial à superfície do solo no local do pé (V)

De acordo com o definido legalmente é necessário proceder ao cálculo da tensão tolerável. A tensão de toque tolerável, de acordo com os estudos científicos de Daziel é determinada pela equação (8), os cálculos para a obtenção das tensões toleráveis, de passo e de toque foram retiradas da norma IEEE Std 80-2000 e não se considera relevante o seu desenvolvimento neste documento:

A tensão de toque tolerável, de acordo com os estudos científicos de Daziel é determinada pela equação:

$$E_{tolerável-passo} = (1000 + 6\rho) \times I_B \quad (8)$$

tendo em consideração uma camada de material protetor

$$E_{tolerável-passo-70Kg} = (1000 + 6C_S \times \rho) \times I_B \quad (9)$$

$$E_{tolerável-toque} = (1000 + 1{,}5\rho) \times I_B \quad (10)$$

tendo em consideração uma camada de material protetor

$$E_{tolerável-toque-70Kg} = (1000 + 1{,}5C_S \times \rho) \times I_B \quad (11)$$

- Fator de correção para a camada superficial

$$C_s = 1 - \frac{0{,}009\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0{,}09} \qquad (12)$$

h_s - Espessura da terra do material à superficie (m)

ρ - Resistência do material protetor (Ω.m)

ρ_s - Resistência do material protetor colocado à superfície (Ω.m)

O método de cálculo apresentado pela norma IEEE Std 80-2000 consiste no cálculo da corrente de defeito máxima na malha de terra $I_{G,}$ cujo valor multiplicado pela resistência da malha de terra R_g (equação 6) permite definir a tensão de defeito malha de terra, o valor obtido é posteriormente comparado com os valores da tensão de toque e de passo toleráveis. Quando a tensão da malha de rede é superior aos valores calculados para as tensões toleráveis, significa que a malha de proteção existente terá de sofrer alterações. Estas alterações são determinadas em funções de novos cálculos e abrangem um conjunto de medidas de projeto como colocação de mais elétrodos de terra, alteração das especificidades dos elétrodos, alteração da camada de material exterior, etc.

Neste trabalho, apenas é efetuada a introdução aos métodos de cálculo (Anexo1). A metodologia de calculo, os aparelhos de medição necessários para a realização e obtenção de valores requer um período de estudo e acompanhamento de ensaios em subestações que se torna inviável para a obtenção de um conjunto de valores e medições considerados como necessários para um estudo mais profundo.

Em alternativa registam-se no capítulo 4 deste documento o acompanhamento de duas medições com recurso a dois tipos de equipamentos.

4 TRATAMENTO E ANÁLISE DE DADOS (MANUAL DE REFERÊNCIA)

O primeiro exemplo que se apresenta é relativo a uma avaliação de uma infra-estrutura elétrica habitacional (ver figuras 8,9,10,11).

A inspeção foi realizada pelo Instituto Electrotécnico Português (IEP), no dia 6 de Junho de 2012 em Matosinhos. O proprietário da instalação tinha efectuado alterações ao projeto elétrico e solicitou este serviço de forma a garantir a qualidade e segurança das instalações elétricas.

Durante o ensaio foi utilizado o aparelho HT MACROTEST 5035, um aparelho multifunções para análise de instalações elétricas.

Com o recurso a este equipamento foram efetuadas medições:

- De verificação de continuidade dos condutores de proteção equipotencial;
- Medida de resistência de terra.

Por razões óbvias não são apresentados os valores registados durante as medições, no entanto apresenta-se o registo fotográfico das avaliações. Salienta-se que a instalação se apresentava conforme.

Figura 8 – Aparelho de medição HT

Figura 9 – Medição no quadro elétrico

Figura 10 – Medição num ponto do sistema

Figura 11 – Instruções do aparelho de medição

O segundo exemplo foi realizado num terreno anexo ao edifício do laboratório de alta tensão do departamento de Engenharia Electrotenica e de Computadores (DEEC) da Faculdade de Engenharia do Porto (FEUP), com a utilização do equipamento de medição terras , o Digital Earth Resistance Tester, modelo ST-1520. Este aparelho utiliza-se para a medição de terras de acordo com a IEC – 1010 (EN61010).

A aquisição de valores , de acordo com as instruções do fabricante, através do equipamento é realizada da seguinte forma:

- Estabelecer as conecção com a terra (designada por E), através do cabo condutor verde, estabelecer as conecções com os respetivos elétrodos de medição, respetivamente com a cor vermelha (designada por C) e amarela (designada por P);

- Os piquetes devem apresentar entre si uma determinada distância (entre 5 a 10m) e apresentar entre eles paralelismo;

- Ligar o equipamento e proceder às medições. Neste equipamento é realizada a ressalva de que a tensão terá de ser inferior a 10 V, caso contrário não será possivel realizar a medição das terras .

Figura 12 – Aparelho de medição ST-1520

Colocação dos elétrodos no solo (figura 13, figura 14). Os elétrodos foram reposicionados três vezes.

Figura 13 - Colocação do elétrodo C

Figura 14 – Colocação do elétrodo terra

Foram efetuadas três medições de acordo com o definido no manual do equipamento.Verificou-se que a resistência de terra diminuia à medida que os elétrodos de terra se aproximavam da malha de terra do edificio. Os valores apresentados comprovam que a terra do local é boa, e à medida que a distancia dos elétrodo diminui relativamente à proximidade do laboratório os valores diminuem.

Estes valores são justificados pela rede de terra existente local nomeadamente a referente à própria estrutura do edificio. Comprovando a conformidade legal para a realização de ensaios no laboratório de alta tensão.

Resultado da primeira medição (1 Ω) (figura 15):

Figura 15 – Resultado da primeira medição

Resultado da segunda medição (0,8 Ω) (figura 16):

Figura 16 – Resultado da segunda medição

Resultado da terceira medição (0,7 Ω)(figura 17):

Figura 17 – Resultado da terceira medição

4.1 Riscos Elétricos – LO1

O choque elétrico define-se de acordo com a Portaria nº949-A/2006 de 11 de Setembro (Assembleia da República Nº 175 -11 de Setembro de 2006) como o efeito fitopatológico resultante da passagem de uma corrente elétrica através do corpo humano ou do corpo de um animal. Os riscos elétricos advêm da exposição, neste caso, dos trabalhadores aos equipamentos elétricos por contato direto, por contato indireto ou por outro tipo de exposição tal como aos efeitos térmicos perigosos resultantes do funcionamento dos equipamentos elétricos e aos efeitos das radiações térmicas. De acordo com Sérgio Miguel, pode definir-se o risco de contato com a corrente elétrica como a probabilidade de circulação de uma corrente elétrica através do corpo humano (Miguel 2006).

O tecido animal é constituído por células que se encontram imersas no líquido intersticial, separadas do citoplasma por uma finíssima membrana. Quer o líquido intersticial, quer o líquido intracelular (citoplasma) são eletrólitos onde os iões de potássio, sódio, cloro, etc., se movem segundo um gradiente de concentração, isto é, tendem a difundir-se para a zona de menor concentração. Alguns tipos de células (nervosas, musculares, etc.) quando sujeitas a estímulo neste caso em concreto, estímulo elétrico, entram em atividade alterando a permeabilidade da membrana. Gera-se então uma corrente iónica e modifica-se a diferença de potencial entre as duas faces, a qual, posteriormente, regressa ao valor primitivo (Miguel 2006).

Nos estímulos elétricos a célula é sensível à quantidade de eletricidade trocada entre o seu interior e exterior. Deve ainda ser referido que existe um músculo do corpo, o coração, que funciona de forma diferente dos outros músculos, neste órgão a tensão elétrica necessária para o seu trabalho é gerada por ele próprio (ISQ - Instituto de Soldadura e Qualidade 1994).

Os estudos recentes realizados para analisar os efeitos biofisiológicos da energia elétrica demonstram que o perigo para os seres vivos não resulta da tensão aplicada, mas da intensidade de corrente que atravessa o corpo humano. Segundo as conclusões de Daziel (1953), o risco inerente a um choque elétrico com correntes à frequência industrial está relacionado com a energia elétrica dissipada no organismo durante a descarga (Matias 1994).

As várias pesquisas experimentais, demonstram que os parâmetros da corrente elétrica com efeito no corpo humano são:

- Intensidade da corrente;
- Duração do efeito;
- Percurso da corrente;
- Frequência e variação brusca da corrente;
- A impedância do corpo humano.

De considerar que o corpo humano apresenta uma componente resistiva e outra capacitiva perante a passagem da corrente elétrica, designada frequentemente por impedância. A impedância do corpo humano, pode ser considerada como uma malha de resistências e capacitâncias, e é variável quando medida entre diferentes pontos de contato, ou seja, mão-mão, mão-pé, ou outra, e dependem de um número de fatores tais como a área de contato, a humidade da pele, a temperatura ambiente e a do corpo humano, do caminho da corrente, da frequência, e da tensão aplicada (ISQ - Instituto de Soldadura e Qualidade 1994).

Na tabela 1 (2.4) é apresentada a impedância do corpo humano em função da tensão de contato. Relembra-se que a tensão de contato (figura 18) é definida como a tensão, que em caso do defeito do isolamento, aparece entre partes simultaneamente acessíveis. A proteção contra choque elétrico tem como critério o limite admissível da tensão de contato, ou seja, o produto da corrente que passa pelo corpo humano por sua impedância total, em função do tempo.

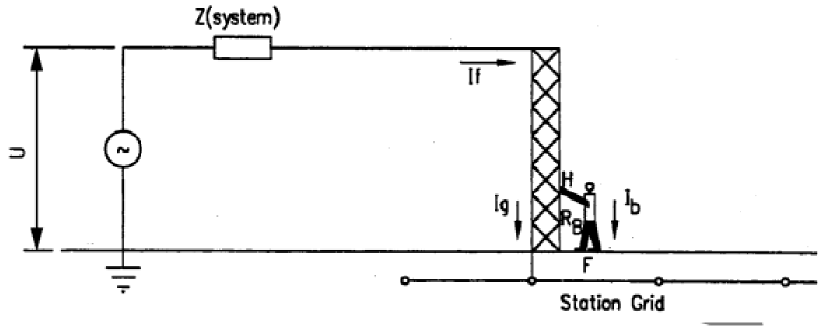


Figura 18 – Tensão de toque (IEEE - Institute of Electrical and Electronics Engineers 2000)

A tensão de contato mais elevada suscetível de aparecer numa instalação elétrica em caso de defeito de uma impedância desprezável é a tensão de contato presumida. Salienta-se ainda a variabilidade da resistência do corpo humano com o nível de humidade da pele figura 4 (2.4).

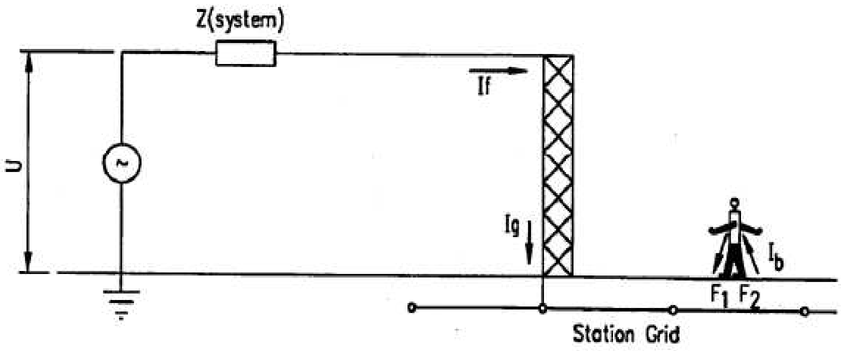


Figura 19 – Tensão de passo (IEEE - Institute of Electrical and Electronics Engineers 2000)

Para além da tensão de contato é de extrema importância a tensão de passo (figura 19), definida como a tensão entre dois pontos à superfície da terra, distanciados 1m. Por vezes quando uma pessoa sofre uma queda por exposição a uma tensão de contato ocorre um sistema em que a pessoa pode ficar exposta à tensão de passo entre pés e mãos (figura 20), e a consequente exposição à tensão de passo, com o risco da passagem da corrente pelo coração.

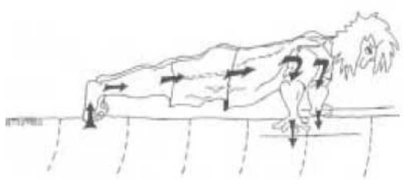


Figura 20 – Pessoa tocando o solo (Fonte: Kindermann, 2000)

Os efeitos da passagem da corrente elétrica pelo corpo humano, são determinados em função do valor da impedância do corpo e das características fisiológicas do indivíduo e produzem várias alterações e lesões temporárias ou permanentes (ver tabela 2, figura 5 e figura 6 (2.4)).

Neste estudo não se pretende descrever de uma forma pormenorizada os efeitos fisiológicos da corrente elétrica no corpo humano, neste item considera-se importante referir que os limites de segurança estipulados são o resultado dos estudos experimentais realizados por vários cientistas com o objetivo final de determinar o valor da tensão suscetível de causar um risco elétrico, ou seja, o valor da tensão à qual se encontram submetidos dois pontos diferentes do corpo humano, tensão de segurança. A tensão de segurança é determinada pela conjugação dos diagramas da impedância do corpo humano e das curvas de variação corrente-tempo e pela Lei de Ohm.

Os limites de perigosidade para o corpo humano sob o efeito das características da corrente elétrica, definida pela conjugação dos parâmetros acima referidos, definem a corrente de choque capaz de provocar os seguintes efeitos fisiológicos:

- Tetanização – Pela ação da corrente elétrica, os músculos, que por ele são percorridos ficam contraídos. Ao nível dos sistema respiratório, pode ocorrer a paragem respiratória, pois em correntes superiores ao limite de largar ocorre uma contração dos músculos ligados à respiração e/ou aos centros nervosos que os comandam, produzem asfixia que, permanecendo a passagem da corrente, levam à perda de consciência e morte por sufocamento e à ocorrência de lesões irreversíveis no cérebro. Ao nível dos membros a passagem da corrente em valores superiores ao limite de largar, provoca a contração dos músculos, impedindo que o acidentado evite o contato com o equipamento sob defeito (Matias 1994).

- Fibrilação ventricular – Ocorre quando uma corrente elétrica de valor apreciável passa pela região cardíaca e provoca perturbações na coordenação das fibras musculares do coração que por sua vez sofrem contrações individualizadas levando a uma perda de pressão dentro da cavidade ventricular o que leva à paragem da circulação sanguínea;

- Queimaduras – Ocorrem frequentemente, para correntes em alta-frequência também ocorrem queimaduras internas, não provocam a sensação de choque, mas podem tem consequências graves. Tipo de queimaduras que podem ocorrer (Matias 1994):
  - Queimaduras por contato;
  - Queimaduras por arco;
  - Queimaduras por radiação;
  - Metal vaporizado;
  - Queimaduras profundas e mortais.

Os efeitos da frequência em corrente alternada são notórios apenas para baixas frequências, entre os 50-60 Hz. Através da análise das curvas da figura 6 (Ver 2.4.), verifica-se que na frequência de 10 a 100Hz estão os menores valores de corrente, e que na frequência entre 50 a 60 Hz estão os valores de corrente mais perigosos. A título conclusivo observa-se que o limiar da sensação e corrente aumenta com o aumento da frequência. As altas-frequências são frequentemente utilizadas na medicina.

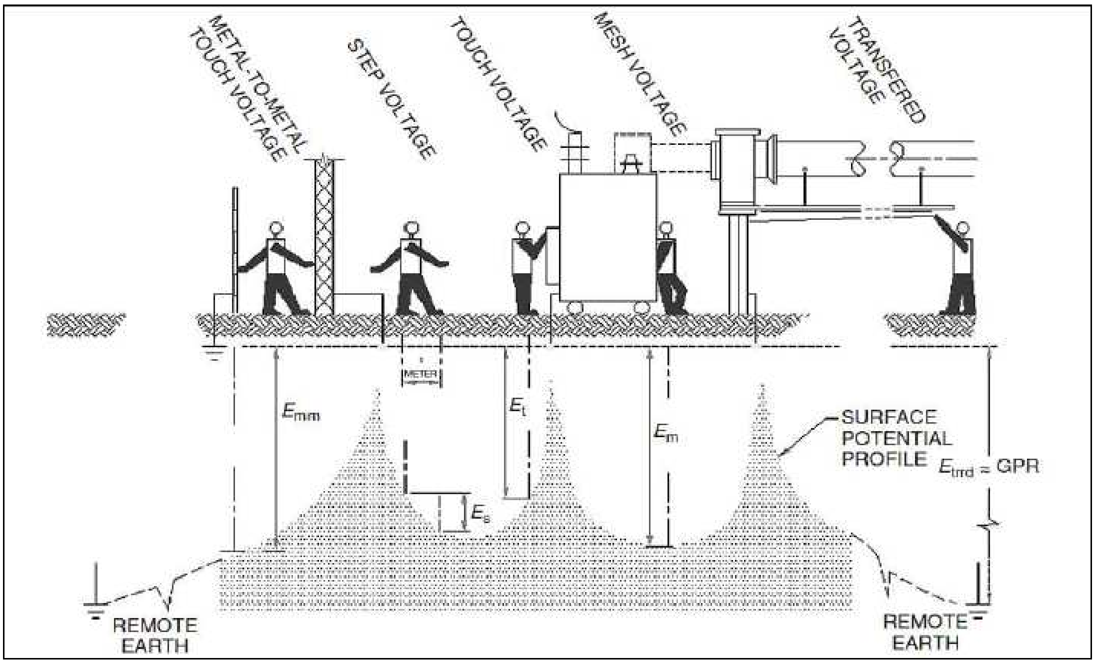


Figura 21 – Situações típicas de choque elétrico (IEEE - Institute of Electrical and Electronics Engineers 2000)

A eletrização é realizada através de cinco modos (figura 21):

1. Contato direto unipolar, quando existe contato com uma parte ativa sob tensão e a terra;
2. Contato direto bipolar , quando existe contato com uma parte ativa sob tensão e contacto com uma parte activa com uma tensão diferente
3. Contato direto bipolar , quando existe contato com uma parte ativa sob tensão e contacto com uma massa acidentalmente sob tensão ;
4. Contato indireto unipolar, quando existe contato com uma massa intencionalmente sob tensão e a terra;
5. Contato indireto bipolar, quando existe contato entre uma massa acidentalmente sob tensão e outra massa, acidentalmente sob tensão diferente (Miguel 2006).

Os sistemas de terra funcionam como mais um método de proteção contra a corrente de defeito de uma instalação cuja função permite ligar todas as partes metálicas entre si à terra (figura 22), assegurando que ficam todas ao mesmo potencial. Os sistemas de terra por serem considerados como um dos elementos de proteção mais importantes são o tema fulcral deste trabalho.

As redes de proteção de terra devem ser dimensionadas/selecionados de forma a que o valor da resistência de terra esteja de acordo com os requisitos funcionais e de proteção da instalação, e que seja permanentemente efetiva. As correntes de defeito à terra ou de fugas devem circular sem perigo de danos devidos aos esforços térmicos, termomecânicos e termoelétricos.

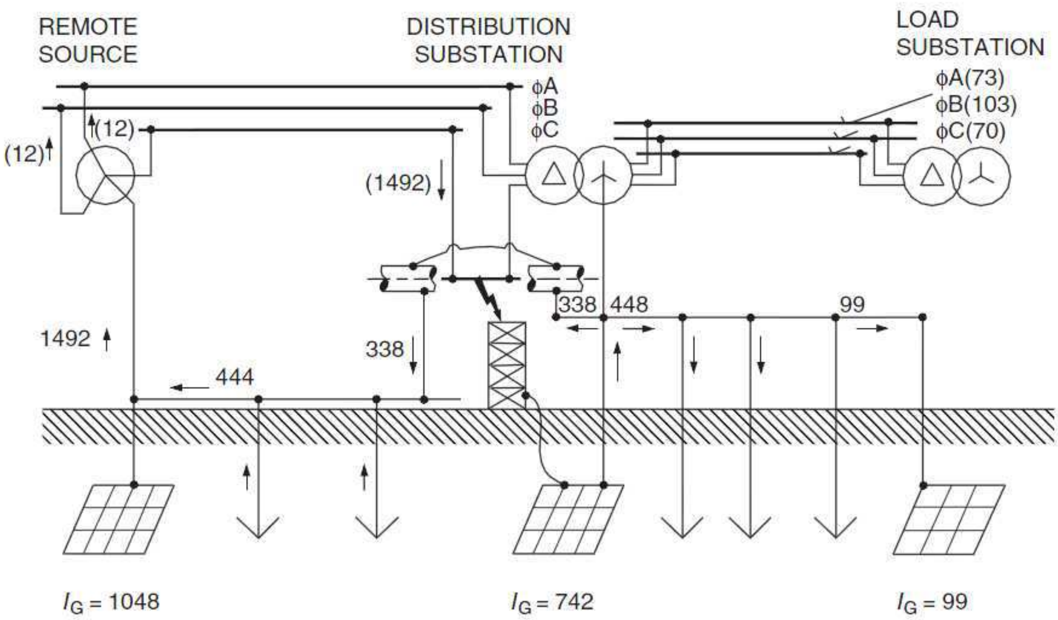


Figura 22 – Divisão típica de corrente para um defeito numa subestação (IEEE - Institute of Electrical and Electronics Engineers 2000)

De uma forma genérica explica-se o tipo de designações pelos quais são referenciados os sistemas de ligação de terra ou regimes de neutro. De acordo com o estipulado legalmente os esquemas de ligação à terra podem ser identificados pelas seguintes classificações TN, TT e IT.

A primeira letra designa o tipo de ligação à terra:

- T, ligação direta a um ou mais pontos de terra;
- I, todas as partes ativas isoladas da terra ou um ponto ligado à terra através de uma impedância;

A segunda letra indica a relação entre as partes condutoras acessíveis da instalação e a terra:

- T, ligação elétrica direta das partes condutoras acessíveis à terra, independentemente da ligação à terra de algum ponto da fonte de energia.
- N, ligação elétrica direta das partes condutoras acessíveis ao ponto de ligação à terra da fonte de energia, que, para corrente alternada, é normalmente o ponto neutro da instalação.
- A, designação TN é ainda subdividida dependendo do modo de instalação do neutro e dos condutores, de proteção, arranjo esse designado por letra ou letras adicionais, sendo:
  - S, as funções de neutro e de proteção asseguradas por condutores separados.
  - C, as funções de neutro e de proteção combinadas num condutor único.

Figura 23 – Exemplo de sistemas de ligação à terra

O esquema TN tem um ponto ligado directamente à terra, sendo as massas da instalação ligadas a esse ponto por meio de condutores de proteção. De acordo com a disposição do condutor neutro e do condutor de proteção, consideram-se os três tipos de esquemas TN (figura 24):

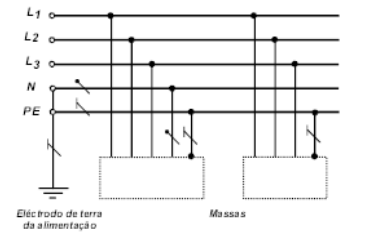
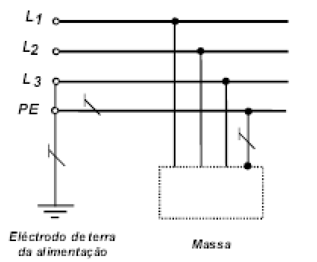
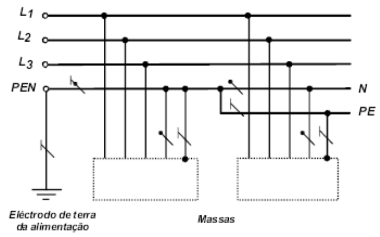
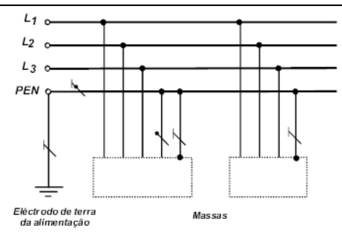
TN-S – Condutores de neutro e de proteção separados em todo o esquema	
TN-S – Condutor ativo ligado à terra e condutor de proteção separado em todos e esquema	
TN-C-S – Funções de neutro e de proteção combinadas num único condutor (PEN) numa parte do esquema	
TN-C – Funções de neutro e de proteção combinadas num único condutor (PEN) em todo o esquema	

Figura 24 – Esquemas TN de ligação à terra (RTIEB)

Os tipos de esquemas TT apresentados na figura 25:

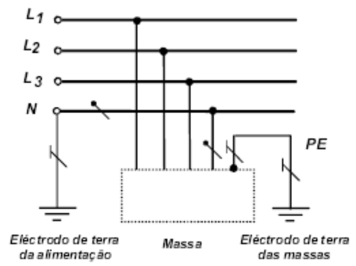
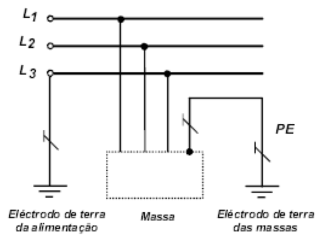
<table>
<tr><td rowspan="2">TT –
Este esquema tem um ponto de alimentação ligado directamente à terra, sendo as massas da instalação elétrica ligadas a elétrodos de terra eletricamente distintos do elétrodo de terra de alimentação</td><td>
</td></tr>
<tr><td>
</td></tr>
</table>

Figura 25 – Esquemas TT de ligação à terra (RTIEBT)

Os tipos de esquemas IT apresentados na figura 26:

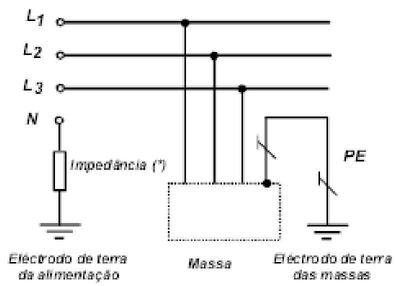
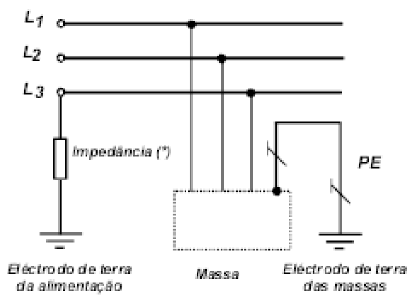
<table>
<tr><td rowspan="2">IT –
Neste esquema todas as partes activas estão isoladas da terra ou num ponto destas está ligado à terra por meio de uma impedância, sendo as massas da instalação elétrica ligadas à terra</td><td>
</td></tr>
<tr><td>
</td></tr>
</table>

Figura 26 – Esquemas IT de ligação à terra (RTIEBT)

4.2 Identificar descrever uma instalação elétrica – LO2

Uma instalação elétrica é definida como um conjunto de equipamentos elétricos associados com vista a uma dada aplicação e possuindo características coordenadas, com a correspondente rede de distribuição destinada à transmissão de energia elétrica a partir de um posto de transformação ou de uma central geradora, constituída por canalizações principais e ramais.

As regras que se encontram definidas neste documento são relativas às regras que se encontram definidas em projeto, pelo que é essencial a obtenção do projeto final característico da instalação.

Durante esta fase inicial de identificação deve o técnico de segurança proceder a uma correta identificação do local, com recurso ao projecto elétrico e sempre que surjam dúvidas deve solicitar a colaboração de um técnico qualificado e instruído de forma a poder esclarecer todas as dúvidas de interpretação do projeto existente. Relembra-se que muitas das vezes se procede a alterações nas instalações, que não constam do projeto nestes casos deve o técnico de segurança informar os responsáveis de forma a poder identificar os perigos e riscos.

A escolha e seleção adequadas das medidas de proteção de segurança de uma instalação elétrica estão dependentes das características da fonte de energia. As medidas de proteção contra o choque elétrico estão grandemente dependentes do sistema de terra implementado e do tipo de caminho pretendido para a corrente de defeito de terra.

A identificação/caracterização da instalação elétrica deve ser realizada de acordo com a parte 1 das regras técnicas das instalações elétricas de baixa tensão. As indicações necessárias para a conceção das instalações elétricas indicadas entre as secções 132.2 a 132.5, as regras relativas à conceção das instalações indicadas entre as secções 132.6 a 132.12 podem ser resumidas na forma de uma lista de verificação que permita uma primeira aproximação à correta identificação da instalação (Anexo 1). No Anexo 1 é apresentado um exemplo de aplicação da utilização das listas de verificação.

Listam-se os itens que devem ser considerados:

- As características da alimentação. Nomeadamente a natureza da corrente, o número e características dos condutores;

- Os valores característicos e tolerâncias;

- Os esquemas de ligações à terra inerentes à alimentação e outras condições relativas à proteção;

- As exigências particulares do distribuidor de energia elétrica;

- A natureza do fornecimento;

- A alimentação de segurança ou de substituição. A alimentação de segurança ou de substituição é caracterizada por:

- As condições ambientais;

- A seção dos condutores;

- O modo de instalação das canalizações;

- Os dispositivos de proteção;

- Os dispositivos para corte de emergência;

- Os dispositivos de secionamento;

- A independência da instalação elétrica;

- A acessibilidade dos equipamentos elétricos.

Os equipamentos elétricos são usados na produção, na transformação, na distribuição ou na distribuição ou na utilização da energia elétrica. A identificação dos aparelhos da instalação elétrica tem por base a categoria dos mesmos e que se podem dividir em: aparelhos de utilização (promovem a transformação da energia elétrica numa outra forma de energia), aparelhagem (estão ligados a um circuito elétrico e garantem uma ou mais funções de proteção, de conexão, de corte, de regulação, de comando, de medição e contagem). Relativamente ao seu deslocamento são classificados como sendo aparelho móvel, aparelho de utilização portátil, aparelho de utilização fixo e aparelho de utilização inamovível.

Tabela 7 – Exemplos de dispositivos/equipamentos elétricos

Equipamentos elétricos	Exemplos:
Proteção	fusíveis, disjuntores, relés
Utilização	lâmpadas, motores, buzinas
Medição e Contagem	amperímetros, voltímetros
Comando	interruptores,inversores,comutadores
Regulação	resistências, bobinas, condensadores
Corte	interruptores, seccionadores, disjuntores
Ligação	Caixas de derivação, caixas de coluna, fichas, tomadas, ligadores

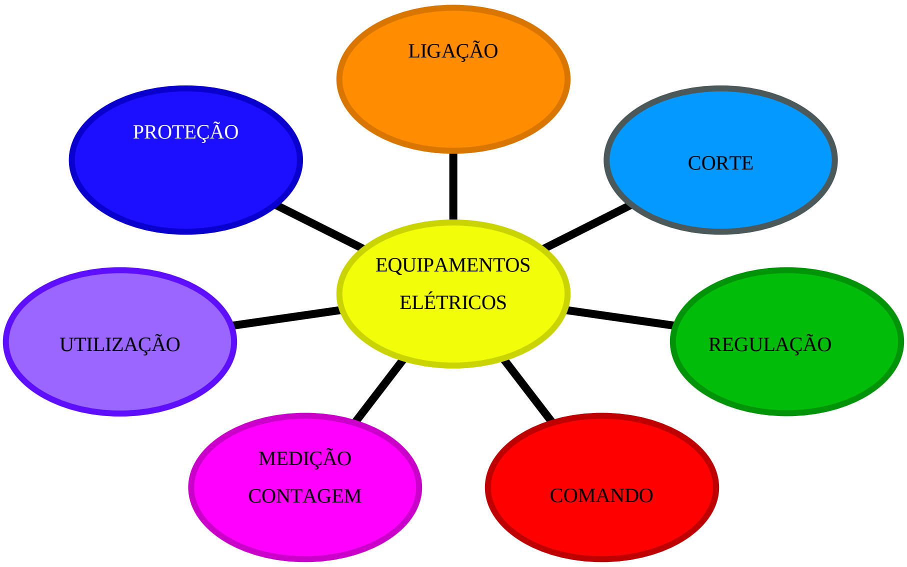


Figura 27 – Esquema dos equipamentos elétricos de baixa Tensão

Uma vez que este documento tem por estrutura base as regras técnicas das instalações elétricas de baixa tensão considera-se não ser necessário a colocação das definições apresentadas na norma legislativa da estrutura base (ver a parte 2 da RTIEBT).

Esquemas de ligações à terra inerentes à alimentação e outras condições relativas à proteção (ver capítulo 4).

Após a caracterização do local e acordo com a parte 1 das RTIEBT, devem ser consideradas as partes 3, 4, 5 da estrutura como forma de identificar os perigos/riscos da instalação.

“300.1— Generalidades.

Na seleção das medidas de proteção para garantir a segurança (veja-se a parte 4) e na seleção e instalação dos equipamentos (veja-se a parte 5) deve ser feita uma avaliação das características da instalação a seguir mencionadas (o número indicado entre parêntesis é o da seção correspondente da presente parte das Regras Técnicas):

a) A utilização prevista para a instalação, a sua estrutura global e as suas alimentações (31);

b) As influências externas a que a instalação pode ficar submetida (32);

c) A compatibilidade dos seus elementos constituintes (33);

d) A sua manutibilidade (34)”

Considera-se que a alínea da d) do ponto 300.1 da parte 3 – “ Determinação das características gerais das instalações” de particular relevância, uma vez que estamos a falar de uma das principais atividades onde ocorrem acidentes elétricos. Durante as operações de manutenção (ver o subcapítulo 2.3 conhecimento cientifico). Neste âmbito é considerado relevante a elaboração de uma lista de verificação para as atividades de manutibilidade. (ver Anexo 1). A alínea b) da secção 300.1 será abordada na linha de orientação 3.

Ainda relativamente às atividades de manutibilidade salienta-se a parte 6 das RTIEBT, uma vez, que se considera que os ensaios e verificações são atividades que devem ser realizadas periodicamente de forma a garantir a conformidade dos equipamentos.

Transcreve-se uma parte da “parte 6” das RTIEBT.

A realização de medições numa instalação elétrica por meio de aparelhos apropriados, através das quais se comprova a eficácia dessa instalação.

As instalações elétricas, durante a sua execução ou após a sua conclusão, mas antes da sua entrada em serviço, devem ser verificadas (por meio de inspeções visuais e de ensaios), com vista a comprovar, na medida do possível, que as presentes Regras Técnicas foram cumpridas.

As informações indicadas na secção 514.5 devem ser colocadas à disposição dos técnicos que efectuarem essas verificações.

Durante a realização das inspeções e dos ensaios, devem ser tomadas as medidas adequadas para evitar os perigos resultantes para as pessoas e os danos para os bens e para os equipamentos instalados.

Quando se fizerem ampliações ou modificações em instalações elétricas existentes, deve ser verificado se essas alterações satisfazem ao indicado nas presentes Regras Técnicas e se não comprometem a segurança da instalação existente.

A verificação de uma instalação elétrica por meio de inspeção visual destina-se a comprovar se os equipamentos elétricos ligados em permanência:

a) Satisfazem às regras de segurança das Normas que lhes são aplicáveis;

b) Foram corretamente selecionados e instalados de acordo com as regras indicadas nas presentes Regras Técnicas e com as indicações fornecidas pelos fabricantes;

c) Não apresentam danos visíveis, que possam afetar a segurança.

A verificação de uma instalação elétrica por meio de inspeção visual deve incluir, quando aplicável, pelo menos, a comprovação das características seguintes:

a) Medidas de proteção contra os choques elétricos, incluindo a medição de distâncias, por exemplo, no que respeita à proteção por meio de barreiras ou de invólucros, por meio de obstáculos, por colocação fora de alcance, por recurso a locais não condutores (vejam-se 412.2,412.3, 412.4, 413.3, 471 e 481);

b) Existência de barreiras corta-fogo ou de outras medidas destinadas a impedir a propagação do fogo e existência de proteção contra os efeitos térmicos (vejam-se 42, 482 e 527);

c) Seleção dos condutores de acordo com as suas correntes admissíveis e com a queda de tensão (vejam-se 523 e 525);

d) Seleção e regulação dos dispositivos de proteção e de vigilância (veja-se 53);

e) Existência de dispositivos apropriados de secionamento e de comando, corretamente localizados (vejam-se 46 e 536);

f) Seleção dos equipamentos e das medidas de proteção apropriadas, de acordo com as condições de influências externas (veja-se 512.2);

g) Identificação dos condutores neutros e dos condutores de proteção (veja-se 514.3);

h) Existência de esquemas, de avisos e de informações análogas (veja-se 514.5);

i) Identificação dos circuitos, dos fusíveis, dos disjuntores, dos interruptores, dos terminais, etc. (veja-se 514);

j) Forma como estão feitas as ligações dos condutores (veja-se 526);

k) Acessibilidade para comodidade de funcionamento e de manutenção.

Ensaios

A verificação por meio de ensaios deve incluir, quando aplicáveis, pelo menos, os seguintes ensaios, os quais devem ser realizados, preferencialmente, pela ordem indicada:

a) Continuidade dos condutores de proteção e das ligações equipotenciais principais e suplementares (612.2);

b) Resistência de isolamento da instalação elétrica (612.3);

c) Proteção por meio da separação dos circuitos (612.4), relativa à:

• Tensão reduzida de segurança TRS ou TRP (veja-se 411.1);

• Separação elétrica (veja-se 413.5).

d) Resistência de isolamento dos elementos da construção (tetos, paredes, etc.) (612.5);

As medições devem ser feitas em corrente contínua, devendo o aparelho usado no ensaio ser capaz de fornecer uma tensão com o valor indicado no quadro 61A das RTIEBT e uma corrente de 1 mA. Quando, na instalação, existirem dispositivos electrónicos, apenas deve ser feita a medição entre os condutores ativos (fases e o neutro) ligados entre si e a terra. Dentro dos conjunto de ensaios a realizar listam-se aqueles que são relativos à tensão reduzida de proteção e que devem obedecer ao estabelecido na tabela 9 das RTIEBT.:

e) Corte automático da alimentação (612.6);

f) Ensaio da polaridade (612.7);

g) Ensaio dielétrico (612.8);

h) Ensaios funcionais (612.9);

i) Proteção contra os efeitos térmicos (612.10);

j) Quedas de tensão (612.11).

Se um dos ensaios conduzir a um resultado não aceitável, esse ensaio, bem como os que o precederam e cujos resultados possam ter sido influenciados pelo ensaio em causa, devem ser repetidos, após ter sido eliminado o defeito. Os métodos dos ensaios descritos nas seções 612.2 a 612.11 são métodos de referência, não sendo de excluir outros métodos, desde que os resultados deles decorrentes sejam igualmente válidos.

4.3 Identificar os condicionalismos da envolvente – LO3

As influências externas a que a instalação pode estar sujeita estão definidas na parte 3 do RTIEBT, seção 32 para este item foi elaborado a lista de verificação LVLO3. Nesta lista estão compiladas as condições das influências externas. Cada influência externa é caracterizada por um código. O código é constituído por um grupo de letras maiúsculas e de algarismo, de acordo com a seguinte ordem:

- A primeira letra caracteriza a categoria geral das influências externas:

A— Ambientes.

B— Utilizações.

C— Construção dos edifícios.

- A segunda letra caracteriza a natureza da influência externa:
A …
B …
C …
…
- O algarismo caracteriza a classe de cada uma das influências externas:
1—
2—
3—
……

Para a identificação correta das influências externas devem ser consultadas as tabelas da parte 3 da RTIEBT.

A seleção das medidas de proteção em função da combinação das várias influências externas, devem ter em conta as condições locais e a natureza dos equipamentos alimentados (ver secção 481). Na seção 481 são definidas as medidas de proteção contra os choques elétricos, nomeadamente as seleção de medidas de proteção contra os contatos diretos (ver secção 481.2) e a seleção das medidas de proteção contra os contatos indiretos (ver seção 481.3). As medidas de proteção contra o incêndio são as indicas nas seções 482.1 a 482.4 (para certas condições de influências externas) devem ser aplicadas em conjunto com as indicadas na secção 42.

4.4 Identificar as atividades a realizar – LO4/Compatibilidade da instalação com as atividades e o meio envolvente –LO5

Antes do início da realização de uma atividade deve a entidade executante proceder à identificação das atividades a realizar de acordo com o estabelecido no decreto-lei nº273/2003 de 29 de Outubro, nomeadamente no que diz respeito à elaboração do Plano de Segurança e Saúde, trabalhos elétricos. O Plano de Segurança e Saúde deve conter todos os elementos necessários à implementação dos Princípios Gerais de Prevenção no que diz respeito, às opções de planeamento e execução tendo em consideração a realização de trabalhos sujeitos à exposição aos riscos elétricos (Gonelha and Saldanha 2005).

"Artigo 6.º - Plano de segurança e saúde em projecto

1- O plano de segurança e saúde em projeto deve ter como suporte as definições do projeto da obra e as demais condições estabelecidas para a execução da obra que sejam relevantes para o planeamento da prevenção dos riscos profissionais, ……"

2 — O plano de segurança e saúde deve concretizar os riscos evidenciados e as medidas preventivas a adoptar, tendo nomeadamente em consideração os seguintes aspetos:

a) Os tipos de trabalho a executar;

b) A gestão da segurança e saúde no estaleiro, especificando os domínios da responsabilidade de cada interveniente;

c) As metodologias relativas aos processos construtivos, bem como os materiais e produtos que sejam definidos no projeto ou no caderno de encargos;

d) Fases da obra e programação da execução dos diversos trabalhos;

e) Riscos especiais para a segurança e saúde dos trabalhadores, referidos no artigo seguinte;

f) Aspetos a observar na gestão e organização do estaleiro de apoio, de acordo com o anexo I ." (Assembleia da República nº 251 29 de Outubro de 2003).

4.5 Identificar os intervenientes (empresas, equipamentos, trabalhadores) – LO6

Todos os intervenientes devem ser identificados e a respetiva documentação deve estar de acordo com o regime jurídico da promoção e prevenção da segurança e saúde no trabalho, Lei 102/2009 de 10 de Setembro. Neste item deve ser realizada uma análise aos principais referenciais legais mais específicos, relativos a empresas, trabalhadores e equipamentos.

Assim sendo e dando provimento ao especificado no artigo 21º do Decreto-Lei 273/2003 de 29 de Outubro devem as entidades executantes organizar um registo, conforme se refere a seguir.

A entidade executante deve organizar um registo que inclua, em relação a cada subempreiteiro ou trabalhador independente por si contratado que trabalhe no estaleiro durante um prazo superior a vinte e quatro horas, de onde consta:

a) A identificação completa, residência ou sede e número fiscal de contribuinte;

b) O número do registo ou da autorização para o exercício da atividade de empreiteiro de obras públicas ou de industrial da construção civil, bem como de certificação exigida por lei para o exercício de outra atividade realizada no estaleiro;

c) A atividade a efetuar no estaleiro e a sua calendarização;

d) A cópia do contrato em execução do qual conste que exerce atividade no estaleiro, quando for celebrado por escrito;

e) O responsável do subempreiteiro no estaleiro.

Relativamente aos equipamentos de trabalho e de acordo com o Decreto-lei nº 50/2005 de 25 de Fevereiro, para assegurar a segurança e a saúde dos trabalhadores na utilização de equipamentos de trabalho, o empregador deve:

a) Assegurar que os equipamentos de trabalho são adequados ou convenientemente adaptados ao trabalho a efectuar e garantem a segurança e a saúde dos trabalhadores durante a sua utilização;

b) Atender, na escolha dos equipamentos de trabalho, às condições e características específicas do trabalho, aos riscos existentes para a segurança e a saúde dos trabalhadores, bem como aos novos riscos resultantes da sua utilização;

c) Tomar em consideração os postos de trabalho e a posição dos trabalhadores durante a utilização dos equipamentos de trabalho, bem como os princípios ergonómicos;

d) Quando os procedimentos previstos nas alíneas anteriores não permitam assegurar eficazmente a segurança ou a saúde dos trabalhadores na utilização dos equipamentos de trabalho, tomar as medidas adequadas para minimizar os riscos existentes;

e) Assegurar a manutenção adequada dos equipamentos de trabalho durante o seu período de utilização, de modo que os mesmos respeitem os requisitos mínimos de segurança constantes dos artigos 10º a 29º e não provoquem riscos para a segurança ou a saúde dos trabalhadores (Gonelha and Saldanha 2005).

4.6 Identificar as medidas preventivas a implementar – LO7

A hierarquização da implementação das medidas preventivas aplicáveis aos riscos elétricos deve ter sempre por base os Princípios Gerais de Prevenção que constam do actual regime jurídico da promoção e prevenção da segurança e saúde no trabalho, Lei 102/2009 de 10 de Setembro. A proteção que evita a exposição aos riscos elétricos deve ser determinada em função dos(as):

-Contatos diretos. As pessoas e os animais devem ser protegidos contra os perigos que possam resultar de um contato com as partes ativas da instalação. Esta proteção pode ser garantida por um dos métodos seguintes:

a) Medidas que impeçam a corrente de percorrer o corpo humano ou o corpo de um animal;

b) Limitação da corrente que possa percorrer o corpo a um valor inferior ao da corrente de choque.

- Contatos indiretos. As pessoas e os animais devem ser protegidos contra os perigos que possam resultar de um contato com as massas, em caso de defeito. Esta proteção pode ser garantida por um dos métodos seguintes:

a) Medidas que impeçam a corrente de defeito de percorrer o corpo humano ou o corpo de um animal;

b) Limitação da corrente de defeito que possa percorrer o corpo a um valor inferior ao da corrente de choque;

c) Corte automático, num tempo determinado, após o aparecimento de um defeito susceptível de, em caso de contato com as massas, ocasionar a passagem através do corpo de uma corrente de valor não inferior ao da corrente de choque.

- Efeitos térmicos. A instalação elétrica deve ser realizada de forma a excluir os riscos de ignição de produtos inflamáveis em consequência das temperaturas elevadas ou dos arcos elétricos. Além disso, em serviço normal, as pessoas e os animais não devem correr riscos de queimadura.

- Proteção contra as sobreintensidades. As pessoas, os animais e os bens devem ser protegidos contra as consequências prejudiciais das temperaturas muito elevadas ou das solicitações mecânicas devidas às sobreintensidades suscetíveis de se produzirem nos condutores ativos. Esta proteção pode ser garantida por um dos métodos seguintes:

a) Corte automático antes que a sobreintensidade atinja um valor perigoso, tendo em conta a sua duração;

b) Limitação da sobreintensidade máxima a um valor seguro, tendo em conta a sua duração.

- Proteção contra as correntes de defeito. Com exceção dos condutores ativos, os restantes condutores e as outras partes destinadas à passagem de correntes de defeito devem poder suportar essas correntes sem atingirem temperaturas demasiado elevadas;

- Proteção contra as sobretensões. As pessoas, os animais e os bens devem ser protegidos contra as consequências prejudiciais de um defeito entre partes ativas de circuitos a tensões diferentes. As pessoas, os animais e os bens devem ser protegidos contra as consequências prejudiciais das sobretensões devidas a causas diferentes das indicadas na secção 131.6.1 quando essas sobretensões forem suscetíveis de se produzir (fenómenos atmosféricos, sobretensões de manobra, etc.).

Neste item é apresentado uma listagem resumo das medidas de proteção tendo em consideração, as RTIEBT (seção 4).

1. Medidas de proteção contra o choque elétricos
    1. Na proteção contra os contatos diretos e contra os contatos indiretos devem ser garantidas as seguintes condições de proteção por tensão reduzida TRS ou TRP:

       a) A tensão nominal não for superior ao limite superior do domínio I (Ver capítulo 2.3 das RTIEBT);

       b) A fonte de alimentação satisfazer às condições indicadas na secção 411.1.2 das regras técnicas. As fontes de alimentação (411.1.2.1 a 411.1.2.5.) constam de transformadores, fontes eletroquímicas (pilhas ou acumuladores), dispositivos eletrónicos que satisfaçam às regras indicadas nas respetivas Normas Fontes móveis, tais como transformadores de segurança ou grupos motor-gerador, selecionadas ou instaladas de acordo com as regras inerentes à medida de proteção por utilização de equipamentos da classe II ou por isolamento equivalente;

       c) Forem verificadas as condições indicadas na seção 411.1.3 e se se verificar ainda uma das condições seguintes:

       - As medidas indicadas na secção 411.1.4, para circuitos não ligados à terra (TRS);

       - As medidas indicadas na secção 411.1.5, para os circuitos ligados à terra.

2. Na proteção contra os contatos diretos devem ser garantidas as seguintes condições:

Proteção por isolamento das partes ativas. As partes ativas da instalação devem ser completamente revestidas por um isolamento que apenas possa ser retirado por destruição.

Para os equipamentos montados em fábrica, o isolamento deve satisfazer às regras correspondentes relativas a estes equipamentos. Para os outros equipamentos, a proteção deve ser garantida por um isolamento capaz de suportar, de forma durável, as solicitações a que possa vir a ser submetido (tais como, as influências mecânicas, químicas, elétricas e térmicas). De um modo geral, não se considera que as tintas, os vernizes, as lacas e os produtos análogos constituam isolamento suficiente no âmbito da proteção contra os contactos diretos;

Proteção por meio de barreiras ou de invólucros, as partes ativas devem ser colocadas dentro de invólucros ou por detrás de barreiras que tenham, pelo menos, um código IP2X; no entanto, se durante a substituição de certas partes (tais como, suportes de lâmpadas, fichas, tomadas e fusíveis) ou para permitir o bom funcionamento dos equipamentos de acordo com as regras que lhes são aplicáveis, resultarem aberturas superiores às correspondentes a este código, deve verificar-se, simultaneamente, o seguinte:

a) Serem tomadas as precauções apropriadas para impedir que as pessoas ou os animais possam tocar acidentalmente nas partes ativas;

b) Ser, sempre, garantido que as pessoas estejam conscientes do facto de as partes que fiquem acessíveis pela abertura são partes ativas e que não devem ser tocadas voluntariamente.

A proteção deverá ser garantida por meio de barreiras ou de invólucros, por meio de obstáculos, por colocação fora de alcance através de proteção complementar por dispositivos de proteção sensíveis à corrente diferencial-residual (abreviadamente dispositivos diferenciais).

O emprego de dispositivos diferenciais, de corrente diferencial estipulada não superior a 30 mA, é reconhecido como medida de proteção complementar em caso de falha de outras medidas de proteção contra os contatos diretos ou em caso de imprudência dos utilizadores. A utilização destes dispositivos referidos na secção 412.5.1 não é reconhecida como constituindo, por si só, uma medida de proteção completa e não dispensa, de modo algum, o emprego de uma das medidas de proteção indicadas nas seções 412.1 a 412.4.

3. Na proteção contra os contatos indiretos recomenda-se as seguintes proteções:

Proteção por corte automático da alimentação, deve existir um dispositivo de proteção que separe automaticamente da alimentação o circuito ou o equipamento quando surgir um defeito entre uma parte activa e uma massa. Esta medida de proteção contra os contatos indiretos destina-se a impedir que, entre partes condutoras simultaneamente acessíveis, possam manter-se, durante um tempo suficiente para criar riscos de efeitos fisiopatológicos perigosos para as pessoas, tensões de contato presumidas superiores às tensões limites convencionais (U_L) seguintes:

a) 50 V em corrente alternada (valor eficaz);

b) 120 V em corrente contínua.

Para tempos de corte não superiores a 5s, podem-se admitir, em certas circunstâncias dependentes do esquema das ligações à terra (veja-se 413.1.3.5), outros valores para a tensão de contato.

Nas ligações à terra as massas devem ser ligadas a condutores de proteção nas condições especificadas para cada um dos esquemas de ligações à terra (veja-se 413.1.3 a 413.1.5). As massas simultaneamente acessíveis devem ser ligadas, individualmente, por grupos ou em conjunto, ao mesmo sistema de ligação à terra.

Nas ligações equipotenciais principais em cada edifício, devem ser ligados à ligação equipotencial principal os elementos condutores seguintes:

a) O condutor principal de proteção;

b) O condutor principal de terra ou o terminal principal de terra;

c) As canalizações metálicas de alimentação do edifício e situadas no interior (por exemplo, de água e gás);

d) Os elementos metálicos da construção e as canalizações metálicas de aquecimento central e de ar condicionado (sempre que possível).

Quando estes elementos condutores tiverem a sua origem no exterior do edifício, esta ligação deve ser feita tão perto quanto possível do seu ponto de entrada no edifício. Os condutores da ligação equipotencial principal devem satisfazer às regras indicadas na seção 54.

Devem, também, ser ligadas à ligação equipotencial principais bainhas metálicas dos cabos de telecomunicações, desde que os proprietários e os utilizadores destes cabos o autorizem.

Nas ligações equipotenciais suplementares em que as condições de proteção indicadas na seção 413.1.1.1 não puderem ser verificadas numa instalação ou numa parte da instalação, deve-se fazer uma ligação local designada por ligação equipotencial suplementar (veja-se 413.1.6).

2. Proteção contra os efeitos térmicos em serviço normal.

As pessoas, os equipamentos fixos e os objectos fixos que se encontrem nas proximidades dos equipamentos elétricos devem ser protegidos contra os efeitos térmicos perigosos resultantes do funcionamento dos equipamentos elétricos ou contra os efeitos das radiações térmicas, nomeadamente:

a) A combustão ou a degradação dos materiais;

b) As queimaduras;

c) A redução da segurança de funcionamento dos equipamentos elétricos instalados.

Os equipamentos elétricos não devem constituir causa de incêndio para os materiais próximos. Para além do indicado nas presentes Regras Técnicas, devem ser respeitadas as instruções fornecidas pelo fabricante.

Quando as temperaturas exteriores dos equipamentos elétricos fixos puderem atingir valores suscetíveis de causarem incêndio nos materiais próximos, os equipamentos devem satisfazer a uma das condições seguintes:

a) Serem instalados sobre ou no interior de materiais de baixa condutibilidade térmica, capazes de suportar aquelas temperaturas;

b) Serem separados dos elementos da construção por materiais de baixa condutibilidade térmica, capazes de suportarem aquelas temperaturas;

c) Serem instalados a uma distância suficiente dos materiais cujas características possam ser comprometidas por aquelas temperaturas, permitindo uma dissipação eficaz do calor. Os suportes dos equipamentos devem ter baixa condutibilidade térmica.

Os equipamentos ligados de modo permanente, suscetíveis de produzirem arcos ou faíscas em serviço normal, devem satisfazer a uma das condições seguintes:

a) Serem completamente envolvidos por materiais resistentes aos arcos;

b) Serem separados dos elementos da construção sobre os quais os arcos possam ter efeitos prejudiciais por meio de écrans feitos em material resistente aos arcos;

c) Serem instalados a uma distância suficiente dos elementos da construção sobre os quais os arcos e as faíscas possam ter efeitos prejudiciais, permitindo a extinção segura do arco e das faíscas.

Os materiais resistentes aos arcos utilizados para cumprimento desta medida de proteção devem ser incombustíveis, ter uma baixa condutibilidade térmica e apresentar uma espessura adequada, que garanta a sua estabilidade mecânica.

Os equipamentos fixos que tenham um efeito de focalização ou de concentração do calor devem estar suficientemente afastados dos objectos fixos e dos elementos da construção por forma a que estes não possam ficar submetidos, em condições normais, a temperaturas perigosas.

Quando equipamentos elétricos instalados no mesmo local contiverem uma quantidade importante de líquido inflamável, devem ser tomadas as medidas adequadas para impedir que o líquido inflamado e os seus produtos de combustão (chamas, fumos, gases tóxicos, etc.) se propaguem a outras partes do edifício.

Os materiais dos invólucros colocados nos equipamentos elétricos durante a instalação devem poder suportar as temperaturas mais elevadas que sejam suscetíveis de se produzirem nesses equipamentos. Os materiais combustíveis não devem ser utilizados no fabrico destes invólucros, exceto se forem tomadas medidas preventivas contra a inflamação (tais como revestimentos feitos em matérias incombustíveis ou dificilmente combustíveis e de baixa condutibilidade térmica).

Na proteção contra queimaduras as partes acessíveis dos equipamentos elétricos instalados no volume de acessibilidade não devem atingir temperaturas suscetíveis de provocarem queimaduras às pessoas. Os limites dessas temperaturas são os indicados no quadro 42A das RTIEBT. Devendo as partes da instalação suscetíveis de atingir, em serviço normal, mesmo durante períodos curtos, temperaturas superiores a estas serem protegidas contra os contactos acidentais.

Na proteção contra sobreaquecimentos com exceção das caldeiras, as instalações de aquecimento por ar forçado, devem ser concebidas por forma a que os seus blocos de aquecimento só possam ser ligados quando o débito de ar tiver atingido o valor prescrito e devem ser desligados quando o débito de ar cessar. Além disso, devem ter dois limitadores de temperatura independente, que impeçam que seja excedida a temperatura admissível nas condutas de ar. Os invólucros dos blocos de aquecimento devem ser construídos em material incombustível.

Aparelhos de produção de água quente ou de vapor. Os aparelhos de produção de água quente ou de vapor devem ser protegidos, por construção ou por instalação, para todas as condições de serviço, contra as temperaturas excessivas. Se o aparelho, no seu todo, não obedecer às normas aplicáveis, a proteção deve ser garantida por um dispositivo sem rearme automático que funcione independentemente do termóstato. Se o aparelho não for do tipo de escoamento livre, deve ser munido, ainda, de um dispositivo que limite a pressão da água.

3. Proteção contra as sobreintensidades.

Os condutores ativos devem ser protegidos contra as sobrecargas (veja-se 433) e contra os curtos-circuitos (veja-se 434) por um ou mais dispositivos de corte automático, devendo a proteção contra as sobrecargas ser coordenada com a proteção contra os curtos-circuitos, de acordo com o indicado na seção 435.

4. Proteção contra as sobretensões

Se necessário, devem ser tomadas medidas para proteger as instalações elétricas contra as consequências perigosas das sobretensões que as possam afetar (vejam-se 442 e 443).

Os dispositivos de proteção contra as sobretensões devem ter características que permitam o seu funcionamento apenas para tensões superiores à tensão mais elevada que possa existir na instalação elétrica, em serviço normal.

5. Proteção das instalações de baixa tensão contra os defeitos à terra nas instalações de alta tensão

As regras indicadas na secção 442 destinam-se a garantir a segurança das pessoas e dos equipamentos nas instalações de baixa tensão, em caso de defeito entre a instalação de alta tensão e a terra na parte de alta tensão do posto que alimenta a instalação de baixa tensão.

6. Sobretensões de origem atmosférica e sobretensões de manobra

As regras relativas à proteção das instalações elétricas contra as sobretensões transitórias de origem atmosférica, transmitidas pelas redes de distribuição e contra as sobretensões de manobra produzidas pelos equipamentos da instalação. Para tal, devem ser consideradas as sobretensões que possam surgir na origem da instalação, o nível cerâunico presumido, a localização e as características dos dispositivos de proteção contra as sobretensões, por forma a que a probabilidade de incidentes devidos a sobretensões seja reduzida a um nível aceitável para a segurança das pessoas e dos bens e para a continuidade de serviço desejada. Os valores das sobretensões transitórias dependem da natureza da rede de alimentação (subterrânea ou aérea) da presença eventual de dispositivos de proteção contra as sobretensões a montante da origem da instalação e das características da alimentação de baixa tensão. Esta secção indica ainda os casos em que a proteção contra as sobretensões é obrigatória e os casos em que é recomendada. Quando a proteção não for feita de acordo com as regras indicadas nesta secção, a coordenação do isolamento não é garantida, devendo ser avaliado o risco resultante das sobretensões.

7. Proteção contra o abaixamento de tensão

Quando a falta de tensão e o seu restabelecimento possam pôr em perigo as pessoas e os bens e uma parte da instalação ou um equipamento puderem sofrer avarias em consequência de um abaixamento de tensão, devem ser tomadas as precauções apropriadas. Não é obrigatório prever dispositivos de proteção contra os abaixamentos de tensão se as avarias causadas na instalação ou nos equipamentos constituírem um risco aceitável e não representarem perigo para as pessoas.

8. Secionamento e comando.

Nesta seção são indicadas as medidas de secionamento e de comando não automático, local ou à distância, utilizadas para evitar ou para suprimir os perigos resultantes das instalações elétricas ou dos aparelhos e das máquinas alimentados pela energia elétrica.

Todos os dispositivos previstos para o secionamento ou para o comando devem, de acordo com as funções pretendidas, satisfazer às regras correspondentes indicadas na secção 536. As regras indicadas na secção 46 não substituem as medidas de proteção indicadas nas seções 41 a 45 no que concerne ao:

— Secionamento;

— Corte para manutenção mecânica;

— Corte de emergência, incluindo paragem de emergência;

— Comando funcional.

9. Aplicação das medidas de proteção para garantir a segurança.

As medidas de proteção indicadas na secção 47 aplicam-se a toda a instalação, a partes da instalação e aos seus equipamentos. A seleção e a aplicação das medidas de proteção devem satisfazer às regras indicadas na seção 48, de acordo com as condições de influências externas. A proteção deve ser garantida por um dos meios seguintes:

a) Pelo próprio equipamento;

b) Pela aplicação de uma medida de proteção durante a sua instalação;

c) Pela combinação dos meios indicados nas alíneas anteriores.

Devem ser tomadas precauções para evitar que medidas de proteção diferentes adotadas numa mesma instalação ou numa mesma parte de uma instalação possam influenciar-se ou anular-se mutuamente.

5 DISCUSSÃO DOS RESULTADOS. PERSPETIVAS FUTURAS

Ao contrário do que seria espectável os resultados que se passam a expor são essencialmente verbais e não numéricos, primeiro porque a apresentação de valores numéricos implicaria a utilização de programas de cálculo numérico num âmbito da engenharia eletrotécnica, ou seja, a cooperação com alguém com um perfil mais técnico, assim como a utilização de equipamentos específicos.

Face ao exposto e no que concerne a exposição aos riscos elétricos são enunciados os seguintes pontos:

- Os estudos relativos à exposição aos riscos elétricos, nomeadamente estatísticas são diminutos ou quase inexistentes. Na maioria das análises aos acidentes de trabalho, apenas existe a referência ao acidente por exposição à corrente elétrica, sem referência à fonte do dano;

- Durante a elaboração do manual para a consulta dos técnicos de segurança conclui-se, que as medidas de segurança aplicáveis aos equipamentos eléctricos não devem ser consideradas como aplicáveis a todos os sistemas elétricos. A cada sistema elétrico existente corresponde um conjunto de medidas preventivas únicas;

- As normas jurídicas existentes devem ser mais exigentes no que diz respeito à conformidade das instalações, nomeadamente na implementação da obrigatoriedade da colocação de uma placa identificativa em todas as instalações elétricas. Nesta placa devem constar as principais especificidades da instalação assim como os ensaios a que a instalação foi sujeita, assim como os trabalhos previstos para o local. O termo todas as instalações elétricas, inclui principalmente valas, caleiras, caminhos de cabos e linhas áreas. Que se defina essa lista de verificação como o “Cadastro local actual do equipamento”;

- As listas de verificação são documentos muito importantes e devem ser implementados como uma forma de registo e acompanhamento dos trabalhos;

- A verificação e a realização de ensaios de todas as instalações são diminutas, insuficientes e deve existir um maior rigor nas actividades de inspeção.

As perspetivas futuras estão principalmente relacionadas com as redes de proteção e os principais estudos que têm vindo a ser realizados.

Embora sejam equipamentos de extrema importância para a segurança da envolvente, das pessoas e animais, o seu estudo em termos de segurança ainda se encontra pouco desenvolvido. Após a implementação das redes de terra em edifícios habitacionais, industriais e principalmente em postos de transformação, as ações para a verificação destes sistemas de proteção, resumem-se fundamentalmente a um ensaio inicial, muitas das vezes efetuado com equipamentos de medição não conforme. Como consequência as ações de verificação ficam limitadas a um ensaio inicial sem o correspondente acompanhamento através de ensaios periódicos, embora estejam previstos na legislação. Resta ainda saber, quais as medidas de proteção que devem ser implementadas quando se verifica que as redes de proteção não garantem as tensões de segurança toleráveis. A apresentação do registo de um exemplo de cada um dos ensaios referidos na parte 6 das RTIEBT seria uma mais valia para este trabalho.

O mundo da eletricidade é muito vasto, e muitos estudos se podem realizar nesta área, tal como a realização de ensaios em vários locais (edifícios de habitação, edifícios industriais, subestações, centrais elétricas e outras). O propósito destes ensaios seria a comparação dos valores obtidos com os valores toleráveis em termos de segurança elétrica, mais interessante seria a comparação entre os vários locais verificando quais os que apresentam maior conformidade com as normas técnicas e jurídicas.

Seria ainda interessante a realização de um estudo relativo às potenciais fontes de danos causados pela exposição ao risco elétrico, em que o estudo devia também contemplar o grau de instrução do acidentado.

Surge ainda uma problemática relativa às competências dos técnicos de segurança e saúde do trabalho relativamente às competências de base que devem possuir de forma a realizar uma análise de riscos correta perante trabalhos que abrangem a exposição à corrente elétrica.

As instalações de alta tensão devem ser objeto da realização de estudos mais pormenorizados.

6 CONCLUSÃO

A título de conclusão fica uma lista resumo das linhas orientadoras para poder orientar o técnico de segurança durante o seu trabalho de identificação de riscos:

1. Utilizar pessoal devidamente qualificado;
2. Usar materiais e equipamentos aprovados;
3. Assegurar que se procede à escolha correta do tipo, dimensão e capacidade dos cabos elétricos de acordo com a potência total máxima dos aparelhos e com o coeficiente de simultaneidade considerado para as instalações por eles alimentados;
4. Assegurar que todo o equipamento é adequado à potência nominal da instalação;
5. Assegurar que os condutores são isolados, protegidos e instalados na posição de menor risco;
6. Assegurar que as juntas e ligações devem ser constituídas de modo a suportar os esforços electromecânicos a que vão estar sujeitas;
7. Assegurar a instalação de órgãos de proteção, convenientemente seleccionados para o local e para a função que devem desempenhar e com um adequado grau de selectividade;
8. Assegurar a correta ligação à terra de partes metálicas que em caso de defeito possam ficar activas, e que o respectivo circuito seja devidamente protegido;
9. Assegurar a correta instalação e ligação de todos os órgãos de corte e ou de proteção;
10. Assegurar que todo o equipamento, que necessite de ser normalmente operado ou assistido por pessoas, seja acessível e de fácil operação;
11. Assegurar que todo o equipamento a ser instalado em situações sujeitas a influências externas adversas, climáticas ou corrosivas, seja do correto tipo para essas condições adversas;
12. Antes de se alterar ou expandir uma instalação, assegurar que essa alteração não vai diminuir as características de segurança da instalação existente;
13. Assegurar que, depois de se completar e colocar em tensão uma instalação, uma adequada inspecção e ensaios são efectuados para verificar que os requisitos de segurança foram cumpridos;
14. Assegurar que todo o equipamento é sujeito a ações de manutenção adequadas às suas condições de funcionamento.

As medidas preventivas relativas à segurança, perante a exposição aos riscos elétricos são aquelas que apresentam um maior rigor técnico por obedecerem essencialmente a normas técnicas, no entanto, perante a permanência num local com equipamentos elétricos quase não existe informação técnica e objetiva que permita uma rápida identificação dos potenciais riscos da instalação.

O tempo previsto para a realização desta tese de mestrado é muito pequeno comparado com a quantidade de informação que se obteve durante este estudo, porque os riscos elétricos vão muito além das inspecções visuais que os técnicos de segurança estão habituados. A avaliação de uma instalação elétrica por um técnico de segurança deve ser sempre completada pelo acompanhamento e cooperação de uma pessoa qualificada, não só pelo seu conhecimento como pela necessária realização de cálculos das tensões toleráveis de segurança.

Revela-se de extrema importância o cumprimento do artigo 16º do Decreto-lei nº 273/2003 de 29 de Outubro relativo à elaboração da compilação técnica da obra, como forma de implementação de medidas preventivas durante futuras actividades de manutenção e reparação. A compilação técnica da obra deve estar acessível e dela devem constar os seguintes elementos:

a) Identificação completa do dono da obra, do autor ou autores do projeto, dos coordenadores de segurança em projeto e em obra, da entidade executante, bem como de subempreiteiros ou trabalhadores independentes cujas intervenções sejam relevantes nas características da mesma;

b) Informações técnicas relativas ao projeto geral e aos projetos das diversas especialidades, incluindo as memórias descritivas, projeto de execução e telas finais, que refiram os aspetos estruturais, as redes técnicas e os sistemas e materiais utilizados que sejam relevantes para a prevenção de riscos profissionais;

c) Informações técnicas respeitantes aos equipamentos instalados que sejam relevantes para a prevenção dos riscos da sua utilização, conservação e manutenção;

d) Informações úteis para a planificação da segurança e saúde na realização de trabalhos em locais da obra edificada.

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ANEXO I

Listas de Verificação

Exemplos de aplicação prática do manual

Tabela de consulta das RTIEBT para acompanhamento – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 1/1

CARACTERISTICAS DA INSTALAÇÃO	CONSULTAR		
	Parte 3 (SEÇÃO)	Parte 4 (SEÇÃO)	Parte 5 (SEÇÃO)
2.1 - Natureza da corrente	313;34;35		
2.2 -Natureza e número de condutores	313;33;34		
2.3-Valores característicos e tolerâncias	313;33;34		
2.4 - Esquemas de ligações à terra inerentes à alimentação e outras condições relativas à proteção.	312;34		
2.5 - Exigências particulares do distribuidor de energia elétrica	314;34,35		
3 - Natureza do fornecimento (O número e os tipos de circuitos necessários para a iluminação, o aquecimento, a força motriz, o comando, a sinalização, as telecomunicações, etc., são determinados com base nas indicações seguintes)	314;33;34		
4 - Alimentação de segurança/ Alimentação de substituição	34		
5— Condições ambientais	32;34		
6- Seção dos condutores	34		
7- Modo de instalação das canalizações	34		
8 – Dispositivos de proteção	34		
9 -Dispositivos para corte de emergência	34		
10 — Dispositivos de secionamento	34		
11— Independência da instalação elétrica	314;34		
12 — Acessibilidade dos equipamentos elétricos	34		

Tabela de consulta das RTIEBT para acompanhamento – LVLO3	**Responsável:** **Data:**
	Designação instalação: **pág:** 1/1

CARACTERISTICAS DAS CONDIÇÕES EXTERNAS	CONSULTAR	
	Parte 4 (SEÇÃO)	Parte 5 (SEÇÃO)
Ambientes		
Temperatura ambiente		512.2;522.1
Condições climáticas		
Altitude		512.2
Presença da água		512.2;522.3
Presença de corpos sólidos estranhos		512.2;522.4
Presença de substâncias corrosivas ou poluentes		512.2;522.5
Acções mecânicas		
Impactos		512.2;522.6
Vibrações		512.2;522.7
Outras ações mecânicas		
Presença de flora ou de bolores		512.2;522.9
Presença de fauna		512.2;522.10
Influências eletromagnéticas, eletrostáticas ou ionizantes		512.2
Radiações solares		512.2;522.11
Efeitos sísmicos		512.2;522.12
Descargas atmosféricas, nível cerâunico	443	512.2
Movimentos do ar		512.2;522.13
Vento		
Utilizações		
Competência das pessoas		512.2
Resistência elétrica do corpo humano	413.1;481.3	
Contactos das pessoas com o potencial da terra		512.2;512.16
Evacuação das pessoas em caso de emergência	482	512.2;522.18
Natureza dos produtos tratados e armazenados	42	512.2;522.18
Construção de edifícios		
Materiais de construção	482	512.2;522.19
Estrutura de edifícios	482	512.2;522.19

EXEMPLO DE APLICAÇÃO DE ACODO COM O GUIA IEEE Std 80-2000

O método de ensaio que tem como guia a norma IEEE Std 80-2000, para a verificação das condições das subestações perante a exposição ao choque elétrico, no que concerne aos ensaios para medição e dimensionamento das redes de proteção consiste na determinação dos parâmetros definidos no subcapítulo 3.3 da dissertação.

O método de cálculo apresentado pela norma IEEE Std 80-2000 consiste no cálculo da corrente de defeito máxima na malha de terra $I_{G,}$ cujo valor multiplicado pela resistência da malha de terra R_g ,permite definir a tensão de defeito malha de terra, o valor obtido é posteriormente comparado com os valores da tensão de toque e de passo toleráveis. Quando a tensão da malha de rede é superior aos valores calculados para as tensões toleráveis, significa que a malha de proteção existente terá de sofrer alterações. Estas alterações são determinadas em funções de novos cálculos e abrangem um conjunto de medidas de projeto como colocação de mais elétrodos de terra, alteração das especificidades dos elétrodos, alteração da camada de material exterior, etc.

O exemplo dos cálculos que se apresenta é idêntico ao exemplo apresentado no Anexo B da IEEE Std 80-2000 (IEEE - Institute of Electrical and Electronics Engineers 2000):

Tabela – Tabela das variáveis

Variáveis	Valores	Unidades
Inserir-Variavéis	0,5	segundos
Tempo de duração do defeito/contato	0,5	m
Profundidade da Malha (h)	400	Ω.m
Resistividade do Solo (ρ)	2500	Ω.m
Resistividade da camada protetora (ρs)	0,102	m
Corrente de Defeito máxima à terra	1908	A
Fator de Divisão de Corrente	0,6	
Comprimento da Malha (C)	70	m
Largura da Malha (L)	70	
Espaçamento entre condutores (D)	7	m
Nº Elétrodos	20	
Comprimento dos elétrodos (Lr)	7,5	m
Tipo de Material Condutor a Usar	Cobre, comercial rígido em várias	

Seguem-se as etapas de cálculo (as equações apresentadas que não se encontram descritas no subcapítulo 3.3 estão na norma IEEE Std 80-2000):

1º Passo:
Considerar a malha quadrada de 70mx70m, Área de 4900m^2
2º Passo:
O valor da corrente de defeito da malha terra é dado (tabela 1)
3º Passo:

$$A_{kcmil} = I \cdot K_f \sqrt{t_c}$$

Utilizar a tabela 2, da página 44 da norma IEEE Std 80-2000

4º Passo:

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0.09}$$

5º Passo:

$$E_{step70} = (1000 + 6C_s\rho_s)0.157/\sqrt{t_s}$$

6º Passo:

$$E_{step70} = (1000 + 1.5C_s\rho_s)0.157/\sqrt{t_s}$$

7º Passo:

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$$

LT – comprimento total dos condutores enterrados

LT = comprimento dos condutores da malha LC+ comprimento total de elétrodos LR

8º Passo:

$$I_G = D_f \cdot I_g$$

$$GPR = I_G \cdot R_g$$

9º Passo:

$$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\left[\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 + h)^2}{8 \cdot D \cdot h} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]\right]$$

$$K_{ii} = \frac{1}{(2 \cdot n)^{\frac{2}{n}}}$$

$$n = n_a \cdot n_b \cdot n_c \cdot n_d$$

$$n_a = \frac{2 \cdot L_C}{L_P}$$

LC comprimento total de condutores da malha

LP – Perímetro da malha

$$K_h = \sqrt{1 + \frac{h}{h_0}}$$

$$K_i = 0.644 + 0.148 \cdot n$$

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + L_R}$$

Seguem-se as tabelas finais dos cálculos:

Tabela – Cálculo das tensões toleráveis

tensões toleráveis	Valores	Unidades
Cálculo da Tensão de Toque Tolerável	840,5479323	v
Cálculo da Tensão de Passo Tolerável	2696,097141	v

Tabela – Seção do condutor

Cálculos Intermédios	Valores	Unidades
Secção	4,825262287	mm^2
Diâmetro do Condutor	2,478651802	mm

Tabela – Tabela de cálculos intermédios

	Valores	Unidades
Fator de correção (Cs)	0,74286	
Área	4900	m^2
Comprimento dos condutores da Malha (LC)	1540	m
Comprimento total dos condutores enterrados (LT)	1690	m
Perimetro da Malha (Lp)	280	m
Comprimento total dos Elétrodos (LR)	150	
h0	1	m
Kh	1,22474	
na	11	
nb	1	
nc	1	
nd	1	
n	11	
Kii	0,57006	
Km	0,78433	
ki	2,272	
k	0,40614	
Ls	1282,5	
LM	1786,36	m
Cálculo da Resistência da Rede de Terra	2,752639794	Ω
GPR (Potêncial da malha)	5252,036726	v

Tabela – Cálculo das tensões da malha de terra

Tensões da malha de terra	Valores	Unidades
Em (Cálculo da tensão máxima da malha)	761,3337512	v
Es (Cálculo da tensão máxima de passo)	549,1107928	v

Verifica-se pela análise dos resultados obtidos que as tensões na malha de terra são inferiores às tensões toleráveis de segurança. Verifica-se que se introduzirem valores diferentes em algumas das variáveis iniciais (nº elétrodos, comprimento dos elétrodos, tipo de material condutor a usar), é possível melhorar e obter valores nas tensões da malha de terra inferiores às tensões toleráveis de segurança.

Caracterização das instalação (dados retirados das LVLO2;LVLO3 4; LVLO3	**Atividades a realizar**	**Identificação dos Perigos**
Posto de transformação que se encontra dependente de uma subestação a montante. Apresenta - Corrente alternada, com 3 condutores ($1x300mm^2x3$) por fase com 2 condutores neutros ($1x70mm^2x2$) ; - Tensão de 400 V, uma frequência de 50 Hz e uma corrente máxima admissível de 1250 Am; - Esquema de ligação à terra TN; - Instalação num complexo industrial abrangido por atmosferas explosivas; - Instalação de comando de 220 V; - Instalação de alimentação constituída por neutro artificial com transformador direto de estrela; - Sistema de telecomuniacções realizado por Sistema Modbas por comando à distância e por Fibra-ótica para a supervisão; - Os dispositivos de comunicação por fibra-ótica encontram-se ligados a uma sala de controlo que permite o corte de emergência; - Canalizações em esteira e em vala sem proteção mecânica. As canalizações apresentam condições de acesso adequadas, no entanto o acesso ao local é restrito a pessoas habilitadas. - Os dispositivos existem e encontram-se no esquema unifiliar do local ; - Dispositivos de secionamento constituídos por disjuntores extraíveis monitorizados; - O local de instalação do quadro apresentam a dimensões adequadas para a realização dos trabalhos.	- Montagem do quadro elétrico; - Realização de ensaios no quadro elétrico; - Colocação em funcionamento do quadro elétrico	Exposição aos efeitos da corrente elétrica. Perigo de explosão e incêndio
Influências externas aplicáveis: Temperatura ambiente, Condições climáticas,O edifício é em alvenaria e encontra-se isolado do exterior; - Apresenta plano de evacuação.		
Todos as atividades de manutibilidade são efetuadas por pessoas qualificadas		

Posto de transformação que se encontra dependente de uma subestação a montante. Apresenta - Corrente alternada, com 3 condutores (1x300mm^{2}x3) por fase com 2 condutores neutros (1x70mm^{2}x2) ; - Tensão de 400 Volts, uma frequência de 50 Hertz e uma corrente máxima admissível de 1250 Amperes; - Esquema de ligação à terra TN; - Instalação num complexo industrial abrangido por atmosferas explosivas; - Instalação de comando de 220 Volts; - Instalação de alimentação constituída por neutro artificial com transformador direto de estrela; - Sistema de telecomuniacções realizado por Sistema Modbas por comando à distância e por Fibra-óptica para a supervisão; - Os dispositivos de comunicação por fibra-optica encontram-se ligados a uma sala de controlo que permite o corte de emergência; - Canalizações em esteira e em vala sem protecção mecânica. As canalizações apresentam condições de acesso adequadas, no entanto o acesso ao local é restrito a pessoas habilitadas. - Os dispositivos existem e encontram-se no esquema unifiliar do local ; - Dispositivos de seccionamento constituídos por disjuntores extraíveis monitorizados; - O local de instalação do quadro apresentam a dimensões adequadas para a realização dos trabalhos.
Influências externas aplicáveis: - Temperatura ambiente; - Condições climáticas; O edifício é em alvenaria e encontra-se isolado do exterior; - Apresenta plano de evacuação
Todos as atividades de manutibilidade são efetuadas por pessoas qualificadas

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 1/4

2.1 - Natureza da corrente			
Alternada		Continua	

2.2 -Natureza e número de condutores		
	N.º	Descrição
Condutor de fase		
Condutor de neutro		
Condutor de protecção		

2.3-Valores característicos e tolerâncias	
	Descrição
Tensões e tolerâncias	
Frequências e tolerâncias	
Corrente máxima admissível	
Corrente presumida de curto-circuito	

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 2/4

2.4 - Esquemas de ligações à terra inerentes à alimentação e outras condições relativas à protecção.	
Descrição:	
2.5 - Exigências particulares do distribuidor de energia eléctrica	
Descrição	

3 - Natureza do fornecimento (O número e os tipos de circuitos necessários para a iluminação, o aquecimento, a força motriz, o comando, a sinalização, as telecomunicações, etc., são determinados com base nas indicações seguintes)

Tipo de circuito	Localização dos pontos de consumo da energia eléctrica	Variação diária e anual do consumo	Condições particulares	Instalação de Comando	Instalação de iluminação	Instalação de telecomunicações	Outras instalações

4 - Alimentação de segurança	Alimentação de substituição

5— Condições ambientais (seção 32 e na Norma IEC 60721)

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 3/4

Descrição:						
6- Seção dos condutores						
7- Modo de instalação das canalizações						
Tipo de canalização	Natureza do local	Natureza das paredes e dos outros elementos da construção que suportam as canalizações	Acessibilidade das canalizações às pessoas e aos animais	Tensão	Solicitações eletromecânicas susceptíveis de se produzirem em caso de curto-circuito	Outras solicitações às quais as canalizações podem ficarem submetidas durante a execução da instalação elétrica ou em serviço
8 – Dispositivos de proteção						
Sobreintensidades (sobrecargas e curto-circuitos)						
Correntes de defeito à terra						
Sobretensões						
Abaixamentos e das faltas de tensão						

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 4/4

9- Dispositivos para corte de emergência.		
10 — Dispositivos de secionamento		
11— Independência da instalação elétrica		
12 — Acessibilidade dos equipamentos elétricos		

Lista de verificação das ações de manutibilidade da instalação elétrica – LVLO34	**Responsável:** **Data:**
	Designação instalação: **pág:** 1/1

34 – Manutibilidade				
	Descrição			
Periocidade da manutibilidade da instalação elétrica				
Qualidade da manutenção				

Frequência e qualidade da manutenção	Sim	Não	Não aplicável
Verificações periódicas			
Descrição:			
Ensaios			
Descrição:			
Manutenção			
Descrição:			
As verificações periódicas, os ensaios e manutenção são efectuados de forma fácil e segura.			
As medidas de proteção são as indicadas para garantir a segurança			
O correto secionamento da instalação é fiável			

Lista de verificação das influências externas – LVLO3	**Responsável:** **Data:** **Designação instalação:** **pág:** 1/1

INFLUÊNCIAS EXTERNAS	APLICÁVEL	NÃO APLICÁVEL
Ambientes		
Temperatura ambiente		
Condições climáticas		
Altitude		
Presença da água		
Presença de corpos sólidos estranhos		
Presença de substâncias corrosivas ou poluentes		
Ações mecânicas		
Impactos		
Vibrações		
Outras ações mecânicas		
Presença de flora ou de bolores		
Presença de fauna		
Influências eletromagnéticas, eletrostáticas ou ionizantes		
Radiações solares		
Efeitos sísmicos		
Descargas atmosféricas, nível cerâunico		
Movimentos do ar		
Vento		
Utilizações		
Competência das pessoas		
Resistência elétrica do corpo humano		
Contatos das pessoas com o potencial da terra		
Evacuação das pessoas em caso de emergência		
Natureza dos produtos tratados e armazenados		
Construção de edifícios		
Materiais de construção		
Estrutura dos edifícios		

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 1/4

2.1 - Natureza da corrente			
Alternada	X	Continua	

2.2 -Natureza e número de condutores		
	N.º	Descrição
Condutor de fase	3	1x300mm^2
Condutor de neutro	Não aplicável	
Condutor de protecção	2	1x70mm^2

2.3-Valores característicos e tolerâncias	
	Descrição
Tensões e tolerâncias	400 Volts
Frequências e tolerâncias	50 Hz
Corrente máxima admissível	1250 Amperes
Corrente presumida de curto-circuito	1550 Amperes

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:** **Designação instalação:** **pág:** 2/4

2.4 - Esquemas de ligações à terra inerentes à alimentação e outras condições relativas à proteção.	
Descrição:	Esquema TN

2.5 - Exigências particulares do distribuidor de energia elétrica	
Descrição	Não aplicável

3 - Natureza do fornecimento (O número e os tipos de circuitos necessários para a iluminação, o aquecimento, a força motriz, o comando, a sinalização, as telecomunicações, etc., são determinados com base nas indicações seguintes)

Tipo de circuito	Localização dos pontos de consumo da energia eléctrica	Variação diária e anual do consumo	Condições particulares	Instalação de Comando	Instalação de iluminação	Instalação de telecomunicações	Outras instalações
Não identificável	Não identificável	Não aplicável	Instalação num complexo industrial abrangido por atmosferas explosivas	220 V	Por neutro artificial com transformador direto de estrela	Sistema Modbas por comando à distância	Não aplicável
						Sistema de Fibra-óptica para a supervisão	

4 - Alimentação de segurança	Alimentação de substituição
Fontes (natureza e características):Não é possivel identificar	Fontes (natureza e características):Não aplicável
Circuitos alimentados pela fonte de segurança: Comando do quadro elétrico	Circuitos alimentados pela fonte de segurança:

5— Condições ambientais (seção 32 e na Norma IEC 60721)
Descrição: Ver a lista de verificação relativa às condições externas

6- Seção dos condutores
Ver o ponto 2.2 da LO2

7- Modo de instalação das canalizações

Tipo de canalização	Natureza do local	Natureza das paredes e dos outros elementos da construção que suportam as canalizações	Acessibilidade das canalizações às pessoas e aos animais	Tensão	Solicitações eletromecânicas suscetíveis de se produzirem em caso de curto-circuito	Outras solicitações às quais as canalizações podem ficarem submetidas durante a execução da instalação elétrica ou em serviço
Enterrada (caminho de cabos sem proteção mecânica)	Ver ponto 5	Ver ponto 5	O acesso apenas é garantido através da abertura de vala	220 V	Não aplicável	Não aplicável
Esteira	Ver ponto 5	Ver ponto 5	Existe facilidade de acesso mas com autorização e respetivo acompanhamento	220 V	Não aplicável	Não aplicável

Lista de verificação de identificação e da instalação elétrica – LVLO2	**Responsável:** **Data:**
	Designação instalação: **pág:** 4/4

8 – Dispositivos de protecção	
Sobreintensidades (sobrecargas e curto-circuitos)	Descritos no esquema unifiliar
Correntes de defeito à terra	Descritos no esquema unifiliar
Sobretensões	Descritos no esquema unifiliar
Abaixamentos e das faltas de tensão	Descritos no esquema unifiliar

9- Dispositivos para corte de emergência.
Os dispositivos de comunicação por fibra-optica que se encontram ligados a uma sala de controlo permite o corte de emergência
10 — Dispositivos de secionamento
Disjuntores extraíveis monitorizados
11— Independência da instalação elétrica
Instalação que se encontra dependente de uma subestação
12 — Acessibilidade dos equipamentos eléctricos

Equipamento Elétrico:	Espaço suficiente para executar a instalação inicial e a posterior substituição dos seus componentes	Acessibilidade para fins de funcionamento, de verificação, de manutenção e de reparação
Quadro elétrico	Sim	Sim

Lista de verificação das ações de manutibilidade da instalação elétrica – LVLO34	**Responsável:** **Data:**
	Designação instalação: **pág:** 1/1

34 – Manutibilidade	
	Descrição
Periodicidade da manutibilidade da instalação eléctrica	Não identificável
Qualidade da manutenção	A manutenção é realizada por pessoas qualificadas

Frequência e qualidade da manutenção	Sim	Não	Não aplicável
Verificações periódicas	**x**		
Descrição: Não identificável			
Ensaios	**x**		
Descrição: Não identificável			
Manutenção	**x**		
Descrição: Não identificável			
As verificações periódicas, os ensaios e manutenção são efectuados de forma fácil e segura.	**x**		
As medidas de proteção são as indicadas para garantir a segurança	**x**		
O correto secionamento da instalação é fiável	**x**		

ANEXO II

Normas Legais e Técnicas

DIRECTIVA 98/34/CE DO PARLAMENTO EUROPEU E DO CONSELHO RELATIVA A UM PROCEDIMENTO DE INFORMAÇÃO NO DOMÍNIO DAS NORMAS E REGULAMENTAÇÕES TÉCNICAS E DAS REGRAS RELATIVAS AOS SERVIÇOS DA SOCIEDADE DA INFORMAÇÃO

Versão consolidada oficiosa preparada pelos serviços da Comissão [*]

Directiva 98/34/CE do Parlamento Europeu e do Conselho, de 22 de Junho de 1998, relativa a um procedimento de informação no domínio das normas e regulamentações técnicas.

e

Directiva 98/48/CE do Parlamento Europeu e do Conselho, de 20 de Julho de 1998, que altera a Directiva 98/34/CE relativa a um procedimento de informação no domínio das normas e regulamentações técnicas.

[*] **Os artigos e as partes do texto alteradas pela Directiva 98/48/CE, que se refere aos serviços da sociedade da informação, estão indicados a negro.**

O PARLAMENTO EUROPEU E O CONSELHO DA UNIÃO EUROPEIA,

Considerandos da directiva 98/34/CE

Tendo em conta o Tratado que institui a Comunidade Europeia e, nomeadamente, os seus artigos 100.ºA, 213.º e 43.º,

Tendo em conta a proposta da Comissão ([1]),

Tendo em conta o parecer do Comité Económico e Social ([2]),

Deliberando nos termos do artigo 189.º B do Tratado ([3]),

(1) Considerando que a Directiva 83/189/CEE do Conselho, de 28 de Março de 1983, relativa a um procedimento de informação no domínio das normas e regulamentações técnicas([4]), foi várias vezes substancialmente alterada; que, por conseguinte, é conveniente, por motivos de lógica e clareza, proceder à codificação da referida directiva;

(2) Considerando que o mercado interno abrange um espaço sem fronteiras internas no qual se encontra garantida a livre circulação de mercadorias, pessoas, serviços e capitais; que, por conseguinte, a proibição das restrições quantitativas bem como das medidas de efeito equivalente a restrições quantitativas ao comércio de mercadorias é um dos fundamentos da Comunidade;

(3) Considerando que, tendo em vista o bom funcionamento do mercado interno, é oportuno garantir a maior transparência das iniciativas nacionais destinadas a estabelecer normas ou regulamentos técnicos;

(4) Considerando que os entraves às trocas comerciais resultantes das regulamentações técnicas relativas aos produtos só podem ser consentidos quando forem necessários para satisfazer exigências imperativas e visem a prossecução de um fim de interesse geral, do qual constituam a garantia essencial;

(5) Considerando que é indispensável que a Comissão disponha das informações necessárias antes da adopção das disposições técnicas; que os Estados-membros que, por força do artigo 5.º do Tratado, são obrigados a facilitar o cumprimento da sua missão, devem notificá-la dos seus projectos no domínio das regulamentações técnicas;

(6) Considerando que todos os Estados-membros devem ser igualmente informados das regulamentações técnicas previstas por um deles;

(7) Considerando que o mercado interno tem por objectivo garantir um ambiente favorável à competitividade das empresas; que uma melhor exploração das vantagens

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([1]) JO C 78 de 12.3.1997, p. 4.
([2]) JO C 133 de 28.4.1997, p. 5.
([3]) Parecer do Parlamento Europeu de 17 de Setembro de 1997 (JO C 304 de 6.10.1997, p. 79), posição comum do Conselho de 23 de Fevereiro de 1998 (JO C 110 de 8.4.1998, p. 1) e Decisão do Parlamento Europeu de 30 de Abril de 1998 (JO C 152 de 18.5.1998). Decisão do Conselho, de 28 de Maio de 1998.
([4]) JO L 109 de 26.4.1983, p. 8. Directiva com a última redacção que lhe foi dada pela Decisão 96/139/CE da Comissão (JO L 32 de 10.2.1996, p. 31).

deste mercado pelas empresas passa, nomeadamente, por uma maior informação; que, por conseguinte, é conveniente prever a possibilidade de os operadores económicos poderem expressar a sua opinião sobre o impacto das regulamentações nacionais técnicas projectadas por outros Estados-membros, mediante a publicação regular dos títulos dos projectos notificados e da alteração das disposições relativas à confidencialidade destes;

(8) Considerando que, para garantir a segurança jurídica, importa que os Estados-membros divulguem o facto de uma regra técnica nacional ter sido adoptada na observância das formalidades da presente directiva;

(9) Considerando que, no que respeita às regulamentações técnicas relativas aos produtos, as medidas destinadas a garantir o bom funcionamento do mercado ou a prosseguir o seu aprofundamento implicam, nomeadamente, o aumento da transparência das intenções nacionais e um alargamento dos motivos e condições de apreciação do eventual efeito no mercado das regulamentações previstas;

(10) Considerando que, nesta perspectiva, importa apreciar o conjunto dos requisitos impostos a um produto e ter em conta a evolução das práticas nacionais em matéria de regulamentação dos produtos;

(11) Considerando que as exigências, salvo as especificações técnicas que visam o ciclo de vida de um produto após a sua colocação no mercado, são susceptíveis de afectar a circulação do produto ou de criar entraves ao bom funcionamento do mercado interno;

(12) Considerando que é necessário esclarecer a noção de regra técnica *de facto*; que, nomeadamente, as disposições através das quais as autoridades públicas se referem às especificações técnicas ou outras exigências ou incitam ao seu cumprimento, bem como as disposições que abrangem produtos aos quais as autoridades públicas são associadas, por interesse público, têm por efeito conferir ao cumprimento das referidas exigências ou especificações um carácter mais vinculativo do que o que teriam normalmente devido à sua origem privada;

(13) Considerando que a Comissão e os Estados-membros devem também poder dispor do prazo necessário para propor uma alteração da medida prevista, com o objectivo de eliminar ou reduzir os entraves à livre circulação de mercadorias que dela podem resultar;

(14) Considerando que o Estado-membro em questão deve ter em conta estas propostas de modificação na elaboração do texto definitivo da medida prevista;

(15) Considerando que o mercado interno implica, nomeadamente na impossibilidade de aplicação do princípio do reconhecimento mútuo pelos Estados-membros, que a Comissão adopte ou proponha a adopção de actos comunitários vinculativos; que foi estabelecido um *statu quo* temporário específico para evitar que a adopção de medidas nacionais comprometa a adopção pelo Conselho ou pela Comissão das propostas de actos comunitários vinculativos, no mesmo domínio;

(16) Considerando que o Estado-membro em causa deve, por força das obrigações gerais resultantes do artigo 5.º do Tratado, suspender a entrada em vigor da medida prevista durante um prazo suficiente que permita quer o exame em comum das alterações propostas quer a elaboração da proposta de um acto comunitário vinculativo do Conselho ou a adopção de um acto comunitário vinculativo da

Comissão; que os prazos previstos no Acordo dos representantes dos Estados-membros, reunidos no seio do Conselho de 28 de Maio de 1969, relativo ao *statu quo* e à informação da Comissão ([5]), alterado pelo acordo de 5 de Março de 1973([6]), se revelaram insuficientes nos casos referidos e que devem, portanto, ser previstos prazos mais longos;

(17) Considerando que o procedimento de *statu quo* e de informação da Comissão contido no acordo de 28 de Maio de 1969 continua aplicável aos produtos por ele abrangidos que não sejam objecto da presente directiva;

(18) Considerando que, para facilitar a adopção pelo Conselho de medidas comunitárias, é conveniente que os Estados-membros se abstenham de adoptar uma regra técnica sempre que o Conselho tenha adoptado uma posição comum sobre a proposta da Comissão sobre a mesma matéria;

(19) Considerando que, na prática, as normas técnicas nacionais podem ter os mesmos efeitos sobre a livre circulação de mercadorias que as regulamentações técnicas;

(20) Considerando que se torna, portanto, necessário assegurar a informação da Comissão relativamente aos projectos de normas em condições análogas às que existem para as regulamentações técnicas; que, por força do artigo 213.º do Tratado, a Comissão pode, para assegurar o cumprimento das missões que lhe são confiadas, recolher todas as informações e proceder a todos os controlos necessários nos limites e condições fixados pelo Conselho nos termos do Tratado;

(21) Considerando que é igualmente necessário que os Estados-membros e os organismos de normalização sejam informados das normas previstas pelos organismos de normalização dos outros Estados-membros;

(22) Considerando que a necessidade de uma notificação sistemática existe de facto, exclusivamente, relativamente aos novos temas de normalização e que, quando abordados a nível nacional, podem dar origem a diferenças nas normas nacionais, susceptíveis, assim, de afectar o funcionamento do mercado; que qualquer notificação ou comunicação posterior da evolução dos trabalhos nacionais deve depender do interesse que estes suscitam junto daqueles a quem foi previamente comunicado o novo tema;

(23) Considerando que a Comissão deve, todavia, poder solicitar a comunicação parcial ou integral dos programas nacionais de normalização, a fim de poder proceder ao exame da evolução da normalização nos sectores económicos em causa;

(24) Considerando que o sistema de normalização europeu deve ser organizado para e pelas partes interessadas, com base na coerência, transparência, abertura, consenso e independência em relação aos interesses privados, eficiência e tomada de decisão com base na representação nacional;

(25) Considerando que o funcionamento da normalização na Comunidade deve assentar em direitos fundamentais dos organismos nacionais de normalização, tais como a possibilidade de obter projectos de normas, conhecer o andamento dado às observações feitas, ser associado aos trabalhos nacionais de normalização ou ainda solicitar a elaboração de normas europeias em substituição das normas nacionais; que

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([5]) JO C 76 de 17.6.1969, p. 9.
([6])JO C 9 de 15.3.1973, p. 3.

incumbe aos Estados-membros adoptar medidas úteis para que os seus organismos de normalização respeitem esses direitos;

(26) Considerando que as disposições relativas ao *statu quo* para os organismos nacionais de normalização devem seguir as disposições adoptadas para este efeito pelos organismos de normalização no âmbito dos organismos europeus de normalização ao ser elaborada uma norma europeia;

(27) Considerando que é oportuno criar um comité permanente, cujos membros serão designados pelos Estados-membros, encarregado de ajudar a Comissão no estudo dos projectos de normas nacionais e de colaborar nos seus esforços para atenuar os eventuais inconvenientes que delas podem resultar para a livre circulação das mercadorias;

(28) Considerando que é conveniente que o comité permanente seja consultado acerca dos projectos de pedido de normalização, referidos na presente directiva;

(29) Considerando que a presente directiva não deve prejudicar as obrigações dos Estados-membros relativas aos prazos de transposição das directivas previstos no Anexo III, Parte B,

Considerandos da directiva 98/48/CE

Tendo em conta o Tratado que institui a Comunidade Europeia e, nomeadamente, os seus artigos 100.ºA e 213.º,

Tendo em conta a proposta da Comissão ([7]),

Tendo em conta o parecer do Comité Económico e Social ([8]),

Deliberando nos termos do artigo 189.ºB do Tratado ([9]),

(1) Considerando que, para permitir o bom funcionamento do mercado interno, é necessário assegurar, através de uma alteração da Directiva 98/34/CE ([10]), a maior transparência das futuras regulamentações nacionais que se aplicarão aos serviços da sociedade da informação;

([7])JO C 307 de 16. 10. 1996, p. 11, e JO C 65 de 28. 2. 1998, p. 12.
([8]) JO C 158 de 26. 5. 1997, p. 1.
([9]) Parecer do Parlamento Europeu de 16 de Maio de 1997 (JO C 167 de 2. 6. 1997, p. 238), posição comum do Conselho de 26 de Janeiro de 1998 (JO C 62 de 26.2.1998, p. 48) e decisão do Parlamento Europeu de 14 de Maio de 1998 (JO C 167 de 1. 6. 1998). Decisão do Conselho de 29 de Junho de 1998.
([10]) JO L 204 de 21. 7. 1998, p. 37.

(2) Considerando que uma grande variedade de serviços, na acepção dos artigos 59.º e 60.º do Tratado, vai beneficiar das oportunidades de prestação à distância, por via electrónica e mediante pedido individual de um destinatário de serviços, abertas pela Sociedade da Informação;

(3) Considerando que o espaço sem fronteiras internas que constitui o mercado interno permite aos prestadores desses serviços desenvolver as suas actividades transfronteiriças a fim de aumentar a sua competitividade, propiciando assim aos cidadãos novas possibilidades de comunicar e de receber informações sem considerações de fronteiras e aos consumidores novas formas de acesso a bens ou serviços;

(4) Considerando que o alargamento da Directiva 98/34/CE não deve obstar a que os Estados-membros tenham em conta as diferentes implicações sociais, societais e culturais inerentes ao advento da Sociedade da Informação; que, em especial, a utilização das regras processuais previstas nesta directiva em matéria de serviços da Sociedade da Informação não deve prejudicar as medidas de política cultural; nomeadamente no domínio audiovisual, que os Estados-membros possam adoptar, segundo o direito comunitário, tendo em conta a sua diversidade linguística, as especificidades nacionais e regionais, bem como os seus patrimónios culturais; que o desenvolvimento da Sociedade da Informação deverá assegurar, de qualquer modo, o correcto acesso dos cidadãos europeus ao património cultural europeu fornecido num ambiente digital;

(5) Considerando que a Directiva 98/34/CE não se destina a ser aplicada a regras nacionais relativas aos direitos fundamentais, como, por exemplo, as regras constitucionais em matéria de liberdade de expressão, e mais precisamente, de liberdade de imprensa; que não se destina igualmente a ser aplicada ao direito penal geral; que, além disso, não se aplica aos acordos de direito privado entre instituições de crédito, nomeadamente aos acordos sobre a realização de pagamentos entre instituições de crédito;

(6) Considerando que o Conselho Europeu realçou a necessidade de criar um quadro jurídico claro e estável a nível comunitário que permita o desenvolvimento da Sociedade da Informação; que o direito comunitário e as disposições relativas ao mercado interno em especial e tanto os princípios do Tratado como o direito derivado constituem já um quadro jurídico de base para o desenvolvimento destes serviços;

(7) Considerando que as regulamentações nacionais existentes aplicáveis aos serviços actuais deverão poder ser adaptadas aos novos serviços da Sociedade da Informação quer para assegurar uma melhor protecção dos interesses gerais quer, pelo contrário, para simplificar essas regulamentações, nos casos em que a sua aplicação seria desproporcionada relativamente aos objectivos visados;

(8) Considerando que, sem coordenação a nível comunitário, esta actividade regulamentar previsível a nível nacional poderia implicar restrições à livre circulação de serviços e à liberdade de estabelecimento, que provocariam uma refragmentação do mercado interno, uma regulamentação excessiva e incoerências regulamentares;

(9) Considerando a necessidade de uma abordagem coordenada a nível comunitário no tratamento das questões relativas a actividades com conotações

eminentemente transnacionais, tais como os novos serviços, a fim de conseguir também uma protecção real e efectiva dos objectivos de interesse geral pertinentes para o desenvolvimento da Sociedade da Informação;

(10) Considerando que, para os serviços de telecomunicações, existe já uma harmonização a nível comunitário ou, eventualmente, um regime de reconhecimento mútuo e que a legislação comunitária existente prevê adaptações ao desenvolvimento tecnológico e aos novos serviços prestados e que por esse facto, na sua maior parte, as regulamentações nacionais dos serviços de telecomunicações não deverão ser notificadas ao abrigo da presente directiva, uma vez que decorrerão das exclusões previstas no n.º 1 do artigo 10.º, ou no ponto 5 do artigo 1.º da Directiva 98/34/CE; que, no entanto, as disposições nacionais que visem especificamente questões não regulamentadas a nível comunitário podem ter influência na livre circulação dos serviços da Sociedade da Informação e que, nessa medida, devem ser notificadas;

(11) Considerando que para outros domínios da Sociedade da Informação ainda pouco conhecidos, seria, contudo, prematuro coordenar estas regulamentações através de uma harmonização extensiva ou exaustiva, a nível comunitário, do direito substantivo, dado que a forma e a natureza dos novos serviços não são suficientemente conhecidas, que não existem ainda a nível nacional actividades regulamentares específicas na matéria e que a necessidade e o conteúdo de tal harmonização relativamente ao mercado interno não podem ser definidos nesta fase;

(12) Considerando que é pois necessário preservar o bom funcionamento do mercado interno e prevenir os riscos de refragmentação, prevendo um procedimento de informação, consulta e cooperação administrativa relativo aos novos projectos de regulamentação; que este procedimento contribuirá, nomeadamente, para garantir uma aplicação eficaz do Tratado, em especial dos artigos 52.º e 59.º ou, se for caso disso, para detectar a necessidade de assegurar a protecção de um interesse geral a nível comunitário; que, além disso, a melhor aplicação do Tratado proporcionada por tal procedimento de informação terá como consequência reduzir a necessidade de regulamentações comunitárias ao estritamente necessário e proporcional em relação ao mercado interno e à protecção de objectivos de interesse geral; que este procedimento de informação permitirá, por último, uma melhor exploração, pelas empresas, das vantagens do mercado interno;

(13) Considerando que a Directiva 98/34/CE visa os mesmos objectivos e que este procedimento, além de eficaz, é o mais aperfeiçoado em função desses objectivos; que os resultados da aplicação desta directiva e os procedimentos nela previstos se coadunam com os projectos de regras relativas aos serviços da Sociedade da Informação; que o procedimento previsto na directiva está actualmente bem integrado a nível das administrações nacionais;

(14) Considerando por outro lado que, nos termos do artigo 7º.A do Tratado, o mercado interno compreende um espaço sem fronteiras internas no qual é assegurada a livre circulação de mercadorias, pessoas, serviços e capitais e que a Directiva 98/34/CE prevê apenas um processo de cooperação administrativa, sem harmonização de regras materiais;

(15) Considerando, por conseguinte, que a alteração da Directiva 98/34/CE para a aplicar aos projectos de regulamentação relativos aos serviços da Sociedade da Informação constitui a abordagem mais adequada para dar uma resposta eficaz às necessidades de transparência no mercado interno no que se refere ao quadro jurídico daqueles serviços;

(16) Considerando que será preciso prever uma notificação, nomeadamente das regras que poderão vir a evoluir no futuro; que, dada a sua diversidade e o seu desenvolvimento futuro, os serviços mais susceptíveis de necessitar e de gerar novas regras e regulamentações são os serviços prestados à distância, por via electrónica, e mediante pedido individual de um destinatário de serviços (serviços da Sociedade da Informação); que, por isso, se deve prever a notificação dos projectos de regras e regulamentações relativos a esses serviços;

(17) Considerando que, desta forma, deverão ser comunicadas as regras específicas relativas ao acesso aos serviços susceptíveis de serem prestados segundo as regras acima definidas e ao seu exercício, mesmo que essas regras estejam incluídas numa regulamentação com um objectivo mais geral; que, todavia, as regulamentações gerais que não prevejam qualquer disposição que vise especificamente esses serviços não deverão ser notificadas;

(18) Considerando que, por regras relativas ao acesso aos serviços e ao seu exercício se deve entender as que fixam exigências relativas aos serviços da Sociedade da Informação, como as relativas aos prestadores, aos serviços e aos destinatários de serviços, que dizem respeito a uma actividade económica susceptível de ser prestada por via electrónica, à distância e mediante pedido individual do destinatário do serviço; que, consequentemente, ficarão por exemplo abrangidas as regras relativas ao estabelecimento dos prestadores destes serviços e, em especial, as relativas ao regime de autorização ou de licenças; que se considera como regra destinada especificamente aos serviços da Sociedade da Informação uma disposição que vise estes últimos, ainda que contida numa regulamentação de carácter geral; que, em contrapartida, não se terão em vista medidas relativas, tanto directa como individualmente, a determinados destinatários especiais (como, por exemplo, licenças em matéria de telecomunicações;

(19) Considerando que por serviços se deve entender, nos termos do artigo 60.º do Tratado interpretado pela jurisprudência do Tribunal de Justiça, uma prestação realizada normalmente mediante remuneração; que essa característica não está presente nas actividades que o Estado desempenha sem contrapartida económica no âmbito da sua missão, nomeadamente nos domínios social, cultural, educativo e judiciário; que, por esse facto, as regras nacionais relativas a essas actividades não estão abrangidas pela definição prevista no artigo 60.º do Tratado e não recaem, por conseguinte, no âmbito de aplicação da presente directiva;

(20) Considerando que a presente directiva não prejudica o âmbito de aplicação da Directiva 89/552/CEE do Conselho, de 3 de Outubro de 1989, relativa à coordenação de certas disposições legislativas, regulamentares e administrativas dos Estados-membros relativas ao exercício de actividades de radiodifusão

televisiva ([11]), corra a redacção que lhe foi dada pela Directiva 97/36/CE do Parlamento Europeu e do Conselho ([12]), ou de eventuais futuras alterações desta directiva;

(21) Considerando que, de qualquer forma, não estão abrangidos pela presente directiva os projectos de disposições nacionais destinadas a transpor o conteúdo das directivas comunitárias em vigor ou a ser adoptadas, uma vez que são já objecto de um exame específico; que, consequentemente, não ficarão abrangidas pelo âmbito de aplicação da presente directiva nem as regulamentações nacionais de transposição da Directiva 89/552/CEE, com a redacção que lhe foi dada pela Directiva 97/36/CE, ou eventuais futuras alterações desta directiva, nem as regulamentações nacionais de transposição ou adoptadas sucessivamente no contexto da Directiva 97/13/CE do Parlamento Europeu do Conselho, de 10 de Abril de 1997, relativa a um quadro comum para as autorizações gerais e as licenças individuais no sector dos serviços de telecomunicações ([13]);

(22) Considerando, além disso, que é importante prever casos excepcionais em que regulamentações nacionais relativas aos serviços da Sociedade da Informação possam ser adoptadas imediatamente e que é igualmente importante admitir esta possibilidade unicamente por motivos urgentes relacionados com situações graves e imprevisíveis, nomeadamente, situações não evidentes anteriormente e cuja origem não é imputável a uma acção das autoridades do Estado-membro em questão, no intuito de não comprometer a finalidade de consulta prévia e de cooperação administrativa inerente à presente directiva;

(23) Considerando que é conveniente que um Estado-membro adie por doze meses - eventualmente por dezoito meses, em caso de posição comum do Conselho - a adopção de um projecto de regra relativa aos serviços apenas na hipótese em que o projecto diga respeito a uma matéria abrangida por uma proposta de directiva, de regulamento ou de decisão já apresentada pela Comissão ao Conselho; que esta obrigação de adiamento só poderá ser contraposta pela Comissão ao Estado-membro em questão no caso de o projecto de regra nacional prever disposições não conformes com o conteúdo da proposta apresentada pela Comissão;

(24) Considerando que a definição do quadro de informação e de consulta a nível comunitário estabelecido pela presente directiva constitui uma condição prévia para uma participação coerente e eficaz da Comunidade Europeia no tratamento das questões relacionadas com os aspectos regulamentares dos serviços da Sociedade da Informação no contexto internacional;

(25) Considerando que é conveniente que, no âmbito do funcionamento da Directiva 98/34/CE, o Comité previsto no artigo 5.º se reúna especificamente para analisar as questões relativas aos serviços da Sociedade da Informação;

(26) Considerando que, na mesma perspectiva, se deve recordar que, sempre que uma medida nacional tenha de ser notificada igualmente na fase de projecto por força de outro acto comunitário, o Estado-membro em questão pode fazer uma

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(1[1]) JO L 298 de 17. 10. 1989, p. 23.
([12]) JO L 202 de 30. 7. 1997, p.1.
([13]) JO L 117 de 7. 5. 1997, p. 15.

comunicação única ao abrigo desse acto, referindo que essa comunicação constitui igualmente uma comunicação na acepção da presente directiva;

(27) Considerando que a Comissão apreciará regularmente a evolução do mercado de novos serviços no âmbito da Sociedade da Informação, em especial no que diz respeito à convergência entre as telecomunicações, as tecnologias da informação e os meios de comunicação, promovendo designadamente estudos e, se necessário, adoptando iniciativas tendentes a adaptar atempadamente a regulamentação, com o objectivo de favorecer o desenvolvimento de novos serviços a nível europeu,

ADOPTARAM A PRESENTE DIRECTIVA:

Dispositivos das directivas 98/34/CE e 98/48/CE consolidados

Artigo 1.º

Para efeitos da presente directiva entende-se por:

1. «Produto»: qualquer produto de fabrico industrial e qualquer produto agrícola, incluindo produtos da pesca.

2. «Serviço»: qualquer serviço da Sociedade da Informação, isto é, qualquer serviço prestado normalmente mediante remuneração, à distância, por via electrónica e mediante pedido individual de um destinatário de serviços.

Para efeitos da presente definição, entende-se por:

- "à distância": um serviço prestado sem que as partes estejam simultaneamente presentes,

- "por via electrónica": um serviço enviado desde a origem e recebido no destino através de instrumentos electrónicos de processamento (incluindo a compressão digital) e de armazenamento de dados, que é inteiramente transmitido, encaminhado e recebido por cabo, rádio, meios ópticos ou outros meios electromagnéticos,

- "mediante pedido individual de um destinatário de serviços": um serviço fornecido por transmissão de dados mediante pedido individual.

No Anexo V figura uma lista indicativa dos serviços não incluídos nesta definição.

A presente directiva não é aplicável:

- aos serviços de radiodifusão sonora,

- aos serviços de radiodifusão televisiva referidos na alínea a) do artigo 1.º da Directiva 89/552/CEE ([14]).

3. «Especificação técnica»: a especificação que consta de um documento que define as características exigidas de um produto, tais como os níveis de qualidade ou de propriedade de utilização, a segurança, as dimensões, incluindo as prescrições aplicáveis ao produto no que respeita à denominação de venda, à terminologia, aos símbolos, aos ensaios e métodos de ensaio, à embalagem, à marcação e à rotulagem, bem como aos processos de avaliação da conformidade.

O termo «especificação técnica» abrange igualmente os métodos e processos de produção relativos aos produtos agrícolas ao abrigo do n.º 1 do artigo 38.º do Tratado, aos produtos destinados à alimentação humana e animal, aos medicamentos

([14]) JO L 298 de 17. 10. 1989, p. 23. Directiva com a redacção que lhe foi dada pela Directiva 97/36/CE (JO L 202 de 30. 7. 1997, p. 1).

definidos no artigo 1.º da Directiva 65/65/CEE ([15]), e aos métodos e processos de produção relativos aos outros produtos, desde que estes tenham incidência sobre as características destes últimos.

4. «Outra exigência»: uma exigência, distinta de uma especificação técnica, imposta a um produto por motivos de defesa, nomeadamente dos consumidores, ou do ambiente, e que vise o seu ciclo de vida após a colocação no mercado, como sejam condições de utilização, de reciclagem, de reutilização ou de eliminação, sempre que essas condições possam influenciar significativamente a composição ou a natureza do produto ou a sua comercialização.

5. «Regra relativa aos serviços»: um requisito de natureza geral relativo ao acesso às actividades de serviços referidas no n.º 2 do presente artigo e ao seu exercício, nomeadamente as disposições relativas ao prestador de serviços, aos serviços e ao destinatário de serviços, com exclusão das regras que não visem especificamente os serviços definidos nessa mesma disposição.

A presente directiva não é aplicável a regras relativas a questões sujeitas à regulamentação comunitária em matéria de serviços de telecomunicações definidos na Directiva 90/387/CEE ([16]).

A presente directiva não é aplicável a regras relativas a questões sujeitas à regulamentação comunitária em matéria de serviços financeiros enumerados exemplificativamente no Anexo VI da presente directiva.

A presente directiva não é aplicável às regras enunciadas pelos ou para os mercados regulamentados na acepção da Directiva 93/22/CE, outros mercados ou órgãos que efectuem operações de compensação ou de liquidação desses mercados, com excepção do n.º 3 do artigo 8.º da presente directiva.

Para efeitos da presente definição:

- considera-se que uma regra tem em vista especificamente os serviços da Sociedade da Informação sempre que, no que diz respeito à sua motivação e ao texto do seu articulado, tenha como finalidade e objecto específicos, na totalidade ou em determinadas disposições pontuais, regulamentar de modo explícito e circunscrito esses serviços,

- não se considera que uma regra tem em vista especificamente os serviços da Sociedade da Informação se apenas disser respeito a esses serviços de modo implícito ou incidente.

6. «Norma»: a especificação técnica aprovada por um organismo reconhecido com actividade normativa para aplicação repetida ou contínua, cujo cumprimento não é obrigatório e pertença a uma das seguintes categorias:

([15]) Directiva 65/65/CEE do Conselho, de 26 de Janeiro de 1965, relativa à aproximação das disposições legislativas, regulamentares e administrativas, respeitantes às especialidades farmacêuticas (JO 22 de 9.2.1965, p.369/65). Directiva com a última redacção que lhe foi dada pela Directiva 93/39/CEE (JO L 214 de 24.8.1993, p. 22).

([16]) JO L 192 de 24. 7. 1990, p. 1. Directiva com a redacção que lhe foi dada pela Directiva 97/51/CE (JO L 295 de 29. 10. 1997, p. 23).

- norma internacional: norma adoptada por uma organização internacional de normalização e colocada à disposição do público,

- norma europeia: norma adoptada por um organismo europeu de normalização e colocada à disposição do público,

- norma nacional: norma adoptada por um organismo nacional de normalização e colocada à disposição do público.

7. «Programa de normalização»: plano de trabalho de um organismo reconhecido com actividade normativa e que estabelece a lista dos assuntos sobre os quais incidem trabalhos de normalização.

8. «Projecto de norma»: o documento que contém o texto das especificações técnicas relativas a um assunto determinado, para o qual se prevê a adopção de acordo com o processo de normalização nacional, tal como resulta dos trabalhos preparatórios e difundido para comentário ou inquérito público.

9. «Organismo europeu de normalização»: um organismo indicado no Anexo I.

10. «Organismo nacional de normalização»: um organismo indicado no Anexo II.

11. «Regra técnica»: uma especificação técnica, outro requisito ou uma regra relativa aos serviços, incluindo as disposições administrativas que lhes são aplicáveis e cujo cumprimento seja obrigatório *de jure* ou *de facto*, para a comercialização, a prestação de serviços, o estabelecimento de um operador de serviços ou a utilização num Estado-membro ou numa parte importante desse Estado, assim como, sob reserva das disposições referidas no artigo 10.º, qualquer disposição legislativa, regulamentar ou administrativa dos Estados-membros que proíba o fabrico, a importação, a comercialização, ou a utilização de um produto ou a prestação ou utilização de um serviço ou o estabelecimento como prestador de serviços.

Constituem nomeadamente regras técnicas de facto:

- as disposições legislativas, regulamentares ou administrativas de um Estado-membro que remetam para especificações técnicas, outros requisitos ou regras relativas aos serviços, ou para códigos profissionais ou de boa prática que se refiram a especificações técnicas, a outros requisitos ou a regras relativas aos serviços, cuja observância confira uma presunção de conformidade com as prescrições estabelecidas pelas referidas disposições legislativas, regulamentares ou administrativas,

- os acordos voluntários em que uma entidade pública seja parte contratante e que visem, numa perspectiva de interesse geral, a observância de especificações técnicas, de outros requisitos ou de regras relativas aos serviços, com excepção dos cadernos de encargos dos contratos públicos,

- as especificações técnicas, outros requisitos ou regras relativas aos serviços, relacionados com medidas de carácter fiscal ou financeiro que afectem o consumo de produtos ou de serviços, incitando à observância dessas especificações técnicas, outros requisitos, ou regras relativas aos serviços; não se

incluem as especificações técnicas, outros requisitos ou as regras relativas aos serviços relacionados com os regimes nacionais de segurança social.

São abrangidas as regras técnicas definidas pelas autoridades designadas pelos Estados-membros e incluídas numa lista a elaborar pela Comissão em 5 de Agosto de 1999 no âmbito do comité previsto no artigo 5.º.

A alteração desta lista efectuar-se-á segundo o mesmo processo.

12. «Projecto de regra técnica»: o texto de uma especificação técnica, de outro requisito ou de uma regra relativa aos serviços, incluindo disposições administrativas, elaborado com o objectivo de a adoptar ou de a fazer adoptar como regra técnica, e que se encontre numa fase de preparação que permita ainda a introdução de alterações substanciais.

A presente directiva não se aplica às medidas que os Estados-membros considerem necessárias, no âmbito do Tratado, para assegurar a protecção das pessoas, e em especial dos trabalhadores, durante a utilização dos produtos, desde que essas medidas não afectem esses produtos.

Artigo 2.º

1. A Comissão e os organismos de normalização indicados nos Anexos I e II serão informados dos novos temas para os quais os organismos nacionais referidos noAnexo II tenham decidido, mediante inscrição no seu programa de normalização, estabelecer uma norma ou alterá-la, excepto se se tratar da transposição idêntica ou equivalente de uma norma internacional ou europeia.

2. As informações a que se refere o n.º 1 devem indicar nomeadamente se a norma em causa:

- constituirá uma transposição não equivalente de uma norma internacional,

- será uma nova norma nacional,

ou

- constituirá uma alteração de uma norma nacional.

Após consulta ao comité referido no artigo 5.º, a Comissão pode estabelecer regras de apresentação codificada dessa informação, bem como um esquema e os critérios segundo os quais as informações deverão ser apresentadas para facilitar a sua avaliação.

3. A Comissão pode solicitar a comunicação total ou parcial dos programas de normalização.

A Comissão colocará esta informação à disposição dos Estados-membros, de forma a permitir avaliar e comparar os diferentes programas.

4. Se necessário, a Comissão alterará o Anexo II com base nas comunicações dos Estados-membros.

5. Sob proposta da Comissão, o Conselho deliberará sobre qualquer alteração do Anexo I.

Artigo 3.º

Os organismos de normalização a que se referem os Anexos I e II e a Comissão receberão, a seu pedido, todos os projectos de norma. Serão informados pelo organismo em questão do seguimento dado às eventuais observações que tenham formulado em relação aos projectos.

Artigo 4.º

1. Os Estados-membros devem tomar todas as medidas necessárias para que os seus organismos de normalização:

- comuniquem as informações previstas nos artigos 2.º e 3.º,

- divulguem os projectos de normas por forma a que possam também ser recolhidas as observações provenientes das partes estabelecidas noutros Estados-membros,

- concedam aos outros organismos referidos no Anexo II o direito de participar passiva ou activamente (enviando um observador) nos trabalhos previstos,

- não se oponham a que um tema de normalização do seu programa de trabalho seja abordado a nível europeu segundo as regras definidas pelos organismos europeus de normalização e não desenvolvam qualquer acção que possa prejudicar uma decisão a este respeito.

2. Os Estados-membros abster-se-ão, em especial, de qualquer acto de reconhecimento, homologação ou utilização por referência a normas nacionais adoptadas em violação do disposto nos artigos 2.º, 3.º e no n.º 1 do presente artigo.

Artigo 5.º

É criado um comité permanente composto por representantes designados pelos Estados-membros, que podem ser assistidos por peritos ou por consultores, e presidido por um representante da Comissão.

O comité estabelecerá o seu regulamento interno.

Artigo 6.º

1. O comité reunir-se-á pelo menos duas vezes por ano com os representantes dos organismos de normalização referidos nos Anexos I e II.

O comité reúne-se com uma composição específica para analisar as questões relativas aos serviços da Sociedade da Informação.

2. A Comissão apresentará ao comité um relatório sobre a execução e aplicação dos procedimentos referidos na presente directiva e propostas tendentes a eliminar entraves ao comércio, existentes ou previsíveis.

3. O comité tomará posição sobre as comunicações e propostas referidas no n.º 2 e pode propor, nomeadamente, que a Comissão:

- convide os organismos europeus de normalização a elaborar uma norma europeia num prazo determinado,

- assegure, se for caso disso, e com o fim de evitar o risco de entraves ao comércio, que, numa primeira fase, os Estados-membros em causa decidam entre eles das medidas apropriadas,

- adopte qualquer medida apropriada,

- identifique as áreas em que se verifique ser necessária uma harmonização e, se for caso disso, realize os trabalhos de harmonização apropriados num dado sector.

4. O comité deve ser consultado pela Comissão:

a) antes de qualquer alteração das listas constantes dos Anexos I e II (n.º 1 do artigo 2.º);

b) aquando do estabelecimento das regras de apresentação codificada da informação, do esquema e dos critérios de acordo com os quais os programas de normalização devem ser apresentados (n.º 2 do artigo 2.º);

c) aquando da escolha do sistema prático a criar para a troca de informações prevista na presente directiva, bem como das alterações eventuais que lhe devam ser feitas;

d) quando for reexaminado o funcionamento do sistema criado pela presente directiva;

e) acerca dos pedidos dirigidos aos organismos de normalização, referidos no primeiro travessão do n.º 3.

5. O comité pode ser consultado pela Comissão sobre qualquer anteprojecto de regra técnica que esta tenha recebido.

6. O comité pode, a pedido do seu presidente ou de um Estado-membro, apreciar qualquer questão relativa à aplicação da presente directiva.

7. Os trabalhos do comité e as informações que lhe forem submetidas são confidenciais.

Contudo, o comité e as administrações nacionais podem, tomando as necessárias precauções, consultar para peritagem pessoas singulares ou colectivas que podem pertencer ao sector privado.

8. No que respeita às regras aplicáveis aos serviços, a Comissão e o comité podem consultar pessoas singulares ou colectivas do sector industrial ou do meio académico, e, quando possível, corpos representativos com competência para emitir um parecer sobre os objectivos e as consequências sociais e societais de qualquer projecto de regra relativa aos serviços, e ter em conta esse parecer sempre que o fizerem.

Artigo 7.º

1. Os Estados-membros tomarão todas as medidas necessárias para garantir que, durante a elaboração da norma europeia referida no n.º 3, primeiro travessão, do artigo 6.º, ou após a respectiva aprovação, os seus organismos de normalização não desenvolvam qualquer acção que possa prejudicar a harmonização pretendida e, em especial, não publiquem, no domínio em questão, uma norma nacional nova ou revista que não seja inteiramente conforme com a norma europeia existente.

2. O n.º 1 não se aplica aos trabalhos dos organismos de normalização desenvolvidos a pedido das autoridades públicas com o objectivo de estabelecer especificações técnicas ou uma norma com vista ao estabelecimento de uma regra técnica para determinados produtos.

Os Estados-membros comunicarão à Comissão, nos termos do n.º 1 do artigo 8.º, qualquer pedido referido no primeiro parágrafo que constitua um projecto de regra técnica, indicando os motivos que justificam a sua adopção.

Artigo 8.º

1. Sob reserva do disposto no artigo 10.º, os Estados-membros comunicarão imediatamente à Comissão qualquer projecto de regra técnica, excepto se se tratar da mera transposição integral de uma norma internacional ou europeia, bastando neste caso uma simples informação relativa a essa norma. Enviarão igualmente à Comissão uma notificação referindo as razões da necessidade do estabelecimento dessa regra técnica, salvo se as mesmas já transparecerem do projecto.

Se necessário, e salvo se tiver sido apresentado com uma comunicação anterior, os Estados-membros comunicarão simultaneamente o texto das disposições legislativas e regulamentares de base, principal e directamente em causa, caso o conhecimento deste texto seja necessário para apreciar o alcance do projecto de regra técnica.

Os Estados-membros farão uma nova comunicação nas mesmas condições, caso introduzam alterações significativas no projecto de regra técnica que tenham por efeito modificar o âmbito de aplicação, reduzir o calendário de aplicação inicialmente previsto, aditar especificações ou exigências ou torná-las mais rigorosas.

Sempre que o projecto de regra técnica se destine em especial a limitar a comercialização ou a utilização de uma substância, de uma preparação ou de um produto químico, inclusive por razões de saúde pública, defesa dos consumidores ou protecção do ambiente, os Estados-membros devem também comunicar um resumo ou as referências dos dados pertinentes relativos à substância, à preparação ou ao produto em causa e os referentes aos produtos alternativos conhecidos e disponíveis, na medida em que tais informações estejam disponíveis, bem como os efeitos previsíveis da medida sobre a saúde pública, a defesa dos consumidores e a protecção do ambiente, com uma análise de risco efectuada, quando necessário, de acordo com os princípios gerais de avaliação de riscos dos produtos químicos referidos no n.º 4 do artigo 10.º do Regulamento (CEE) nº 793/93 ([17]) quando se trate de uma substância existente e no n.º 2 do artigo 3.º da Directiva 67/548/CEE ([18]), quando se trate de uma nova substância.

A Comissão transmitirá de imediato aos outros Estados-membros o projecto de regra técnica e todos os documentos que lhe tenham sido comunicados; pode ainda submetê-lo aos pareceres do comité referido no artigo 5.º e, eventualmente, do comité competente no domínio em questão.

No que respeita às especificações técnicas, outros requisitos ou regras relativas aos serviços referidas no ponto 11, segundo parágrafo, terceiro travessão, do artigo 1.º, as observações ou os pareceres circunstanciados da Comissão ou dos Estados-membros apenas podem incidir sobre os aspectos susceptíveis de entravar as trocas comerciais ou, no que diz respeito às regras relativas aos serviços, a livre circulação dos serviços ou a liberdade de estabelecimento dos operadores de serviços, e não sobre a vertente fiscal ou financeira da medida em questão.

2. A Comissão e os Estados-membros podem enviar ao Estado-membro que tiver apresentado um projecto de regra técnica, observações que este Estado-membro tomará em consideração, na medida do possível, aquando da elaboração definitiva da regra técnica.

3. Os Estados-membros devem comunicar de imediato à Comissão o texto definitivo de qualquer regra técnica.

4. Salvo pedido expresso do Estado-membro autor da notificação, as informações ao abrigo do presente artigo não são consideradas confidenciais. Qualquer pedido deste tipo deverá ser justificado.

Se esse pedido for formulado, o comité e as administrações nacionais, tomando as precauções necessárias, podem consultar, para efeitos de peritagem, pessoas singulares ou colectivas, eventualmente do sector privado.

5. Sempre que os projectos de regras técnicas se insiram em medidas cuja comunicação na fase de projecto esteja prevista noutros actos comunitários, os Estados-membros podem efectuar a comunicação referida no n.º 1 nos termos desse acto, sob reserva de indicarem formalmente que a comunicação é igualmente válida nos termos da presente directiva.

A ausência de reacção da Comissão no âmbito da presente directiva, em relação a um projecto de regra técnica, não prejudica a decisão a adoptar no âmbito dos outros actos comunitários.

([17])Regulamento (CEE) n.º 793/93 do Conselho, de 23 de Março de 1993, relativo à avaliação e controlo dos riscos ambientais associados às substâncias existentes (JO L 84 de 5.4.1993, p. 1).

([18]) Directiva 67/548/CEE do Conselho, de 27 de Junho de 1967, relativa à aproximação das disposições legislativas, regulamentares e administrativas respeitantes à classificação, embalagem e rotulagem das substâncias perigosas (JO L 196 de 16.8.1967, p. 1). Directiva alterada pela Directiva 92/32/CEE (JO L 154 de 5.6.1992, p. 1).

Artigo 9.º

1. Os Estados-membros adiarão a adopção de um projecto de regra técnica por três meses a contar da data de recepção, pela Comissão, da comunicação referida no n.º 1 do artigo 8.º.

2. Os Estados-membros adiarão:

- por quatro meses a adopção de um projecto de regra técnica sob a forma de acordo voluntário na acepção do ponto 11, segundo parágrafo, segundo travessão, do artigo 1.º,

- por seis meses, sem prejuízo do disposto nos n.ºs 3, 4 e 5, a adopção de qualquer outro projecto de regra técnica (com exclusão dos projectos relativos aos serviços),

a contar da data de recepção pela Comissão da comunicação referida no n.º 1 do artigo 8.º se, no prazo de três meses subsequentes a essa data, a Comissão ou outro Estado-membro emitir um parecer circunstanciado segundo o qual a medida prevista apresenta aspectos que podem eventualmente criar obstáculos à livre circulação das mercadorias no âmbito do mercado interno;

- por quatro meses, sem prejuízo do disposto nos n.ºs 4 e 5, a adopção de um projecto de regra relativa aos serviços, a contar da data de recepção pela Comissão da comunicação referida no n.º 1 do artigo 8.º, se, no prazo de três meses subsequentes a essa data, a Comissão ou outro Estado-membro emitir um parecer circunstanciado segundo o qual a medida prevista apresenta aspectos que podem eventualmente criar obstáculos à livre circulação dos serviços ou à liberdade de estabelecimento dos operadores de serviços no âmbito do mercado interno.

Quanto aos projectos de regras relativas aos serviços, os pareceres circunstanciados da Comissão ou dos Estados-membros não podem prejudicar as medidas de política cultural, nomeadamente no domínio do audiovisual, que os Estados possam adoptar, nos termos do direito comunitário, tendo em conta a sua diversidade linguística, as especificidades nacionais e regionais, e os seus patrimónios culturais.

O Estado-membro em causa apresentará à Comissão um relatório sobre o seguimento que pretende dar a esses pareceres circunstanciados. A Comissão comentará essa reacção.

No que respeita às regras relativas aos serviços, o Estado-membro em questão deverá indicar, sempre que for oportuno, os motivos pelos quais não é possível ter em conta os pareceres circunstanciados.

3. Os Estados-membros adiarão a adopção de um projecto de regra técnica, com exclusão dos projectos de regras relativas aos serviços, por doze meses a contar da data de recepção pela Comissão da comunicação a que se refere o n.º 1 do artigo 8.º se, no prazo de três meses subsequentes a essa data, a Comissão manifestar a intenção de propor ou adoptar uma directiva, um regulamento ou uma decisão nessa matéria, nos termos do artigo 189.º do Tratado.

4. Os Estados-membros adiarão a adopção do projecto de regra técnica por 12 meses a contar da data de recepção pela Comissão da comunicação referida no n.º 1 do artigo 8.º se, nos três meses subsequentes, a Comissão verificar que o projecto de regra técnica incide sobre uma matéria abrangida por uma proposta de directiva, de regulamento ou de decisão apresentada ao Conselho nos termos do artigo 189.º do Tratado.

5. Se o Conselho adoptar uma posição comum durante o período de *statu quo* referido nos n.ºs 3 e 4, esse período será, sob reserva do disposto no n.º 6, aumentado para 18 meses.

6. As obrigações a que se referem os n.ºs 3, 4 e 5 cessam quando:

- a Comissão informar os Estados-membros de que renuncia à sua intenção de propor ou adoptar um acto comunitário vinculativo, ou

- a Comissão informar os Estados-membros da retirada do seu projecto ou da sua proposta, ou

- for adoptado pelo Conselho ou pela Comissão um acto comunitário vinculativo.

7. Os n.ºs 1 a 5 não se aplicam sempre que um Estado-membro:

- por razões urgentes, resultantes de uma situação grave e imprevisível que envolva a defesa da saúde das pessoas e dos animais, a preservação das plantas ou a segurança e, no que se refere às regras relativas aos serviços, a ordem pública, nomeadamente a protecção dos menores, tenha de elaborar, com a maior brevidade, regras técnicas a adoptar e aplicar de imediato, sem possibilidade de proceder a uma consulta, ou

- por razões urgentes, resultantes de uma situação grave que envolva a protecção da segurança e integridade do sistema financeiro, nomeadamente tendo em vista a defesa dos depositantes, investidores e segurados, tenha de adoptar e aplicar de imediato regras relativas aos serviços financeiros.

Na comunicação referida no artigo 8.º, o Estado-membro deverá indicar os motivos que justificam a urgência das medidas em questão. A Comissão pronunciar-se-á sobre essa comunicação no mais curto prazo possível, tomará as medidas adequadas em caso de recurso abusivo a este procedimento e manterá também o Parlamento Europeu informado.

Artigo 10.º

1. Os artigos 8.º e 9.º não são aplicáveis às disposições legislativas, regulamentares ou administrativas dos Estados-membros ou aos acordos voluntários através dos quais estes:

- dêem cumprimento aos actos comunitários vinculativos cujo efeito seja a adopção de especificações técnicas ou de regras relativas aos serviços,

- observem os compromissos decorrentes de um acordo internacional cujo efeito seja a adopção de especificações técnicas ou de regras relativas aos serviços e que sejam comuns a toda a Comunidade,

- recorram a cláusulas de salvaguarda previstas em actos comunitários vinculativos,

- apliquem o disposto no n.º 1 do artigo 8.º da Directiva 92/59/CEE ([19]),

- se limitem a dar execução a um acórdão do Tribunal de Justiça das Comunidades Europeias,

- se limitem a alterar uma regra técnica na acepção do ponto 11, do artigo 1.º, de acordo com um pedido da Comissão tendo em vista eliminar um entrave às trocas comerciais ou, quanto às regras relativas aos serviços, à livre circulação dos serviços ou à liberdade de estabelecimento dos operadores de serviços.

2. O artigo 9.º não se aplica às disposições legislativas, regulamentares e administrativas dos Estados-membros que visem a proibição de fabrico, na medida em que não entravem a livre circulação dos produtos.

3. Os n.ºs 3 a 6 do artigo 9.º não são aplicáveis aos acordos voluntários previstos no ponto 11, segundo parágrafo, segundo travessão do artigo 1.º.

4. O artigo 9.º não é aplicável às especificações técnicas ou outros requisitos, nem às regras relativas aos serviços a que se refere o ponto 11, segundo parágrafo, terceiro travessão, do artigo 1.º.

Artigo 11.º

De dois em dois anos, a Comissão apresentará um relatório ao Parlamento Europeu, ao Conselho e ao Comité Económico e Social sobre os resultados da aplicação da presente directiva. As listas do trabalho de normalização atribuído às organizações europeias de normalização nos termos da presente directiva e às estatísticas sobre as comunicações recebidas serão publicadas anualmente no Jornal Oficial das Comunidades Europeias.

O mais tardar dois anos a contar da data prevista no n.º 1, primeiro parágrafo, do artigo 2.º, a Comissão apresentará ao Parlamento Europeu e ao Conselho, uma avaliação da aplicação da Directiva 98/34/CE, em função, nomeadamente, da evolução tecnológica e do mercado dos serviços referidos no n.º 2 do artigo 1.º. O mais tardar três anos a contar da data prevista no n.º 1, primeiro parágrafo, do artigo 2.º da presente directiva, a Comissão apresentará eventualmente propostas de alteração da directiva ao Parlamento Europeu e ao Conselho.

Para esse efeito, a Comissão tomará em consideração as observações que os Estados-membros lhe possam comunicar ([20]).

Artigo 12.º

([19])Directiva 92/59/CEE do Conselho, de 29 de Junho de 1992, relativa à segurança geral dos produtos (JO L 228 de 11.8.1992, p. 24).

([20]) Os dois últimos parágrafos deste artigo reproduzem o artigo 3 da directiva 98/48/CE, adaptado.

Sempre que os Estados-membros adoptem uma regra técnica, esta fará referência à presente directiva ou será acompanhada dessa referência na publicação oficial. As modalidades de referência serão adoptadas pelos Estados-membros.

Artigo 13.º

1. As directivas e decisões enunciadas na parte A do Anexo III são revogadas, sem prejuízo das obrigações dos Estados-membros quanto aos prazos de transposição previstos na parte B do Anexo III.

2. As referências às directivas e decisões revogadas entender-se-ão como sendo feitas à presente directiva e serão lidas de acordo com o quadro de correspondência do Anexo IV.

3. Os Estados-membros porão em vigor as disposições legislativas, regulamentares e administrativas necessárias para dar cumprimento à presente directiva o mais tardar em 5 de Agosto de 1999. Do facto informarão imediatamente a Comissão.

Quando os Estados-membros adoptarem essas disposições, estas devem incluir uma referência à presente directiva ou ser acompanhadas dessa referência na publicação oficial. As modalidades dessa referência serão adoptadas pelos Estados-membros.

4. Os Estados-membros comunicarão à Comissão o texto das principais disposições de direito interno que adoptem no domínio regido pela directiva 98/48/CE ([21]).

Artigo 14.º

A directiva 98/34/CE entra em vigor no vigésimo dia seguinte ao da sua publicação no Jornal Oficial das Comunidades Europeias (publicação efectuada em 21 de Julho de 1998).

A directiva 98/48/CE entra em vigor na data da sua publicação no Jornal Oficial das Comunidades Europeias (publicação efectuada em 5 de Agosto de 1998) ([22]).

Artigo 15.º

Os Estados-membros são os destinatários das directivas 98/34 et **98/48/CE.**

Feito no Luxemburgo, em 22 de Junho de 1998.

Pelo Parlamento Europeu | Pelo Conselho

([21]) Os pontos 3 e 4 deste artigo reproduzem o artigo 2 da directiva 98/48, adaptado.
([22]) Este parágrafo reproduz o artigo 4 da directiva 98/48/CE, adaptado.

O Presidente	O Presidente
J. M. GIL-ROBLES	J. CUNNINGHAM

Feito em Bruxelas, em 20 de Julho de 1998.

Pelo Parlamento Europeu	**Pelo Conselho**
O Presidente	**O Presidente**
J. M. GIL-ROBLES	**W. MOLTERER**

ANEXO I

ORGANISMOS EUROPEUS DE NORMALIZAÇÃO

CEN

Comité Europeu de Normalização

CENELEC

Comité Europeu de Normalização Electrotécnica

ETSI

Instituto Europeu de Normalização das Telecomunicações

ANEXO II

ORGANISMOS NACIONAIS DE NORMALIZAÇÃO

1. BÉLGICA
IBN/BIN
Institut belge de normalisation
Belgisch Instituut voor Normalisatie
CEB/BEC
Comité électrotechnique belge
Belgisch Elektrotechnisch Comité

2. DINAMARCA
DS
Dansk Standard
NTA
Telestyrelsen, National Telecom Agency

3. ALEMANHA
DIN
Deutsches Institut für Normung e. V.
DKE
Deutsche Elektrotechnische Kommission im DIN und VDE

4. GRÉCIA

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5. ESPANHA
AENOR
Asociación Española de Normalización y Certificación

6. FRANÇA

AFNOR

Association française de normalisation

UTE

Union technique de l'électricité - Bureau de normalisation auprès de l'AFNOR

7. IRLANDA

NSAI

National Standards Authority of Ireland

ETCI

Electrotechnical Council of Ireland

8. ITÁLIA

UNI[23]

Ente nazionale italiano di unificazione

CEI[24]

Comitato elettrotecnico italiano

9. LUXEMBURGO

ITM

Inspection du travail et des mines

SEE

Service de l'énergie de l'État

10. PAÍSES BAIXOS

NNI

Nederlands Normalisatie instituut

NEC

Nederlands Elektrotechnisch Comité

([23]) O UNI e o CEI, em cooperação com o Istituto ¨Superiore delle Poste e Telecomunicazioni e o ministero dell'Industria, atribuíram os trabalhos realizados no âmbito do ETSI ao CONCIT (Comitato nazionale di coordinamento per le tecnologie dell'informazione).

([24]) Idem 23

11. ÁUSTRIA

ON

Österreichisches Normungsinstitut

ÖVE

Österreichischer Verband für Elektrotechnik

12. PORTUGAL

IPQ

Instituto Português da Qualidade

13. REINO UNIDO

BSI

British Standards Institution

BEC

British Electrotechnical Committee

14. FINLÂNDIA

SFS

Suomen Standardisoimisliitto SFS ry

Finlands Standardiseringsförbund SFS rf

THK/TFC

Telehallintokeskus

Teleförvaltningscentralen

SESKO

Suomen Sähköteknillinen Standardisoimisyhdistys SESKO ry

Finlands Elektrotekniska Standardiseringsförening SESKO rf

15. SUÉCIA

SIS

Standardiseringen i Sverige

SEK

Svenska elektriska kommissionen

ITS

Informationstekniska standardiseringen

ANEXO III

PARTE A

Directivas e decisões revogadas

(referidas no artigo 13.º)

Directiva 83/189/CEE do Conselho e alterações sucessivas:

Directiva 88/182/CEE do Conselho

Decisão 90/230/CEE da Comissão

Decisão 92/400/CEE da Comissão

Directiva 94/10/CE do Parlamento Europeu e do Conselho

Decisão 96/139/CE da Comissão

PARTE B

Lista dos prazos de transposição para o direito nacional
(referidos no artigo 13.º)

Directivas	Data-limite de transposição
Directiva 83/189/CEE (JO L 109 de 26.4.1983, p.8)	31.3.1984
Directiva 88/182/CEE (JO L 81 de 26.3.1988, p.75)	1.1.1989
Directiva 94/10/CE (JO L 100 de 19.4.1994, p.30)	1.7.1995
Directiva 98/48/CE (JO L 217 de 5.8.1998, p.18)	**5.8.1999**

ANEXO IV

Quadro de correspondência (adaptado)

Directiva 98/34/CE	**Presente directiva (codificação)**
Artigo 1.º	Artigo 1.º
Artigo 2.º	Artigo 2.º
Artigo 3.º	Artigo 3.º
Artigo 4.º	Artigo 4.º
Artigo 5.º	Artigo 5.º
Artigo 6.º	Artigo 6.º
Artigo 7.º	Artigo 7.º
Artigo 8.º	Artigo 8.º
Artigo 9.º	Artigo 9.º
Artigo 10.º	Artigo 10.º
Artigo 11.º	Artigo 11.º
Artigo 12.º	Artigo 12.º
Artigo 13.º	Artigo 13.º
Artigo 14.º	Artigo 14.º
Artigo 15.º	Artigo 15.º
Anexo I	Anexo I
Anexo II	Anexo II
Anexo III	Anexo III
Anexo IV	Anexo IV
-	**Anexo V**
-	**Anexo VI**

ANEXO V

Lista indicativa de serviços não abrangidos pelo artigo 1.º, ponto 2, segundo parágrafo

1. Serviços que não são prestados "à distância"

Serviços prestados na presença física do prestador e do destinatário, mesmo que impliquem a utilização de dispositivos electrónicos:

a) exames ou tratamentos num consultório médico por meio de equipamentos electrónicos mas na presença física do paciente;

b) consulta de um catálogo electrónico num estabelecimento comercial na presença física do cliente;

c) reserva de um bilhete de avião de uma rede de computadores numa agência de viagem na presença física do cliente;

d) disponibilização de jogos electrónicos numa sala de jogos na presença física do utilizador.

2. Serviços que não são fornecidos "por via electrónica"

- Serviços cujo conteúdo é material mesmo quando impliquem a utilização de dispositivos electrónicos:

a) distribuição automática de notas e bilhetes (notas de banco, bilhetes de comboio);

b) acesso às redes rodoviárias, parques de estacionamento, etc., mediante pagamento, mesmo que existam dispositivos electrónicos à entrada e/ou saída para controlar o acesso e/ou garantir o correcto pagamento.

- Serviços *off-line*: distribuição de CD-Rom ou de *software* em disquetes

- Serviços não fornecidos por intermédio de sistemas electrónicos de armazenagem e processamento de dados:

a) serviços de telefonia vocal;

b) serviços de telecópia/telex;

c) serviços prestados por telefonia vocal ou telecópia;

d) consulta de um médico por telefone/telecópia;

e) consulta de um advogado por telefone/telecópia;

f) marketing directo por telefone/telecópia.

3. Serviços que não são fornecidos "a pedido individual"

Serviços fornecidos por envio de dados sem pedido individual e destinados à recepção simultânea por um número ilimitado de destinatários (transmissão de "ponto para multi-ponto"):

a) serviços de radiodifusão televisiva (incluindo o quase vídeo a pedido) previstos no artigo 1º, alínea a), da Directiva 89/552/CEE;

b) serviços de radiodifusão sonora;

c) teletexto (televisivo).

ANEXO VI

Lista indicativa dos serviços financeiros previstos no artigo 1.º, ponto 5, terceiro parágrafo

- Serviços de investimento

- Operações de seguro e resseguro

- Serviços bancários

- Operações relativas aos fundos de pensões

- Serviços relativos a operações a prazo ou em opção.

Estes serviços compreendem em especial:

a) os serviços de investimento referidos no anexo da Directiva 93/22/CEE ([25]), os serviços de empresas de investimento colectivo,

b) os serviços abrangidos pelas actividades que beneficiam do reconhecimento mútuo contemplados no anexo da Directiva 89/646/CEE ([26]),

c) as operações respeitantes às actividades de seguro e resseguro referidas:

- no artigo 1.º da Directiva 73/239/CEE ([27]),

- no anexo da Directiva 79/267/CEE [28],

- na Directiva 64/225/CEE ([29]),

- nas Directivas 92/49/CEE ([30]) e 92/96/CEE ([31]).

([25]) JO L 141 de 11. 6. 1993, p. 27.

([26]) JO L 386 de 30. 12. 1989, p. 1. Directiva com a redacção que lhe foi dada pela Directiva 92/30/CEE (JO L 110 de 28.4.1992, p. 52).

([27]) JO L 228 de 16. 8. 1973, p. 3. Directiva com a última redacção que lhe foi dada pela Directiva 92/49/CEE (JO L 228 de 11. 8. 1992, p. 1).

([28]) JO L 63 de 13.3.1979, p.1. Directiva com última redacção que lhe foi dada pela Directiva 90/619/CEE (JO L 330 du 29.11.1990, P. 50).

([29]) JO 56 de 4. 4. 1964, p. 878/64. Directiva com a última redacção que lhe foi dada pelo Acto de Adesão de 1973.

([30]) JO L 228 de 11. 8. 1992, p. 1.

([31]) JO L 360 de 9. 12. 1992, p. 1.

RAPPORT TECHNIQUE
TECHNICAL REPORT

CEI
IEC
479-1

Troisième édition
Third edition
1994-09

PUBLICATION FONDAMENTALE DE SÉCURITÉ
BASIC SAFETY PUBLICATION

Effets du courant sur l'homme et les animaux domestiques –

Partie 1:
Aspects généraux

Effects of current on human beings and livestock –

Part 1:
General aspects

IEC

Numéro de référence
Reference number
CEI/IEC 479-1: 1994

Validité de la présente publication

Le contenu technique des publications de la CEI est constamment revu par la CEI afin qu'il reflète l'état actuel de la technique.

Des renseignements relatifs à la date de reconfirmation de la publication sont disponibles auprès du Bureau Central de la CEI.

Les renseignements relatifs à ces révisions, à l'établissement des éditions révisées et aux amendements peuvent être obtenus auprès des Comités nationaux de la CEI et dans les documents ci-dessous:

- **Bulletin de la CEI**
- **Annuaire de la CEI**
  Publié annuellement
- **Catalogue des publications de la CEI**
  Publié annuellement et mis à jour régulièrement

Terminologie

En ce qui concerne la terminologie générale, le lecteur se reportera à la CEI 50: *Vocabulaire Electrotechnique International* (VEI), qui se présente sous forme de chapitres séparés traitant chacun d'un sujet défini. Des détails complets sur le VEI peuvent être obtenus sur demande. Voir également le dictionnaire multilingue de la CEI.

Les termes et définitions figurant dans la présente publication ont été soit tirés du VEI, soit spécifiquement approuvés aux fins de cette publication.

Symboles graphiques et littéraux

Pour les symboles graphiques, les symboles littéraux et les signes d'usage général approuvés par la CEI, le lecteur consultera:

– la CEI 27: *Symboles littéraux à utiliser en électrotechnique*;

– la CEI 417: *Symboles graphiques utilisables sur le matériel. Index, relevé et compilation des feuilles individuelles;*

– la CEI 617: *Symboles graphiques pour schémas;*

et pour les appareils électromédicaux,

– la CEI 878: *Symboles graphiques pour équipements électriques en pratique médicale*.

Les symboles et signes contenus dans la présente publication ont été soit tirés de la CEI 27, de la CEI 417, de la CEI 617 et/ou de la CEI 878, soit spécifiquement approuvés aux fins de cette publication.

Publications de la CEI établies par le même comité d'études

L'attention du lecteur est attirée sur les listes figurant à la fin de cette publication, qui énumèrent les publications de la CEI préparées par le comité d'études qui a établi la présente publication.

Validity of this publication

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology.

Information relating to the date of the reconfirmation of the publication is available from the IEC Central Office.

Information on the revision work, the issue of revised editions and amendments may be obtained from IEC National Committees and from the following IEC sources:

- **IEC Bulletin**
- **IEC Yearbook**
  Published yearly
- **Catalogue of IEC publications**
  Published yearly with regular updates

Terminology

For general terminology, readers are referred to IEC 50: *International Electrotechnical Vocabulary (IEV)*, which is issued in the form of separate chapters each dealing with a specific field. Full details of the IEV will be supplied on request. See also the IEC Multilingual Dictionary.

The terms and definitions contained in the present publication have either been taken from the IEV or have been specifically approved for the purpose of this publication.

Graphical and letter symbols

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to publications:

– IEC 27: *Letter symbols to be used in electrical technology;*

– IEC 417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets;*

– IEC 617: *Graphical symbols for diagrams;*

and for medical electrical equipment,

– IEC 878: *Graphical symbols for electromedical equipment in medical practice*.

The symbols and signs contained in the present publication have either been taken from IEC 27, IEC 417, IEC 617 and/or IEC 878, or have been specifically approved for the purpose of this publication.

IEC publications prepared by the same technical committee

The attention of readers is drawn to the end pages of this publication which list the IEC publications issued by the technical committee which has prepared the present publication.

RAPPORT TECHNIQUE – Type 2
TECHNICAL REPORT – Type 2

CEI
IEC
479-1

Troisième édition
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PUBLICATION FONDAMENTALE DE SÉCURITÉ
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Effets du courant sur l'homme et les animaux domestiques –

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Part 1:
General aspects

Bureau Central de la Commission Electrotechnique Internationale 3, rue de Varembé Genève, Suisse

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

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Pour prix, voir catalogue en vigueur
For price, see current catalogue

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

EFFETS DU COURANT SUR L'HOMME ET LES ANIMAUX DOMESTIQUES –

Partie 1: Aspects généraux

AVANT-PROPOS

1) La CEI (Commission Electrotechnique Internationale) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de la CEI). La CEI a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. A cet effet, la CEI, entre autres activités, publie des Normes internationales. Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec la CEI, participent également aux travaux. La CEI collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.
2) Les décisions ou accords officiels de la CEI en ce qui concerne les questions techniques, préparés par les comités d'études où sont représentés tous les Comités nationaux s'intéressant à ces questions, expriment dans la plus grande mesure possible un accord international sur les sujets examinés.
3) Ces décisions constituent des recommandations internationales publiées sous forme de normes, de rapports techniques ou de guides et agréées comme telles par les Comités nationaux.
4) Dans le but d'encourager l'unification internationale, les Comités nationaux de la CEI s'engagent à appliquer de façon transparente, dans toute la mesure possible, les Normes internationales de la CEI dans leurs normes nationales et régionales. Toute divergence entre la norme de la CEI et la norme nationale ou régionale correspondante doit être indiquée en termes clairs dans cette dernière.

La tâche principale des comités d'études de la CEI est d'élaborer des Normes internationales. Exceptionnellement, un comité d'études peut proposer la publication d'un rapport technique de l'un des types suivants:

- type 1, lorsque, en dépit de maints efforts, l'accord requis ne peut être réalisé en faveur de la publication d'une Norme internationale;
- type 2, lorsque le sujet en question est encore en cours de développement technique ou lorsque, pour une raison quelconque, la possibilité d'un accord pour la publication d'une Norme internationale peut être envisagée pour l'avenir mais pas dans l'immédiat;
- type 3, lorsqu'un comité d'études a réuni des données de nature différente de celles qui sont normalement publiées comme Normes internationales, cela pouvant comprendre, par exemple, des informations sur l'état de la technique.

Les rapports techniques de types 1 et 2 font l'objet d'un nouvel examen trois ans au plus tard après leur publication afin de décider éventuellement de leur transformation en Normes internationales. Les rapports techniques de type 3 ne doivent pas nécessairement être révisés avant que les données qu'ils contiennent ne soient plus jugées valables ou utiles.

La CEI 479-1, rapport technique de type 2, a été établie par le comité d'études 64 de la CEI: Installations électriques des bâtiments.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international cooperation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters, prepared by technical committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
3) They have the form of recommendations for international use published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 479-1, which is a technical report of type 2, has been prepared by IEC technical committee 64: Electrical installations of buildings.

Le texte de ce rapport technique est issu des documents suivants:

Projets de comité	Rapports de vote
64(BC)211 64(BC)234	64(BC)235 64(BC)241

Les rapports de vote indiqués dans le tableau ci-dessus donnent toute information sur le vote ayant abouti à l'approbation de ce rapport technique.

Le présent document est publié dans la série des rapports techniques de type 2 (conformément au paragraphe G.4.2.2 de la partie 1 des Directives CEI/ISO) comme «norme prospective d'application provisoire» dans le domaine des installations électriques des bâtiments (et des effets du courant sur l'homme et les animaux) car il est urgent d'avoir des indications sur la meilleure façon d'utiliser les normes dans ce domaine afin de répondre à un besoin déterminé.

Ce document ne doit pas être considéré comme une «Norme internationale». Il est proposé pour une mise en oeuvre provisoire, dans le but de recueillir des informations et d'acquérir de l'expérience quant à son application dans la pratique. Il est de règle d'envoyer les observations éventuelles relatives au contenu de ce document au Bureau Central de la CEI.

Il sera proposé à un nouvel examen de ce rapport technique de type 2 trois ans au plus tard après sa publication, avec la faculté d'en prolonger la validité pendant trois autres années, de le transformer en Norme internationale ou de l'annuler.

Cette troisième édition annule et remplace la seconde édition de la CEI 479-1 parue en 1984.

Le présent rapport technique a le statut d'une publication fondamentale de sécurité conformément au Guide 104 de la CEI.

Les annexes A, B, C et D font partie intégrante de ce rapport technique.

L'annexe E est donnée uniquement à titre d'information.

The text of this technical report is based on the following documents:

Committee drafts	Reports on voting
64(CO)211 64(CO)234	64(CO)235 64(CO)241

Full information on the voting for the approval of this technical report can be found in the reports on voting indicated in the above table.

This document is issued in the type 2 technical report series of publications (according to G.4.2.2 of part 1 of the IEC/ISO Directives) as a "prospective standard for provisional application" in the field of electrical installations in buildings (and the effects of current on human beings and livestock) because there is an urgent requirement for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the IEC Central Office.

A review of this type 2 technical report will be carried out not later than three years after its publication, with the options of either extension for a further three years or conversion to an International Standard or withdrawal.

This third edition cancels and replaces the second edition of IEC 479-1 published in 1984.

This technical report has the status of a basic safety publication in accordance with IEC Guide 104.

Annexes A, B, C and D form an integral part of this technical report.

Annex E is for information only.

INTRODUCTION

Le présent rapport technique est destiné à fournir les informations fondamentales sur les effets des courants électriques sur l'homme et les animaux domestiques, servant de guide pour l'établissement des prescriptions de sécurité électrique.

Afin d'éviter des erreurs fondamentales dans l'interprétation de ce rapport, il doit être souligné que les valeurs données sont essentiellement basées sur des expériences effectuées sur des animaux ainsi que sur les informations résultant d'observations cliniques. Seules quelques expériences avec des courants de choc de courte durée ont été effectuées sur l'homme.

Selon les connaissances actuelles, provenant essentiellement des expériences sur des animaux, les valeurs sont dans le sens de la sécurité de sorte que le rapport s'applique aux personnes dans des conditions physiologiques normales, y compris les enfants, quels que soient leur âge et leur poids.

D'autres aspects doivent toutefois être pris en compte, tels que la probabilité de défauts, la probabilité de contact avec des parties actives ou avec des parties en défaut, le rapport entre la tension de contact et la tension de défaut, l'expérience acquise, les possibilités techniques et économiques. Ces paramètres doivent être soigneusement pris en considération en établissant les prescriptions de sécurité, par exemple les caractéristiques de fonctionnement des dispositifs de protection dans les installations électriques.

La forme de rapport a été retenue parce qu'elle rassemble les résultats obtenus jusqu'à présent et qui sont utilisés par le comité d'études 64 comme base d'établissement des prescriptions pour la protection contre les chocs électriques. Ces résultats sont considérés comme suffisamment importants pour justifier une publication de la CEI qui peut également servir de guide pour d'autres comités de la CEI et pour les pays ayant besoin de telles informations.

La première édition de la CEI 479, parue en 1974, était basée sur une longue recherche dans la littérature et sur l'évaluation des réponses reçues à un questionnaire. Cependant, depuis cette date, de nouvelles recherches expérimentales ont été effectuées. Leur étude et une analyse plus précise des publications antérieures ont permis de se faire une meilleure idée de l'action du courant électrique sur les organismes vivants, et en particulier sur l'homme et les animaux domestiques.

Cela est particulièrement vrai pour les limites de la fibrillation ventriculaire, qui constitue la cause essentielle de décès dus à l'électricité, et l'analyse de l'ensemble des travaux récents sur la physiologie cardiaque et sur le seuil de la fibrillation a permis une meilleure compréhension de l'influence des principaux paramètres physiques, en particulier du temps de passage du courant.

Des recherches récentes ont aussi été effectuées sur les autres paramètres physiques des accidents, en particulier la forme et la fréquence du courant et l'impédance du corps humain. C'est pourquoi il est apparu souhaitable d'entreprendre cette révision de la CEI 479 qui doit être considérée comme le développement et l'évolution logiques de la deuxième édition.

INTRODUCTION

This Technical Report is intended to provide basic guidance on the effects of shock currents on human beings and livestock, for use in the establishment of electrical safety requirements.

In order to avoid errors in the interpretation of this report it is to be emphasized that the data given herein is mainly based on experiments with animals as well as on information available from clinical observations. Only a few experiments with shock currents of short duration have been carried out on living human beings.

On the evidence available, mostly from animal research, the values are so conservative that the report applies to persons under normal physiological conditions, including children irrespective of age and weight.

There are, however, other aspects to be taken into account, such as probability of faults, probability of contact with live or faulty parts, ratio between touch voltage and fault voltage, experience gained, technical feasibilities, and economics. These parameters have to be considered carefully when fixing safety requirements, for example, operating characteristics of protective devices for electrical installations.

The form of the report has been adopted, as it summarizes results so far achieved which are being used by technical committee 64 as a basis for fixing requirements for protection against shock. These results are considered important enough to justify an IEC publication, which may serve also as a guide to other IEC committees and countries having need of such information.

The first edition of IEC 479 was issued in 1974 and was based on an extensive search in literature and on the evaluation of replies received to a questionnaire. However, since that date, new research work has been conducted on this subject. The study of this work and a more precise analysis of preceding publications have allowed a better understanding of the effects of electric current on living organisms and, in particular, on human beings and livestock.

This specifically applies to the limits of ventricular fibrillation which is the main cause of deaths by electric current, and the analysis of all results of recent research work on cardiac physiology and on the fibrillation threshold, taken together, has made it possible to better appreciate the influence of the main physical parameters, and especially of the duration of the current flow.

Recent research work has also been conducted on the other physical accident parameters, especially the waveform and frequency of the current and the impedance of the human body. This revision of IEC 479 was therefore considered necessary and should be viewed as the logical development and evolution of the second edition.

EFFETS DU COURANT SUR L'HOMME ET LES ANIMAUX DOMESTIQUES –

Partie 1: Aspects généraux

1 Généralités

1.1 *Domaine d'application et objet*

Pour un même trajet du courant à travers le corps humain, le danger qu'encourent les personnes dépend essentiellement de l'intensité et de la durée de passage du courant. Toutefois, les zones temps/courant spécifiées dans les articles suivants ne sont pas, dans beaucoup de cas, directement applicables en pratique pour concevoir la protection contre les chocs électriques; le critère est la limite admissible de la tension de contact (c'est-à-dire le produit du courant passant par le corps humain et de son impédance) en fonction du temps. La relation entre le courant et la tension n'est pas linéaire du fait que l'impédance du corps humain varie avec la tension de contact. Il importe donc de disposer de données quant à cette relation. Les différentes parties du corps humain – telles que la peau, le sang, les muscles, d'autres tissus et les articulations – présentent pour le courant électrique une certaine impédance composée d'éléments résistifs et capacitifs.

Les valeurs de ces impédances dépendent de plusieurs facteurs et notamment du trajet du courant, de la tension de contact, de la durée de passage du courant, de la fréquence du courant, de l'état d'humidité de la peau, de la surface de contact, de la pression exercée et de la température.

Les valeurs d'impédance indiquées dans ce Rapport technique résultent d'un examen minutieux des résultats expérimentaux disponibles de mesures effectuées principalement sur des cadavres et sur quelques personnes vivantes.

L'article 3 est principalement fondé sur les données concernant les effets du courant électrique à la fréquence de 50 Hz ou 60 Hz, qui est le courant le plus utilisé dans les installations électriques. Les valeurs indiquées sont toutefois considérées comme applicables dans la gamme de fréquences de 15 Hz à 100 Hz, les valeurs de seuil aux limites de cette gamme étant plus élevées que celles à la fréquence de 50 Hz ou 60 Hz. C'est principalement le risque de fibrillation ventriculaire du coeur qui est, dans cette gamme de fréquences, considéré comme la cause essentielle des accidents mortels.

Les accidents en courant continu sont beaucoup moins fréquents que l'on pourrait le croire en considérant le nombre d'applications du courant continu et des accidents mortels se produisant seulement dans des conditions très défavorables, par exemple dans des mines. Cela est dû en partie au fait que, pour des durées de choc supérieures à la période du cycle cardiaque, le seuil de fibrillation ventriculaire est beaucoup plus élevé qu'en courant alternatif.

Les principales différences entre les effets du courant alternatif et ceux du courant continu sur le corps humain proviennent du fait que les excitations du courant (stimulation des nerfs et des muscles, provocation de la fibrillation auriculaire ou ventriculaire du coeur) sont liées aux variations d'intensité notamment lorsque le courant est établi ou interrompu.

EFFECTS OF CURRENT ON HUMAN BEINGS AND LIVESTOCK –

Part 1: General aspects

1 General

1.1 *Scope and object*

For a given current path through the human body, the danger to persons depends mainly on the magnitude and duration of the current flow. However, the time/current zones specified in the following clauses are, in many cases, not directly applicable in practice for designing protection against electrical shock, the necessary criterion being the admissible limit of touch voltage (i.e. the product of the current through the body and the body impedance) as a function of time. The relationship between current and voltage is not linear because the impedance of the human body varies with the touch voltage, and data on this relationship is therefore required. The different parts of the human body – such as the skin, blood, muscles, other tissues and joints – present to the electric current a certain impedance composed of resistive and capacitive components.

The values of these impedances depend on a number of factors and, in particular, on the current path, on the touch voltage, the duration of the current flow, the frequency, the degree of moisture of the skin, the surface area of contact, the pressure exerted and on the temperature.

The impedance values indicated in this Technical Report result from a close examination of the experimental results available from measurements carried out principally on corpses and on some living persons.

Clause 3 is primarily based on the findings related to the effects of current at frequencies of 50 Hz or 60 Hz which are the most common in electrical installations. The values given are, however, deemed applicable over the frequency range from 15 Hz to 100 Hz, threshold values at the limits of this range being higher than those at 50 Hz or 60 Hz. It is considered principally the risk of ventricular fibrillation which is the main cause of fatal accidents in that range of frequencies.

Accidents with direct current are much less frequent than would be expected from the number of d.c. applications, and fatal accidents occur only under very unfavourable conditions, for example, in mines. This is partly due to the fact that with direct current, the let-go of parts gripped is less difficult and that for shock durations longer than the period of the cardiac cycle, the threshold of ventricular fibrillation remains considerably higher than for alternating current.

The main differences between the effects of a.c. and d.c. on the human body result from the fact that excitatory actions of the current (stimulation of nerves and muscles, induction of cardiac atrial or ventricular fibrillation) are linked to the changes of the current magnitude especially when making and breaking the current. To produce the same excitatory

Pour produire une même excitation, les intensités constantes nécessaires en courant continu sont de deux à quatre fois supérieures à celles qui sont nécessaires en courant alternatif.

1.2 *Référence normative*

Le document normatif suivant contient des dispositions qui, par suite de la référence qui y est faite, constituent des dispositions valables pour le présent Rapport technique. Au moment de la publication, l'édition indiquée était en vigueur. Tout document normatif est sujet à révision et les parties prenantes aux accords fondés sur le présent Rapport technique sont invitées à rechercher la possibilité d'appliquer l'édition la plus récente du document normatif indiqué ci-après. Les membres de la CEI et de l'ISO possèdent le registre des Normes internationales en vigueur.

CEI 479-2: 1987, *Effets du courant passant par le corps humain – Deuxième partie: Aspects particuliers*

1.3 *Définitions*

Pour les besoins de ce Rapport technique, les définitions suivantes sont applicables.

1.3.1 *Impédance électrique du corps humain*

1.3.1.1 **impédance interne du corps humain (Z_i):** Impédance entre deux électrodes en contact avec deux parties du corps humain en négligeant les impédances de la peau.

1.3.1.2 **impédance de la peau (Z_P):** Impédance entre une électrode sur la peau et les tissus conducteurs sous-jacents.

1.3.1.3 **impédance totale du corps humain (Z_T):** Somme vectorielle de l'impédance interne et des impédances de la peau (voir figure 1).

1.3.1.4 **résistance initiale du corps humain (R_o):** Résistance limitant la valeur de crête du courant au moment où la tension de contact est appliquée.

1.3.2 *Effets du courant alternatif de fréquence comprise entre 15 Hz et 100 Hz*

1.3.2.1 **seuil de perception:** Valeur du courant qui provoque une sensation pour une personne à travers laquelle ce courant passe.

1.3.2.2 **seuil de réaction:** Valeur minimale du courant qui provoque une contraction musculaire.

1.3.2.3 **seuil de non-lâcher:** Valeur maximale du courant à laquelle une personne tenant les électrodes peut lâcher les électrodes.

1.3.2.4 **seuil de fibrillation ventriculaire:** Valeur minimale du courant qui provoque la fibrillation ventriculaire.

1.3.2.5 **facteur de courant de coeur *F*:** Rapport de l'intensité du champ électrique (densité de courant) dans le coeur pour un trajet donné du courant au champ électrique (densité de courant) dans le coeur pour un courant de même intensité suivant le trajet de la main gauche aux deux pieds.

effects the magnitude of direct current flow of constant strength is two to four times greater than that of alternating current.

1.2 *Normative reference*

The following normative document contains provisions which, through reference in this text, constitutes provisions of this Technical Report. At the time of publication, the edition indicated was valid. All normative documents are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the normative document indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 479-2: 1987, *Effects of current passing through the human body – Part 2: Special aspects*

1.3 *Definitions*

For the purpose of this Technical Report the following definitions apply.

1.3.1 *Electrical impedance of the human body*

1.3.1.1 **internal impedance of the human body (Z_i):** Impedance between two electrodes in contact with two parts of the human body, neglecting skin impedances.

1.3.1.2 **impedance of the skin (Z_p):** Impedance between an electrode on the skin and the conductive tissues underneath.

1.3.1.3 **total impedance of the human body (Z_T):** Vectorial sum of the internal impedance and the impedance of the skin (see figure 1).

1.3.1.4 **initial resistance of the human body (R_o):** Resistance limiting the peak value of the current at the moment when the touch voltage occurs.

1.3.2 *Effects of sinusoidal alternating current in the range 15 Hz to 100 Hz*

1.3.2.1 **threshold of perception:** Minimum value of current which causes any sensation for the person through which it is flowing.

1.3.2.2 **threshold of reaction:** Minimum value of current which causes involuntary muscular contraction.

1.3.2.3 **threshold of let-go:** Maximum value of current at which a person holding electrodes can let go of the electrodes.

1.3.2.4 **threshold of ventricular fibrillation:** Minimum value of current through the body which causes ventricular fibrillation.

1.3.2.5 **heart-current factor** *F*: Relates the electric field strength (current density) in the heart for a given current path to the electric field strength (current density) in the heart for a current of equal magnitude flowing from left hand to feet.

NOTE – Dans le coeur, la densité de courant est proportionnelle à l'intensité du champ électrique.

1.3.2.6 **période vulnérable:** Concerne une partie relativement petite du cycle cardiaque pendant laquelle les fibres du coeur sont dans un état non homogène d'excitabilité et la fibrillation ventriculaire se produit si elles sont excitées par un courant électrique d'intensité suffisante.

NOTE – La période vulnérable correspond à la première partie de l'onde T dans l'électrocardiogramme et représente environ 10 % du cycle cardiaque (voir figures 12 et 13).

1.3.3 *Effets du courant continu*

1.3.3.1 **facteur d'équivalence entre courant continu et courant alternatif (*k*):** Rapport du courant continu à la valeur efficace équivalente du courant alternatif présentant la même probabilité de provoquer la fibrillation ventriculaire.

NOTE – Par exemple, pour des durées de choc supérieures à la durée d'un cycle cardiaque et une probabilité de fibrillation ventriculaire de 50 %, le facteur d'équivalence est approximativement égal à:

$$k = \frac{I_{\text{c.c.-fibrillation}}}{I_{\text{c.a.-fibrillation (eff.)}}} = \frac{300\ \text{mA}}{80\ \text{mA}} = 3{,}75$$

1.3.3.2 **courant longitudinal:** Courant passant dans le sens de la longueur à travers le tronc du corps humain, par exemple entre main et pieds.

1.3.3.3 **courant transversal:** Courant passant dans le sens transversal à travers le tronc du corps humain, par exemple entre main et main.

1.3.3.4 **courant montant:** Courant continu à travers le corps humain pour lequel les pieds représentent le pôle positif.

1.3.3.5 **courant descendant:** Courant continu à travers le corps humain pour lequel les pieds représentent le pôle négatif.

2 Caractéristiques de l'impédance du corps humain

Cet article indique les valeurs d'impédance électrique du corps humain en fonction de la tension de contact, de la fréquence du courant, de l'état d'humidité de la peau, du trajet du courant et de la surface de la zone de contact.

Le schéma de la figure 1 représente les impédances de corps humain.

2.1 *Impédance interne du corps humain (Z_i)*

L'impédance interne du corps humain peut être considérée comme principalement résistive. Sa valeur dépend principalement du trajet du courant et, dans une moindre mesure, de la surface de contact.

NOTE – Les mesures montrent qu'une faible composante capacitive existe (traits interrompus de la figure 1).

La figure 2 indique les valeurs de l'impédance interne du corps humain, pour différents trajets, exprimées en pourcentage de la valeur pour le trajet main à pied.

NOTE – In the heart, the current density is proportional to the electric field strength.

1.3.2.6 **vulnerable period:** Covers a comparatively small part of the cardiac cycle during which the heart fibres are in an inhomogeneous state of excitability and ventricular fibrillation occurs if they are excited by an electric current of sufficient magnitude.

NOTE – The vulnerable period corresponds to the first part of the T-wave in the electrocardiogram which is approximately 10 % of the cardiac cycle (see figures 12 and 13).

1.3.3 *Effects of direct current*

1.3.3.1 **d.c./a.c. equivalence factor (*k*):** Ratio of direct current to its equivalent r.m.s. value of alternating current having the same probability of inducing ventricular fibrillation.

NOTE – As an example for shock durations longer than the period of one cardiac cycle and 50 % probability for ventricular fibrillation, the equivalence factor is approximately:

$$k = \frac{I_{\text{d.c.-fibrillation}}}{I_{\text{a.c.-fibrillation (r.m.s.)}}} = \frac{300\ \text{mA}}{80\ \text{mA}} = 3{,}75$$

1.3.3.2 **longitudinal current:** Current flowing lengthwise through the trunk of the human body such as from hand to feet.

1.3.3.3 **transverse current:** Current flowing crosswise through the trunk of the human body such as from hand to hand.

1.3.3.4 **upward current:** Direct current through the human body for which the feet represent the positive polarity.

1.3.3.5 **downward current:** Direct current through the human body for which the feet represent the negative polarity.

2 Electrical impedance of the human body

This clause indicates values for the electric impedance of the human body as a function of the touch voltage, the frequency, the degree of moisture of the skin, the current path, and the surface area of contact.

A schematic diagram for the impedance of the human body is shown in figure 1.

2.1 *Internal impedance of the human body (Z_i)*

The internal impedance of the human body can be considered as mostly resistive. Its value depends primarily on the current path and, to a lesser extent, on the surface area of the contact.

NOTE – Measurements indicate that a small capacitive component exists (dashed lines in figure 1).

Figure 2 shows the internal impedance of the human body for its different parts expressed as percentages of that related to the path hand to foot.

Pour les trajets de courant main à main ou main à pieds, les impédances sont essentiellement localisées dans les extrémités (bras et jambes). Si l'impédance du tronc du corps est négligée, un diagramme simplifié peut être représenté (voir figure 3).

NOTE – Afin de simplifier le diagramme, il est supposé que les impédances des bras et des jambes ont la même valeur.

2.2 *Impédance de la peau* (Z_p)

L'impédance de la peau peut être considérée comme un ensemble de résistances et de capacités. Sa structure est constituée par une couche semi-conductrice et de petits éléments conducteurs (pores). L'impédance de la peau décroît lorsque le courant augmente. Des marques de courant sont parfois observées (voir 2.5.4).

La valeur d'impédance de la peau dépend de la tension, de la fréquence, de la durée de passage du courant, de la surface de contact, de la pression de contact, de l'état d'humidité de la peau, de la température et du type de peau.

Pour des tensions de contact jusqu'à 50 V environ en courant alternatif, la valeur de l'impédance de la peau varie largement, même pour une personne, en fonction de la surface de contact, de la température, de la transpiration, d'une respiration rapide, etc.

Pour des tensions de contact croissantes (supérieures à 50 V environ), l'impédance de la peau décroît rapidement et devient négligeable lorsque la peau est perforée.

En ce qui concerne l'influence de la fréquence, l'impédance de la peau décroît quand la fréquence augmente.

2.3 *Impédance totale du corps humain* (Z_T)

L'impédance totale du corps humain est constituée de composants résistifs et capacitifs.

Pour des tensions de contact jusqu'à 50 V environ, en raison des variations importantes de l'impédance de la peau Z_p, l'impédance totale du corps humain Z_T varie dans de larges limites.

Pour des tensions de contact plus élevées, l'impédance totale dépend de moins en moins de l'impédance de la peau et sa valeur s'approche, après perforation de la peau, de celle de l'impédance interne Z_i.

En ce qui concerne l'influence de la fréquence, compte tenu de la variation de l'impédance de la peau en fonction de la fréquence, l'impédance totale du corps humain est plus élevée en courant continu et décroît quand la fréquence augmente.

2.4 *Résistance initiale du corps humain* (R_o)

Au moment où la tension de contact est appliquée, les capacités du corps humain ne sont pas chargées, c'est pourquoi les impédances de la peau Z_{p1} et Z_{p2} sont négligeables et la résistance initiale R_o est approximativement égale à l'impédance interne du corps humain Z_i (voir figure 1). La résistance initiale R_o dépend principalement du trajet du courant et, dans une moindre mesure, de la surface de contact.

La résistance initiale R_o limite les pointes de courant d'impulsions brèves (par exemple les chocs dus à des clôtures électriques).

For current paths hand to hand or hand to feet, the impedances are mainly located in the extremities (arms and legs). If the impedance of the trunk of the body is neglected, a simplified circuit diagram can be established which is shown in figure 3.

NOTE – In order to simplify the circuit diagram, it is assumed that the impedance of arms and legs have the same values.

2.2 *Impedance of the skin* (Z_p)

The impedance of the skin can be considered as a network of resistances and capacitances. Its structure is made up of a semi-insulating layer and small conductive elements (pores). The skin impedance falls when the current is increased. Sometimes current marks are observed (see 2.5.4).

The value of the impedance of the skin depends on the voltage, frequency, duration of the current flow, surface area of contact, pressure of contact, the degree of moisture of the skin, temperature and type of the skin.

For touch voltages up to approximately a.c. 50 V, the value of the impedance of the skin varies widely with surface area of contact, temperature, perspiration, rapid respiration, etc., even for one person.

For higher touch voltages over approximately 50 V, the skin impedance decreases considerably and becomes negligible when the skin breaks down.

As regards the influence of frequency, the impedance of the skin decreases when the frequency increases.

2.3 *Total impedance of the human body* (Z_T)

The total impedance of the human body consists of resistive and capacitive components.

For touch voltages up to approximately 50 V, on account of considerable variations in the impedance of the skin Z_p, the total impedance of the human body Z_T similarly varies widely.

For higher touch voltages, the total impedance depends less and less on the impedance of the skin and its value approaches that of the internal impedance Z_i.

As regards the influence of frequency, taking into account the frequency dependence of the skin, the total impedance of the human body is higher for direct current and decreases when the frequency increases.

2.4 *Initial resistance of the human body* (R_o)

At the moment when the touch voltage occurs, capacitances in the human body are not charged. Therefore skin impedances Z_{p1} and Z_{p2} are negligible and the initial resistance R_o is approximately equal to the internal impedance of the human body Z_i (see figure 1). The initial resistance R_o depends mainly on the current path and to a lesser extent on the surface area of contact.

The initial resistance R_o limits the current peaks of short impulses (e.g. shocks from electric fence controllers).

2.5 *Valeurs de l'impédance totale du corps humain* (Z_T)

2.5.1 *Courant alternatif sinusoïdal 50/60 Hz*

Les valeurs de l'impédance totale du corps humain indiquées dans le tableau 1 sont valables pour des êtres vivants, un trajet main à main avec des surfaces de contact importantes (5 000 mm^2 à 10 000 mm^2) dans des conditions sèches.

Pour des tensions de contact jusqu'à 50 V, les valeurs mesurées avec des surfaces de contact mouillées par de l'eau fraîche sont plus faibles de 10 % à 25 % par rapport aux conditions sèches et des solutions conductrices diminuent considérablement l'impédance, jusqu'à la moitié des valeurs mesurées dans des conditions sèches.

Pour des tensions supérieures à environ 150 V, l'impédance totale du corps humain dépend peu de l'humidité et de la surface de contact.

Les mesures ont été effectuées sur des adultes des deux sexes. Elles sont décrites en annexe A. La plage des valeurs de l'impédance totale du corps humain pour des tensions de contact jusqu'à 5 000 V est représentée sur la figure 4, et pour des tensions de contact jusqu'à 220 V sur la figure 5 (ligne pointillée).

Les valeurs du tableau 1 et des figures 4 et 5 représentent actuellement la meilleure connaissance de l'impédance totale du corps humain pour les adultes vivants. L'état actuel des connaissances laisse penser que l'impédance totale du corps des enfants serait du même ordre de grandeur mais un peu plus élevée.

Tableau 1 – Impédance totale du corps humain Z_T pour un trajet de courant main à main en courant alternatif 50/60 Hz pour des surfaces de contact importantes

Tension de contact V	Valeurs de l'impédance totale (Ω) du corps humain qui ne sont pas dépassées par		
	5 % de la population	50 % de la population	95 % de la population
25	1 750	3 250	6 100
50	1 450	2 625	4 375
75	1 250	2 200	3 500
100	1 200	1 875	3 200
125	1 125	1 625	2 875
220	1 000	1 350	2 125
700	750	1 100	1 550
1 000	700	1 050	1 500
Valeur asymptotique	650	750	850
NOTE – Quelques mesures indiquent que l'impédance totale du corps humain pour un trajet de courant main à pied est un peu plus faible que pour un trajet main à main (10 % à 30 %).			

2.5.2 *Courant alternatif sinusoïdal jusqu'à des fréquences de 20 kHz*

Les valeurs des impédances totales du corps humain à 50/60 Hz diminuent pour des fréquences plus élevées en raison de l'influence des capacités de la peau et sont proches de l'impédance interne du corps humain Z_i pour des fréquences supérieures à 5 kHz.

2.5 *Values of the total impedance of the human body (Z_T)*

2.5.1 *Sinusoidal alternating current 50/60 Hz*

The values of the total body impedance given in table 1 are valid for living human beings and a current path hand to hand for large surface areas of contact (5 000 mm^2 to 10 000 mm^2) and dry conditions.

At voltages up to 50 V, values measured with contact areas wetted with fresh water, are 10 % to 25 % lower than in dry conditions and conductive solutions decrease the impedance considerably down to half of values measured in dry conditions.

At voltages higher than approximately 150 V, the total body impedance depends less and less on humidity and on the surface area of contact.

The measurements have been made on adults, males and females. They are described in annex A. The range of the total body impedance for touch voltages up to 5 000 V is presented in figure 4 and for touch voltages up to and including 220 V in figure 5 (dashed line).

The values of table 1 and figures 4 and 5 represent the best knowledge on the total body impedance for living adults. On the knowledge at present available the total body impedance for children is expected to be somewhat higher but of the same order of magnitude.

Table 1 – Total body impedance Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact

Touch voltage V	Values for the total body impedance (Ω) that are not exceeded for a percentage (percentile rank) of		
	5 % of the population	50 % of the population	95 % of the population
25	1 750	3 250	6 100
50	1 450	2 625	4 375
75	1 250	2 200	3 500
100	1 200	1 875	3 200
125	1 125	1 625	2 875
220	1 000	1 350	2 125
700	750	1 100	1 550
1 000	700	1 050	1 500
Asymptotic value	650	750	850

NOTE – Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

2.5.2 *Sinusoidal alternating current with frequencies up to 20 kHz*

The values of the total body impedances for 50/60 Hz decrease at higher frequencies due to the influence of the capacitances of the skin and approach for frequencies above 5 kHz the internal body impedance Z_i.

Les mesures qui ont été menées jusqu'à des fréquences de 20 kHz avec des tensions de contact de 10 V et de 25 V sont décrites dans l'annexe B.

La figure 6 montre que l'impédance totale du corps humain Z_T, pour un trajet de courant main à main et d'importantes surfaces de contact pour une tension de contact de 10 V, est dépendante de la fréquence variant de 25 Hz à 20 kHz.

La figure 7 montre que l'impédance totale du corps humain Z_T, pour un trajet de courant main à main et d'importantes surfaces de contact pour une tension de contact de 25 V, est dépendante de la fréquence variant de 25 Hz à 2 kHz. A partir des résultats, des courbes ont été déduites donnant la fonction de l'impédance totale du corps humain Z_T d'une population avec un pourcentage de 50 % pour des tensions de contact variant entre 10 V et 1 000 V et une plage de fréquence de 50 Hz à 2 kHz pour un trajet de courant main à main ou main à pied. Les courbes sont représentées à la figure 8.

2.5.3 *Courant continu*

La résistance totale du corps humain R_T en courant continu est plus élevée que l'impédance totale du corps humain Z_T en courant alternatif pour des tensions de contact jusqu'à environ 150 V en raison du pouvoir bloquant des capacités de la peau humaine.

Les mesures effectuées en courant continu pour d'importantes surfaces de contact sont décrites en annexe C.

Les valeurs de résistance totale du corps humain R_T en courant continu, déterminées selon la méthode décrite en annexe C, sont présentées dans le tableau 2 (voir figure 5, ligne continue).

2.5.4 *Effets du courant sur la peau*

La figure 9 montre la dépendance des altérations de la peau humaine vis-à-vis de la densité de courant et de la durée du passage de courant.

Les altérations de la peau humaine dépendent de la densité de courant i_s (mA/mm^2) et de la durée de passage du courant.

A titre de guide, les valeurs suivantes peuvent être données:

- en dessous de 10 mA/mm^2, en général, aucune altération de la peau n'est observée. Pour des durées plus importantes de passage de courant (plusieurs secondes), la peau située sous l'électrode peut devenir blanc-gris avec une surface rugueuse (zone 0);
- entre 10 mA/mm^2 et 20 mA/mm^2, une rougeur de la peau apparaît avec un gonflement en forme de vague de couleur blanchâtre le long des bords de l'électrode (zone 1);
- entre 20 mA/mm^2 et 50 mA/mm^2, une couleur brunâtre se développe sous l'électrode placée dans la peau. Pour des durées plus importantes de passage de courant (plusieurs dizaines de secondes), des marques de courant nettes (boursouflures) sont observées autour de l'électrode (zone 2);
- au-dessus de 50 mA/mm^2, une carbonisation de la peau peut se produire (zone 3).

The measurements which have been carried out with frequencies up to 20 kHz at touch voltages of 10 V and 25 V are described in annex B.

Figure 6 shows the frequency dependence of the total body impedance Z_T for a current path hand to hand and large contact areas for a touch voltage of 10 V and frequencies from 25 Hz to 20 kHz.

Figure 7 shows the frequency dependence of the total body impedance Z_T for a current path hand to hand and large contact areas for a touch voltage of 25 V and frequencies from 25 Hz to 2 kHz. From the results, the curves have been derived giving the dependence of the total body impedance Z_T of a population for a percentile rank of 50 % for touch voltages from 10 V to 1 000 V and a frequency range from 50 Hz to 2 kHz for a current path hand to hand or hand to foot. The curves are shown in figure 8.

2.5.3 *Direct current*

The total body resistance R_T for direct current is higher than the total body impedance Z_T for alternating current for touch voltages up to approximately 150 V due to the blocking effect of the capacitances of the human skin.

The measurements which have been carried out with direct current for large surface areas of contact are described in annex C.

The values for the total body resistance R_T for direct current determined in the way described in annex C are presented in table 2 (see figure 5, continuous line).

2.5.4 *Effects of current on the skin*

Figure 9 shows the dependence of the alterations of the human skin on current density and duration of current flow.

Alterations of the human skin depend on current density i_s (mA/mm^2) and on duration of current flow.

As a guideline the following values can be given:

- below 10 mA/mm^2, in general no alterations of the skin are observed. For longer durations of current flow (several seconds) the skin below the electrode may be of greyish-white colour with a coarse surface (zone 0);

- between 10 mA/mm^2 and 20 mA/mm^2, a reddening of the skin occurs with a wave like swelling of whitish colour along the edges of the electrode (zone 1);

- between 20 mA/mm^2 and 50 mA/mm^2, a brownish colour develops below the electrode sinking into the skin. For longer durations of current flow (several tens of seconds) full current marks (blisters) are to be observed around the electrode (zone 2);

- above 50 mA/mm^2, carbonization of the skin can occur (zone 3).

Pour les zones de contact importantes, les densités de courant peuvent être suffisamment faibles de telle manière qu'aucune altération de la peau ne se produise bien que les intensités soient mortelles.

Tableau 2 – Résistance totale du corps humain R_T pour un trajet de courant main à main en courant continu pour d'importantes surfaces de contact

Tension de contact V	Valeurs de l'impédance totale R_T (Ω) du corps humain qui ne sont pas dépassées par		
	5 % de la population	50 % de la population	95 % de la population
25	2 200	3 875	8 800
50	1 750	2 990	5 300
75	1 510	2 470	4 000
100	1 340	2 070	3 400
125	1 230	1 750	3 000
220	1 000	1 350	2 125
700	750	1 100	1 550
1 000	700	1 050	1 500
Valeurs asymptotiques	650	750	850

NOTE – Des mesures indiquent que la résistance totale du corps humain pour un trajet de courant main à pied est un peu plus faible que pour un trajet main à main (10 % à 30 %).

2.6 *Valeur de la résistance initiale du corps humain (R_0)*

La valeur de la résistance initiale du corps humain R_0, pour un trajet de courant main à main ou main à pied et pour d'importantes surfaces de contact, peut être prise égale à 500 Ω pour un pourcentage de 5 % en courant alternatif 50/60 Hz et en courant continu.

NOTE – La valeur de 500 Ω pour la résistance initiale R_0 est un peu plus basse que la valeur asymptotique de 650 Ω de l'impédance totale du corps humain Z_T en courant alternatif 50/60 Hz et la résistance totale du corps humain R_T en courant continu pour un pourcentage de 5 %, parce qu'au moment du contact, les capacités de la peau et la capacité interne du corps sont déchargées.

2.7 *Sujétion des impédances du corps à la surface de contact en courant alternatif 50/60 Hz et en courant continu*

Les valeurs de l'impédance interne du corps humain Z_i et de la résistance initiale du corps humain R_0 dépendent peu des surfaces de contact.

Cependant, lorsque la surface de contact est très petite, de l'ordre de quelques millimètres carrés, les valeurs croissent.

Les valeurs de l'impédance totale du corps humain Z_T dépendent de la surface de contact tant que la peau n'a pas claqué (pour des tensions de contact jusqu'à 50 V environ) ou a partiellement claqué (pour des tensions de contact supérieures à 50 V).

La sujétion de l'impédance totale du corps Z_T pour un trajet de courant main à main et une surface de contact (de 1 mm^2 à 8 000 mm^2 environ) pour une plage de tension de 25 V à 200 V, en courant alternatif à 50 Hz est montrée en figure 10. Pour des tensions de contact inférieures à 100 V et de petites surfaces de contact, des variations de mesure peuvent aisément être de l'ordre de ±50 % par rapport à la moyenne, fonction de la température, de la pression, de l'endroit de la paume de la main, etc. Même une respiration rapide modifie l'impédance.

At large contact areas, current densities may be low enough not to cause any alterations of the skin in spite of fatal current magnitudes.

Table 2 – Total body resistance R_T for a current path hand to hand, d.c. for large surface areas of contact

Touch voltage V	Values for the total body resistance R_T (Ω) that are not exceeded for a percentage (percentile rank) of:		
	5 % of the population	50 % of the population	95 % of the population
25	2 200	3 875	8 800
50	1 750	2 990	5 300
75	1 510	2 470	4 000
100	1 340	2 070	3 400
125	1 230	1 750	3 000
220	1 000	1 350	2 125
700	750	1 100	1 550
1 000	700	1 050	1 500
Asymptotic values	650	750	850

NOTE – Some measurements indicate that the total body resistance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

2.6 *Value of the initial resistance of the human body (R_o)*

The value of the initial resistance of the human body R_o for a current path hand to hand or hand to foot and large contact areas can be taken as equal to 500 Ω for a percentile rank of 5 % for a.c. 50/60 Hz and for d.c.

NOTE – The value of 500 Ω for initial resistance R_o is somewhat lower than the asymptotic value of 650 Ω for the total body impedance Z_T for a.c. 50/60 Hz and the total body resistance R_T for d.c. for a percentile rank of 5 % because at contact making the capacitances of the skin and the internal capacitance of the body are uncharged.

2.7 *Dependence of body impedances on the surface area of contact for a.c. 50/60 Hz and for d.c.*

The values of the internal body impedance Z_i and of the initial body resistance R_o depend only to a small extent on the surface areas of contact.

However, when the surface area of contact is very small, in the order of a few square millimetres, the values are increased.

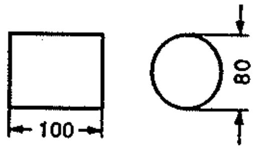
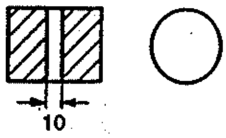
The values of the total body impedance Z_T depend on the surface area of contact when the skin has not broken down (for touch voltages up to approximately 50 V) or has only partially broken down (for touch voltages above 50 V).

The dependence of the total body impedance Z_T for a current path hand to hand on the surface area of contact (from 1 mm^2 up to approximately 8 000 mm^2) for a touch voltage range of 25 V to 200 V, a.c. 50 Hz, is shown in figure 10. For touch voltages below 100 V and small contact areas, deviations in the measurements can easily reach an order of ±50 % of the average, depending on temperature, pressure, location within the palm of the hand, etc. Even rapid breathing changes the impedance.

La sujétion de l'impédance totale du corps Z_T entre les bouts des doigts droit et gauche (surface de contact d'environ 250 mm^2), pour une tension de contact en courant alternatif de 50/60 Hz et en courant continu pour une plage de tension de 25 V à 200 V, est montrée en figure 11.

La manière dont les mesures ont été réalisées est décrite en annexe D. Les mesures indiquent que l'impédance d'un doigt est de l'ordre de 1 000 Ω.

Tableau 3 – Electrodes utilisées pour les mesures de l'assujettissement de l'impédance du corps humain Z_T à la surface de contact

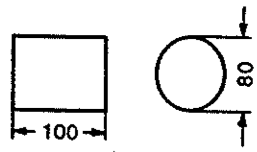
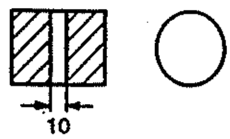
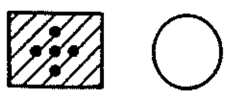
Essai de série	Forme de la zone de contact	Surface de contact réelle mm^2	Schémas mm
A	Cylindre en cuivre	8 000 environ	
B	Forme en anneau avec protection appropriée fournie par une bande isolante	1 000 environ	
C	Forme carrée avec protection appropriée fournie par une bande isolante	100	
D	Cylindre en matériau isolant avec une électrode circulaire	10	
E	Cylindre en matériau isolant avec électrodes circulaires*	1	

* Pour ce type, quatre électrodes circulaires complémentaires de 1 mm^2 ont été utilisées situées en croix à une distance de 30 mm de l'électrode centrale afin de mesurer les variations en ces points à l'intérieur de la paume de la main.

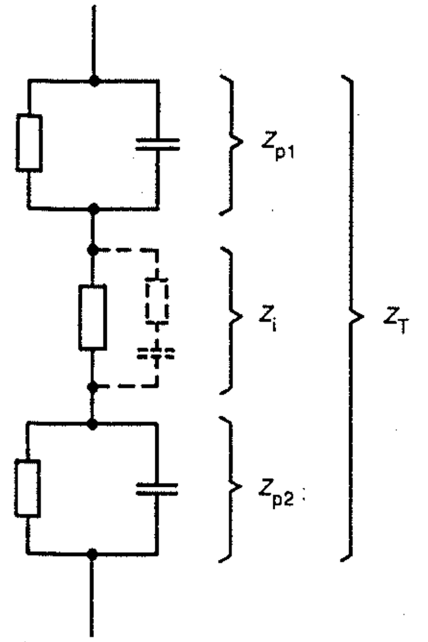
The dependence of the total body impedance Z_T between the tips of the right and left forefinger (surface area of contact approximately 250 mm^2) on the touch voltage for a.c. 50/60 Hz and d.c. for a voltage range from 25 V to 200 V is shown in figure 11.

The way the measurements have been made is described in annex D. The measurements indicate that the impedance of one finger is in the order of 1 000 Ω.

Table 3 – Electrodes used for the measurement of the dependence of the impedance of the human body Z_T on the surface area of contact

Test series	Shape of contact area	Effective contact area mm^2	Drawings mm
A	Brass cylinder	8 000 approximately	
B	Form of a ring by appropriate covering with insulating tape	1 000 approximately	
C	Square by appropriate covering with insulated tape	100	
D	Cylinder of insulating material with circular electrode	10	
E	Cylinder of insulating material with circular electrode*	1	

* For this type, four further circular electrodes of 1 mm^2 area were used situated crosswise at a distance of 30 mm from the electrode at the centre of the surface of the cylinder in order to measure the deviations for these points inside the palm of the hand.

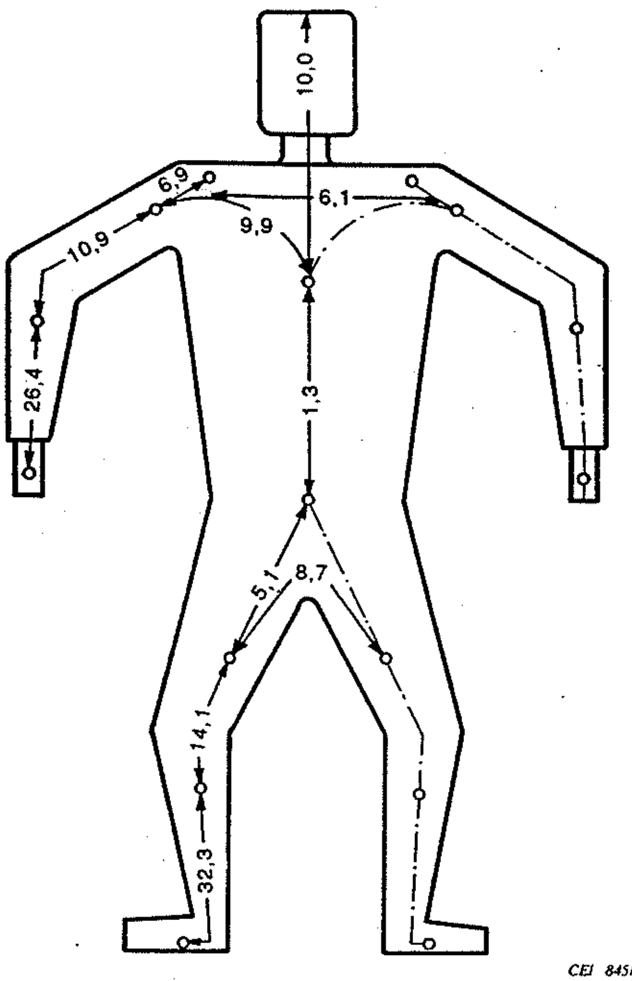


Z_i impédance interne

Z_{p1}, Z_{p2} impédance de la peau

Z_T impédance totale

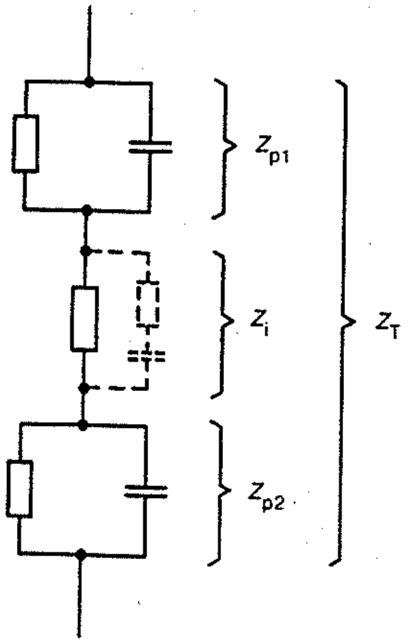
Figure 1 – Impédances du corps humain



Les chiffres indiquent le pourcentage de l'impédance interne du corps humain pour la partie du corps concernée par rapport à celle du trajet main à pied.

NOTE – Afin de calculer l'impédance totale du corps Z_T pour un trajet de courant donné, les impédances internes de toutes les parties du corps parcourues par le courant doivent être ajoutées ainsi que les impédances de la peau des surfaces de contact.

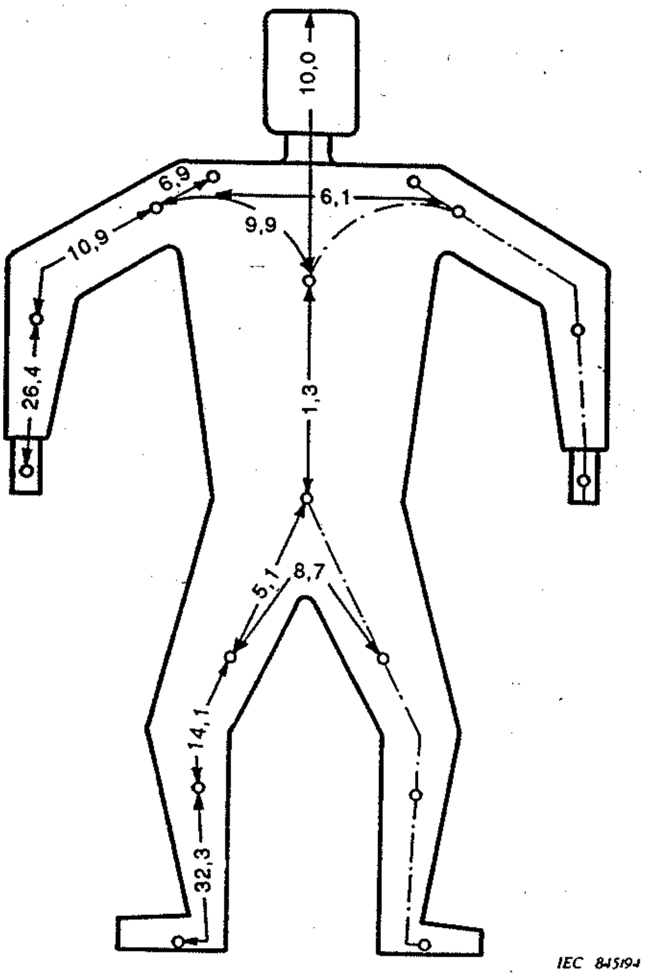
Figure 2 – Impédances internes du corps humain



Z_i	Internal impedance
Z_{p1}, Z_{p2}	impedance of the skin
Z_T	total impedance

IEC 844/94

Figure 1 – Impedances of the human body

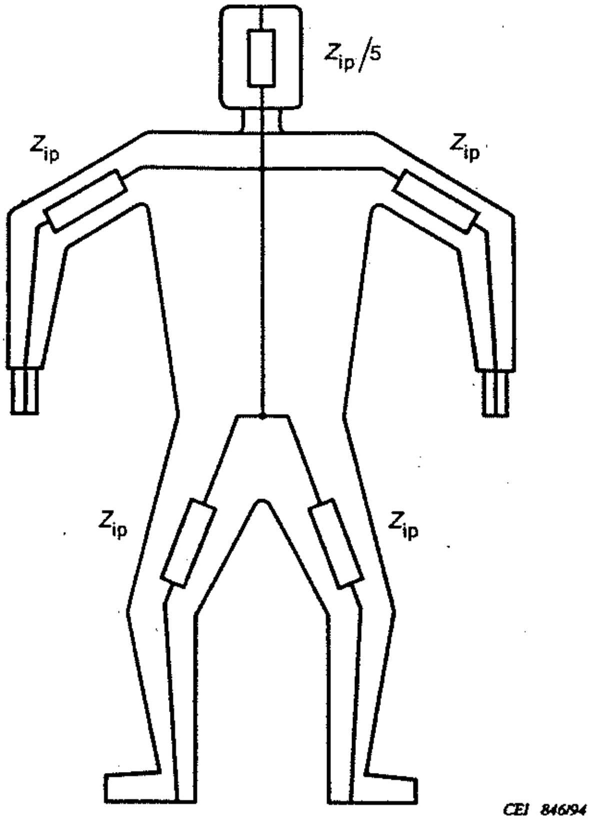


The numbers indicate the percentage of the internal impedance of the human body for the part of the body concerned, in relation to the path hand to foot.

NOTE – In order to calculate the total body impedance Z_T for a given current path, the internal impedances for all parts of the body of the current path have to be added as well as the impedances of the skin of the contact areas.

IEC 845/94

Figure 2 – Internal impedances of the human body



Z_{ip} impédance partielle interne d'une extrémité (bras ou jambe)

NOTE – L'impédance interne d'une main aux deux pieds est d'environ 75 %, l'impédance des deux mains au deux pieds de 50 % et l'impédance des deux mains au tronc du corps 25 % de l'impédance main à main ou main à pied.

Figure 3 – Schéma simplifié des impédances internes du corps humain

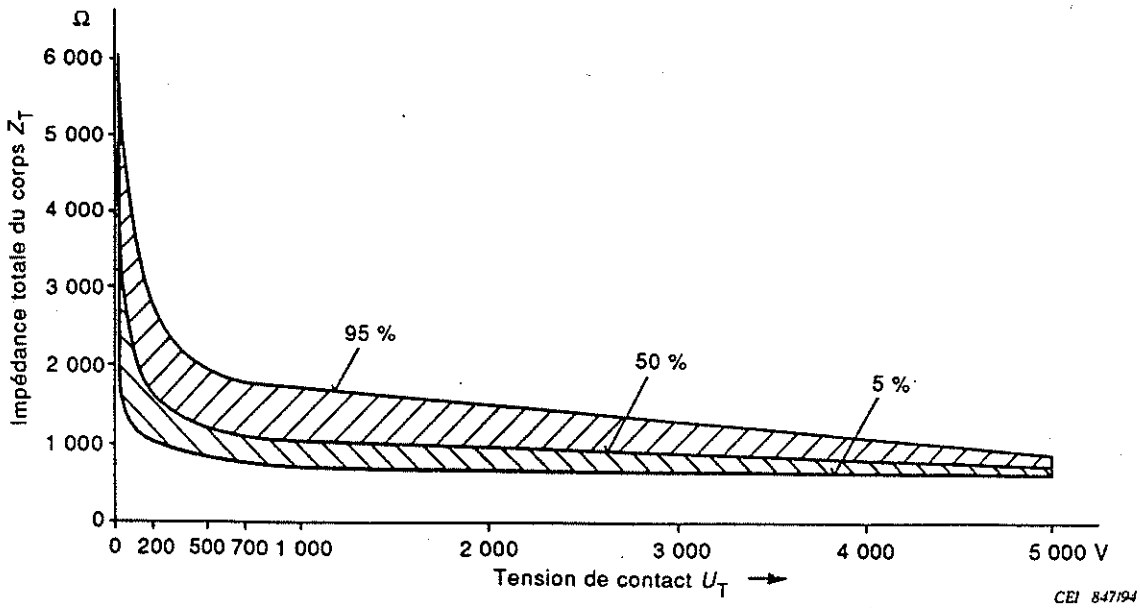
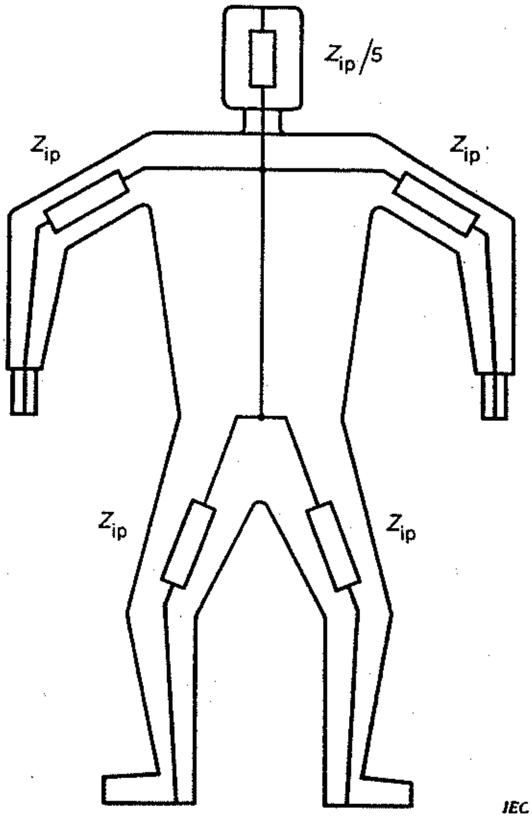


Figure 4 – Valeurs statistiques des impédances totales du corps valables pour des sujets humains vivants pour un trajet courant main à main ou main à pied pour des tensions de contact jusqu'à 5 000 V en courant alternatif 50/60 Hz



Z_{ip} internal partial impedance of one extremity (arm or leg)

NOTE – The internal impedance from one hand to both feet is approximately 75 %, the impedance from both hands to both feet 50 % and the impedance from both hands to the trunk of the body 25 % of the impedance hand to hand or hand to foot.

Figure 3 – Simplified schematic diagram for the internal impedances of the human body

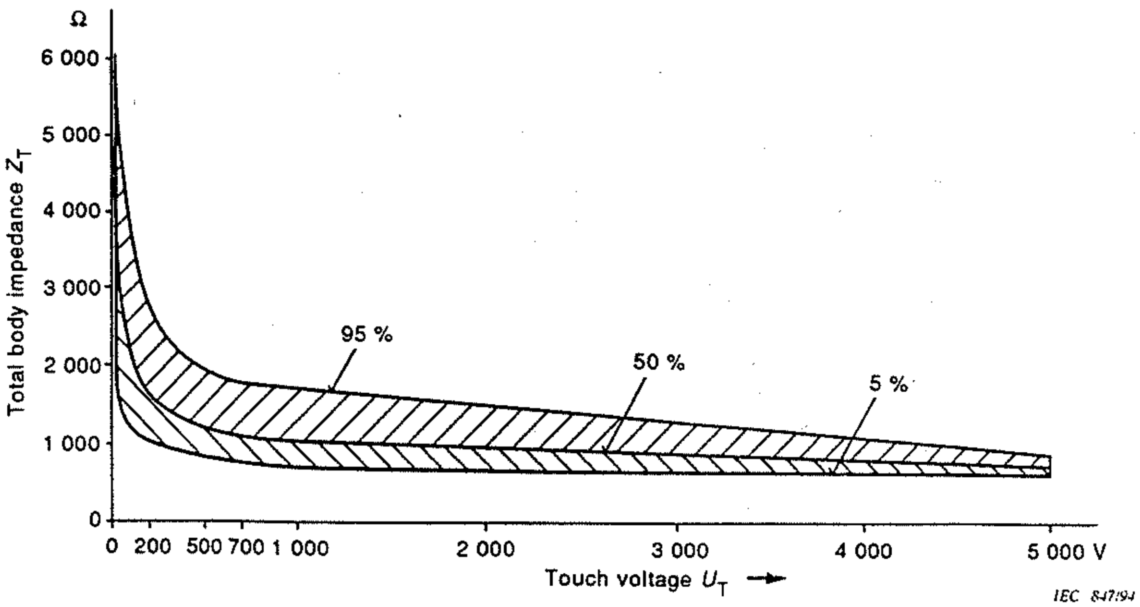


Figure 4 – Statistical values of total body impedances valid for living human beings for the current path hand to hand or hand to foot, for touch voltages up to 5 000 V for a.c. 50/60 Hz

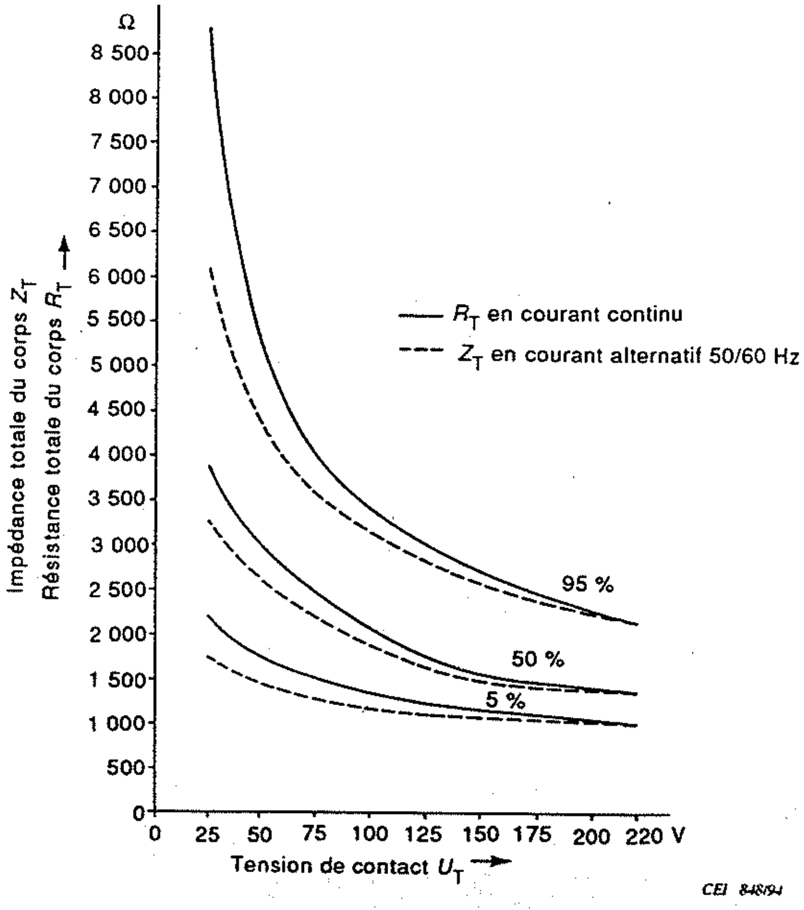


Figure 5 – Valeurs statistiques des impédances totales du corps pour des sujets humains vivants pour un trajet de courant main à main ou main à pied, pour des tensions de contact jusqu'à 220 V en courant alternatif 50/60 Hz et en courant continu

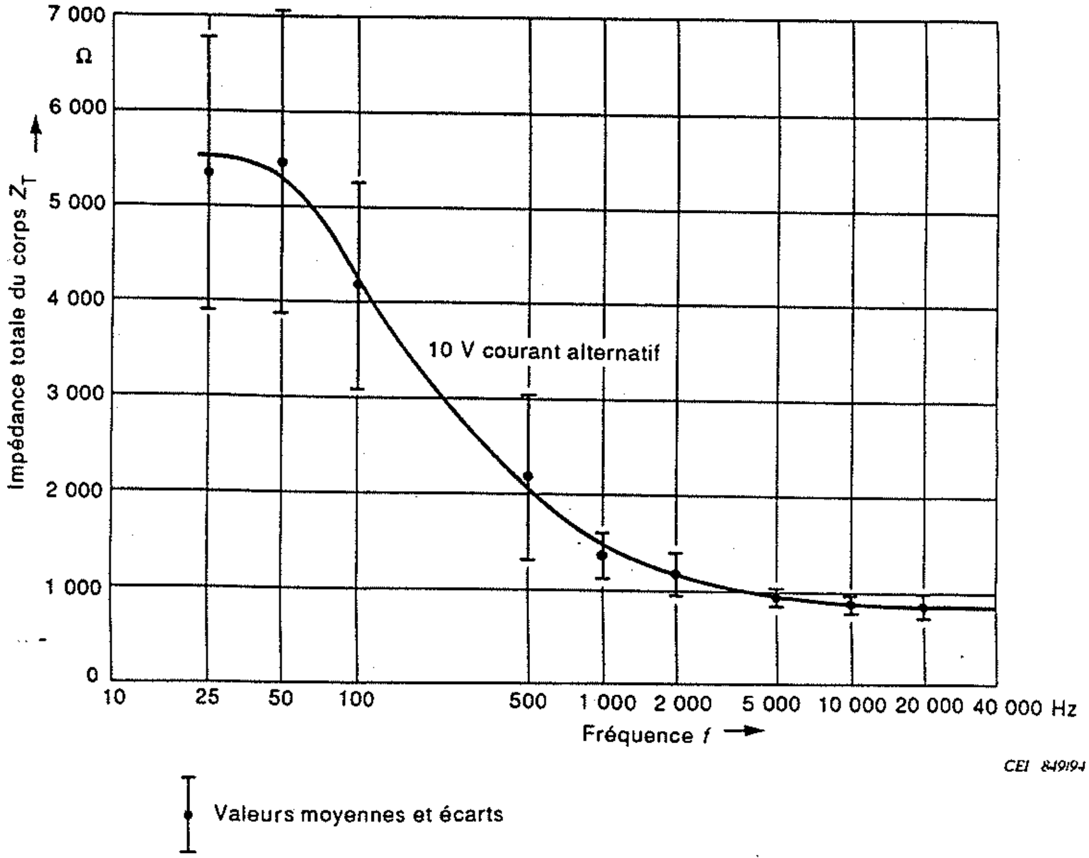


Figure 6 – Valeurs de l'impédance totale Z_T mesurée sur 10 sujets humains vivants, avec un trajet de courant main à main et d'importantes zones de contact pour une tension de contact de 10 V et des fréquences de 25 Hz à 20 kHz

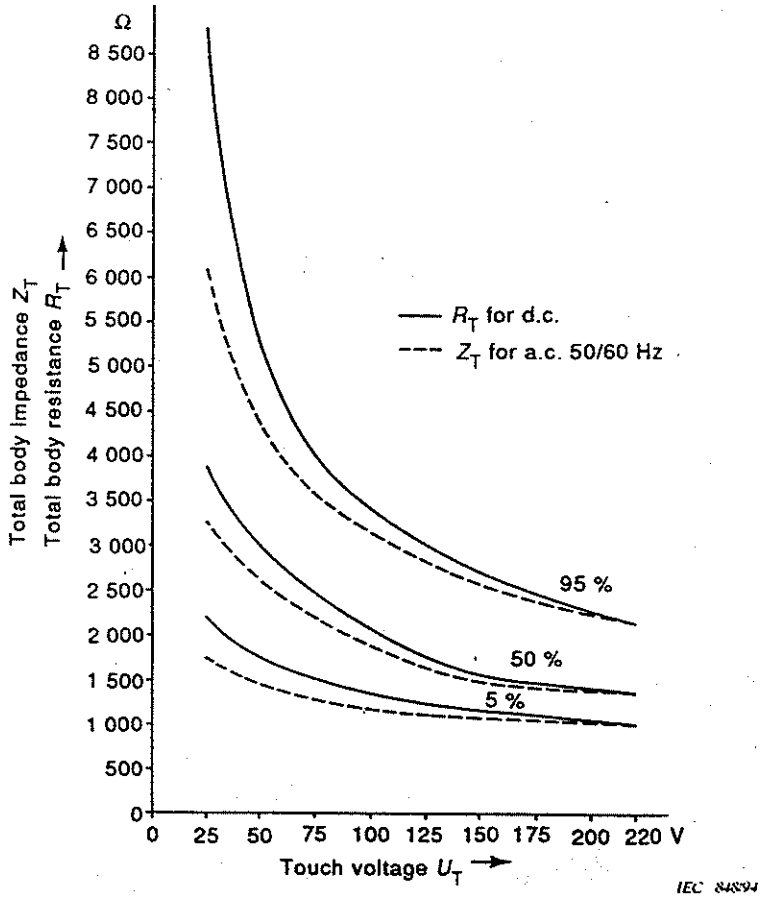


Figure 5 – Statistical values of total body impedances valid for living human beings for the current path hand to hand or hand to foot, for touch voltages up to 220 V, for a.c. 50/60 Hz and d.c.

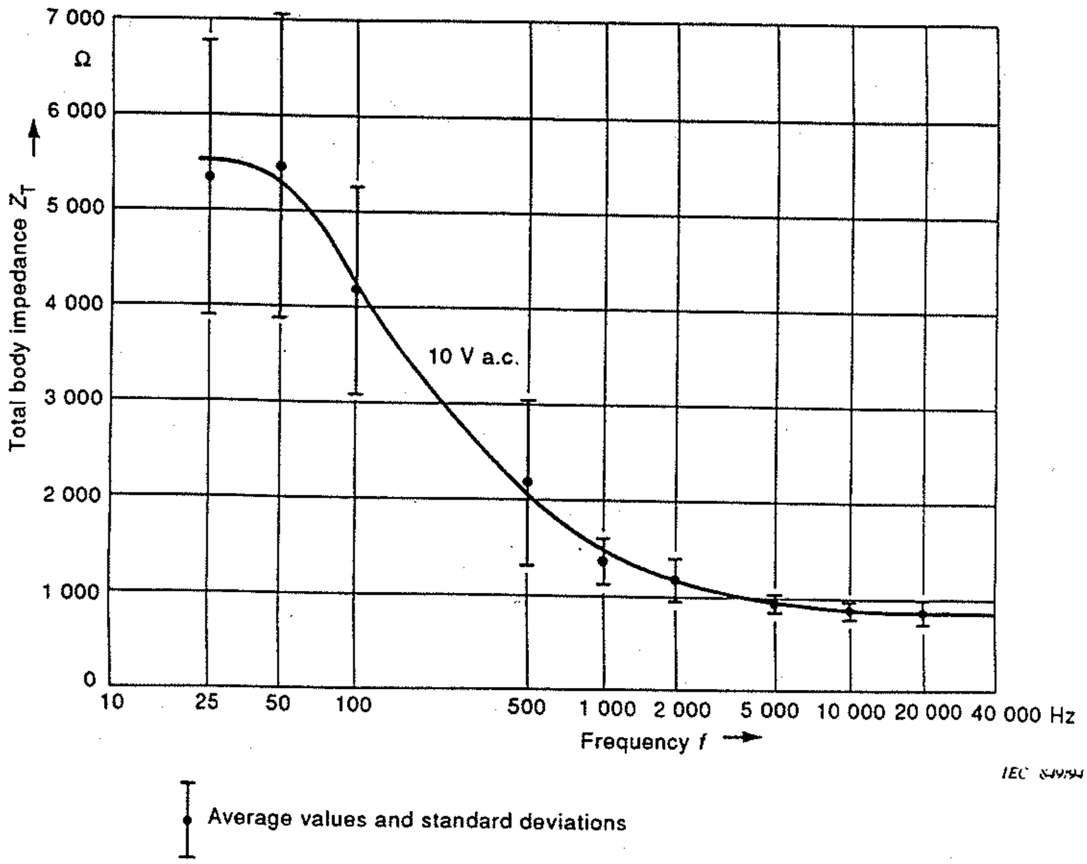


Figure 6 – Values of total body impedance Z_T measured on 10 living human beings with a current path hand to hand and large contact areas for a touch voltage of 10 V and frequencies from 25 Hz to 20 kHz

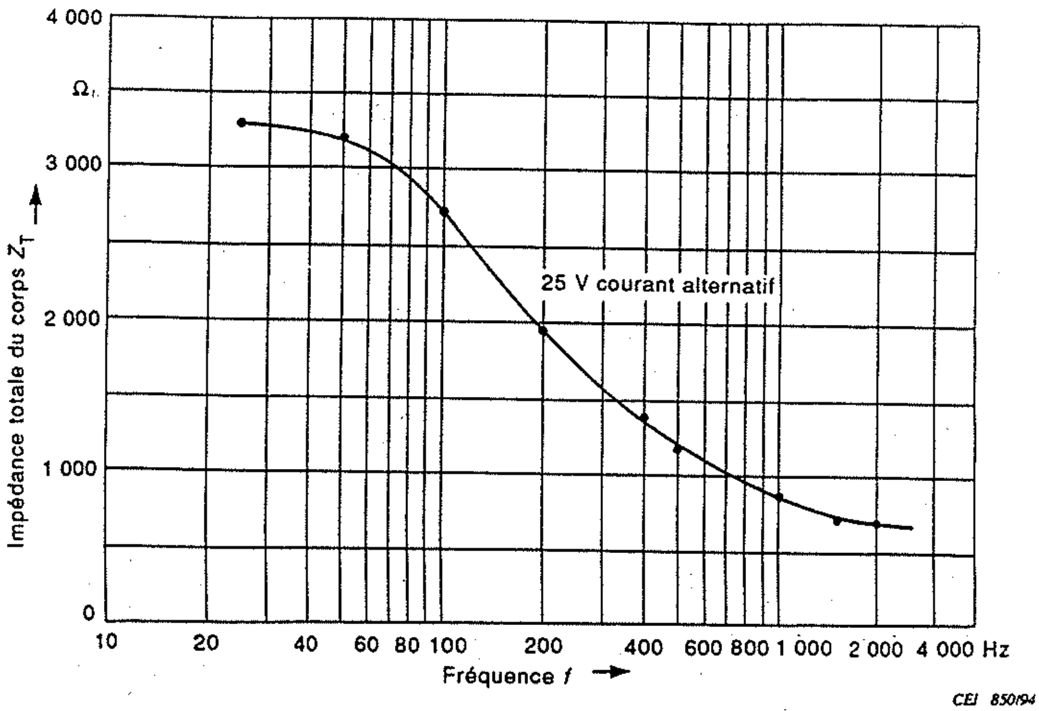


Figure 7 – Valeurs de l'impédance totale du corps Z_T mesurée sur un sujet humain vivant avec un trajet de courant main à main et d'importantes zones de contact pour une tension de contact de 25 V et des fréquences de 25 Hz à 2 kHz

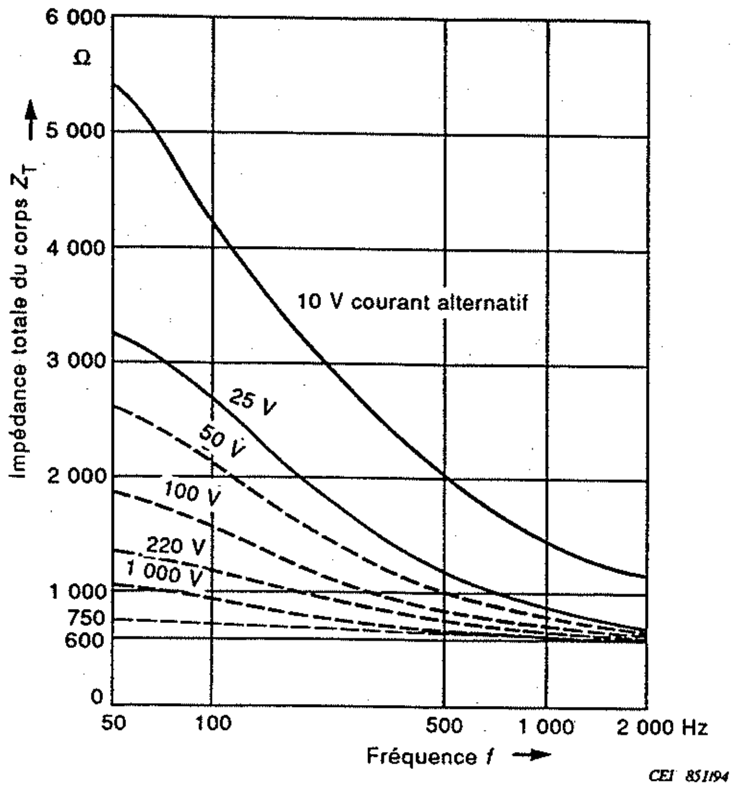


Figure 8 – Assujettissement en fréquence de l'impédance totale du corps humain Z_T d'une population de 50 % pour des tensions de contact de 10 V à 1 000 V et une plage de fréquences de 50 Hz à 2 kHz avec un trajet de courant main à main ou main à pied

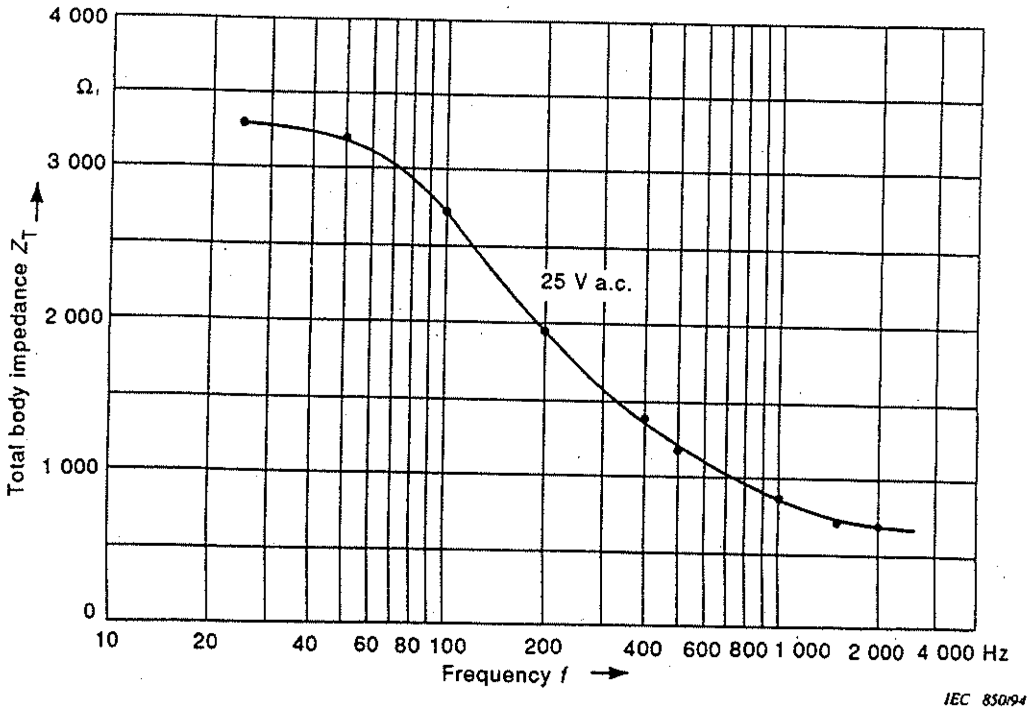


Figure 7 – Values of total body impedance Z_T measured on one living human being with a current path hand to hand and large contact areas for a touch voltage of 25 V and frequencies from 25 Hz to 2 kHz

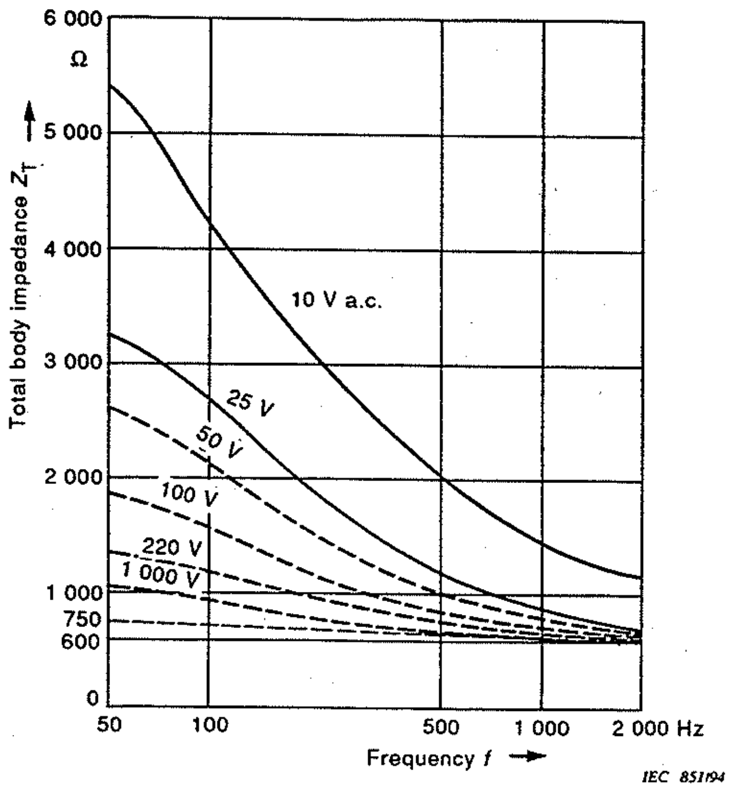


Figure 8 – Frequency dependence of the total body impedance Z_T of a population for a percentile rank of 50 % for touch voltages from 10 V to 1 000 V and a frequency range from 50 Hz to 2 kHz for a current path hand to hand or hand to foot

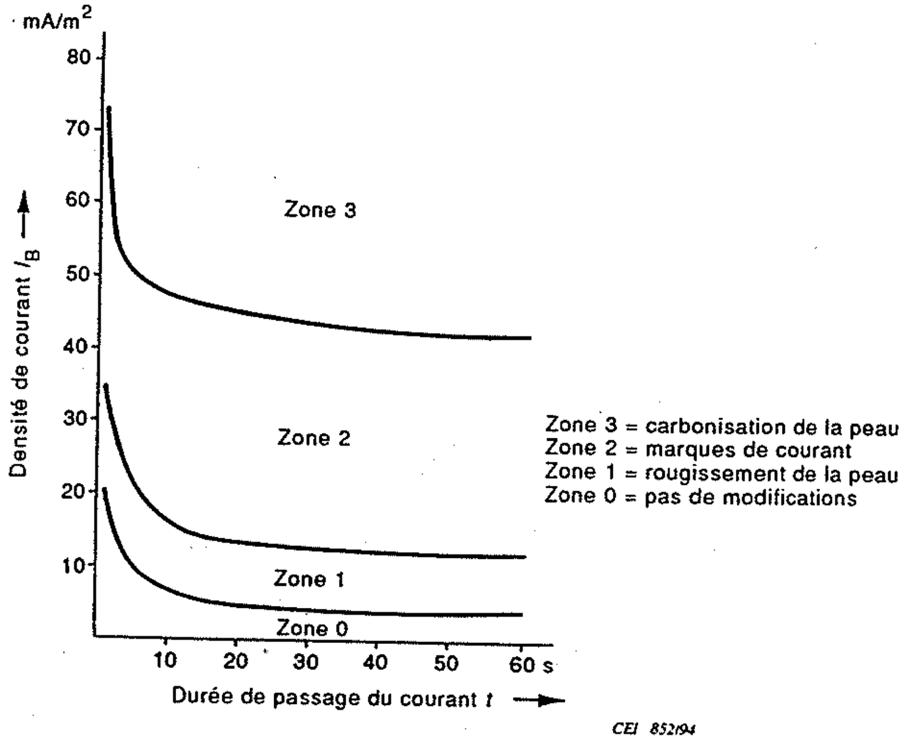


Figure 9 – Assujettissement des modifications de la peau humaine à la densité du courant et à la durée du passage du courant
(Pour une description détaillée des zones, voir 2.5.4)

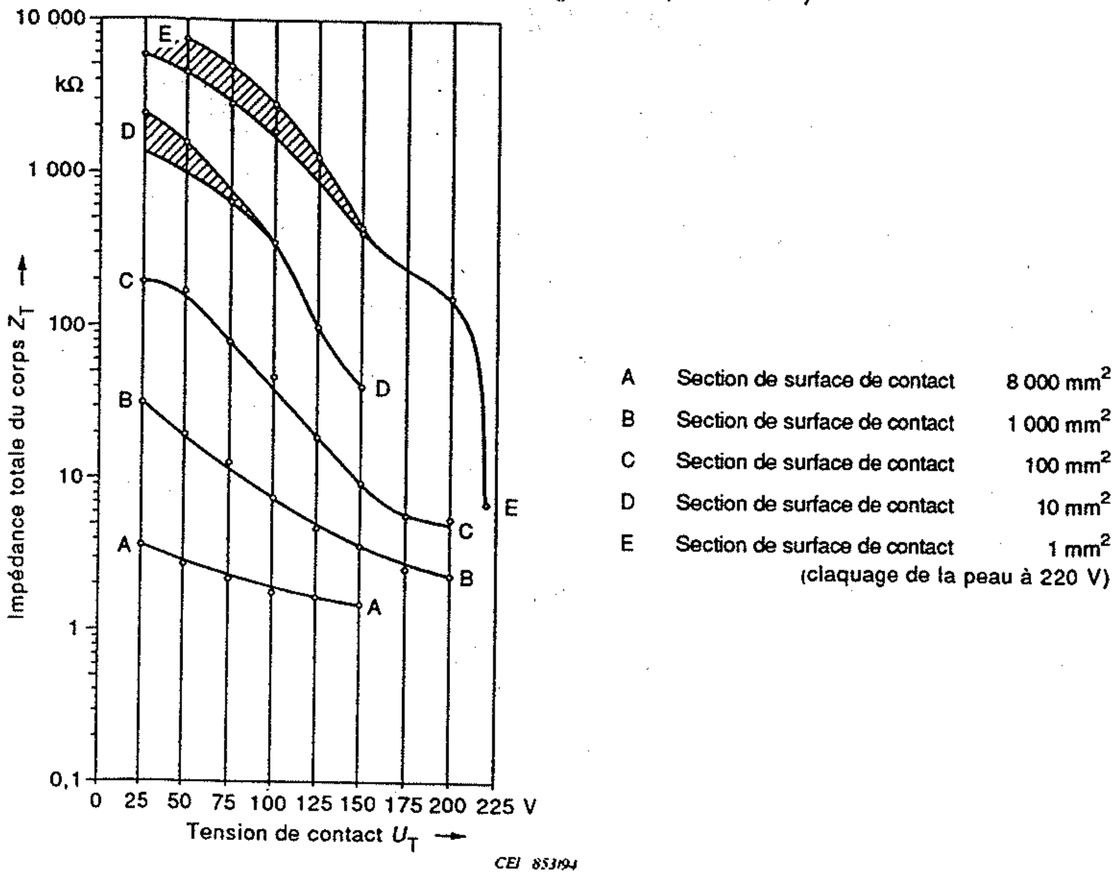


Figure 10 – Assujettissement de l'impédance totale du corps humain à la surface de contact et à la tension de contact (50 Hz)
(Pour plus de détails, voir annexe D)

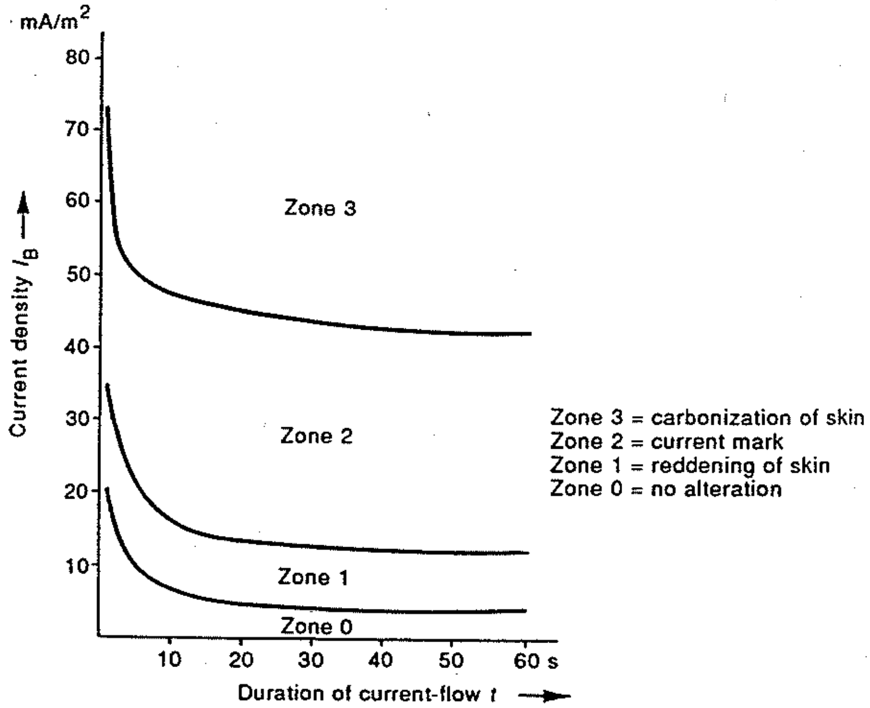


Figure 9 – Dependence of the alterations of the human skin on current density and duration of current flow
(For detailed description of zones, see 2.5.4)

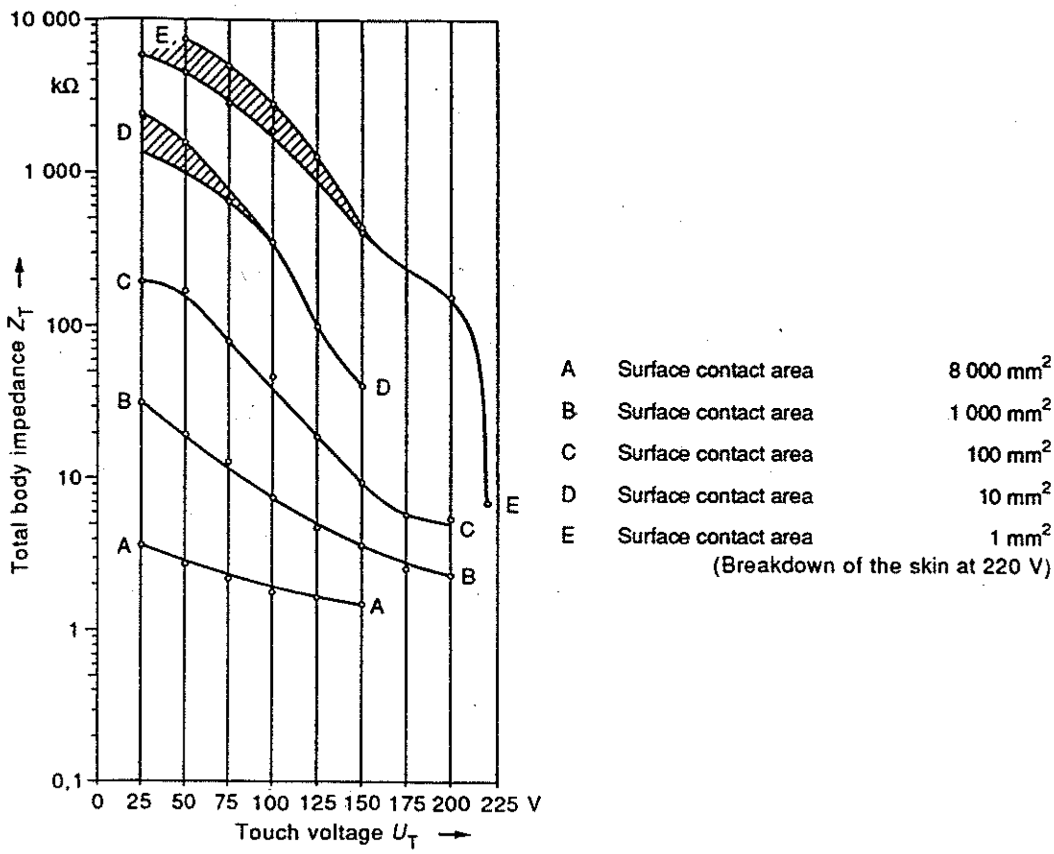
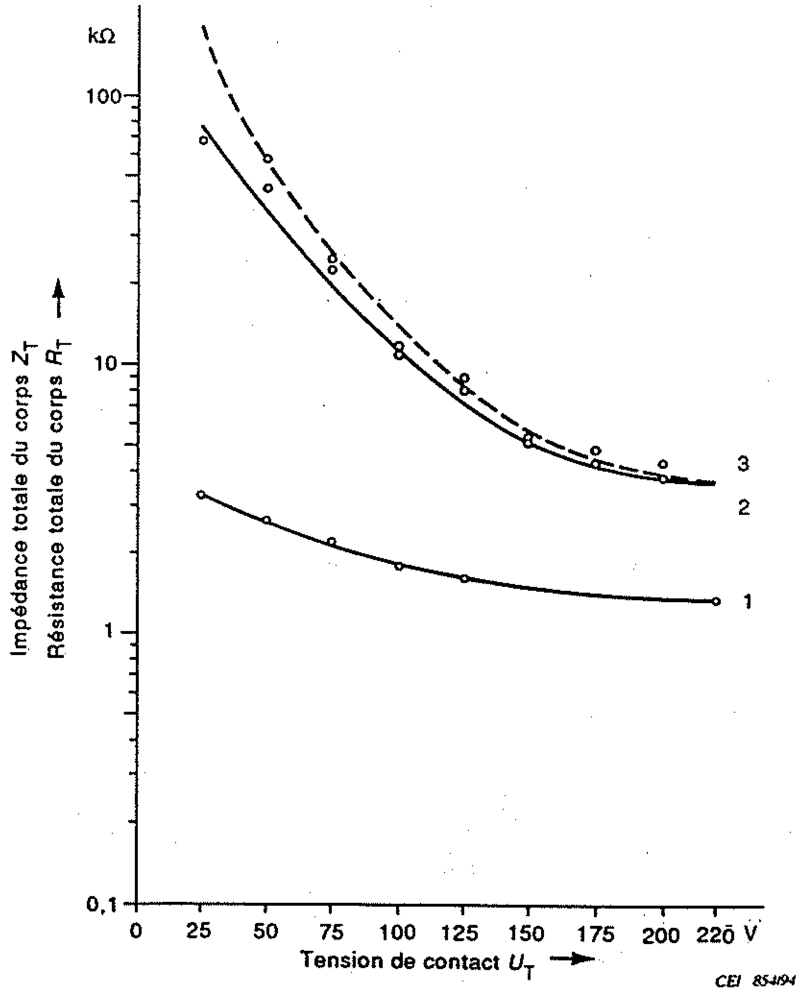


Figure 10 – Dependence of the total impedance of the human body on the surface area of contact and the touch voltage (50 Hz)
(For further details, see annex D)

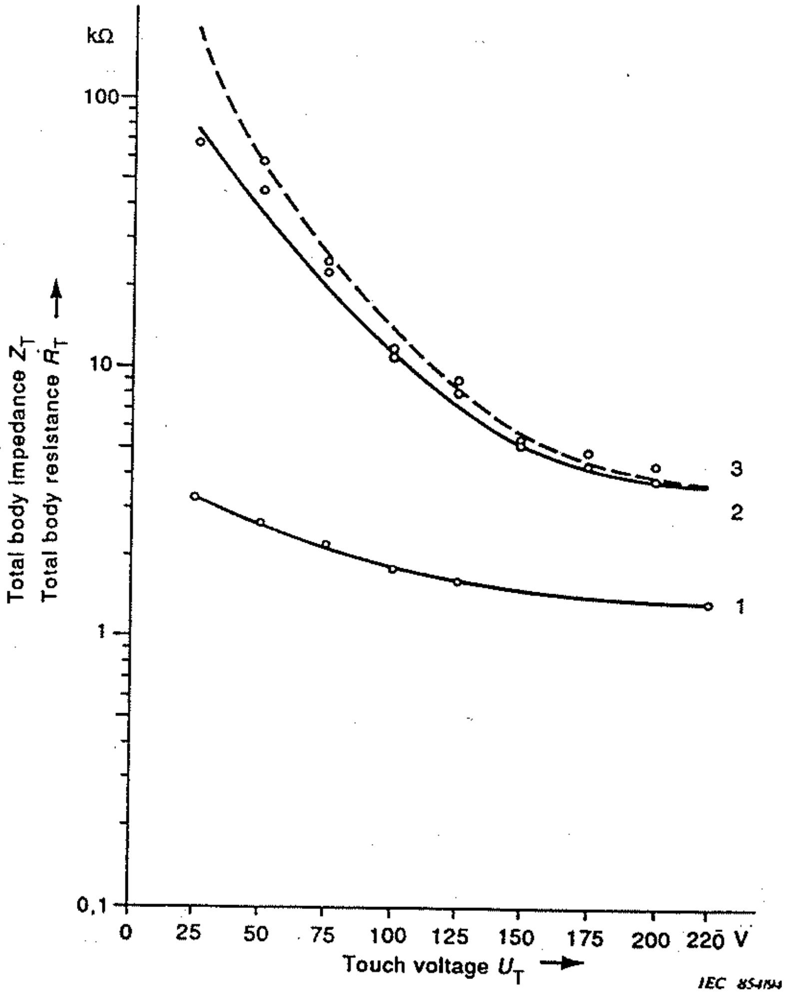


1 Impédance totale du corps humain pour un trajet de courant main à main conforme au tableau 1 en courant alternatif 50 Hz par une population de 50 % et d'importantes surfaces de contact (environ 8 000 mm^2) pour la durée du passage du courant, voir annexe A.

2 Impédance totale du corps humain pour un trajet de courant du bout de l'index droit à l'index gauche en courant alternatif 50 Hz. Durée de passage du courant 0,02 s.

3 Comme 2, mais en courant continu.

Figure 11 – Assujettissement de l'impédance totale du corps humain à la tension pour un trajet de courant entre index droit et gauche en courant alternatif 50 Hz et en courant continu pour des surfaces de contact d'environ 250 mm^2



1 Total impedance of the human body for a current path hand to hand according to table 1 for a.c. 50 Hz, for a percentage of 50 % of the population for large areas of contact (approximately 8 000 mm^2). For duration of current flow, see annex A.

2 Total impedance of the human body for a current path from the tips of the right to left forefinger for a.c. 50 Hz. Duration of current flow 0,02 s.

3 As 2, but for d.c.

Figure 11 – Dependence of the total impedance of the human body on the touch voltage for a current path from the tips of the right to the left forefinger for a.c. 50 Hz and d.c. for surface areas of contact of approximately 250 mm^2

3 Effets du courant alternatif de fréquence comprise entre 15 Hz et 100 Hz

Cet article décrit les effets du courant électrique passant par le corps humain pour les courants alternatifs de fréquence comprise entre 15 Hz et 100 Hz.

NOTE – A moins qu'il n'en soit spécifié autrement, les valeurs de courant définies ci-après sont des valeurs efficaces.

3.1 *Seuil de perception et seuil de réaction*

Ces seuils dépendent de plusieurs paramètres, tels que la surface du corps, le contact avec une électrode (surface de contact), les conditions de contact (sèches, humides, pression, température), ainsi que des caractéristiques physiologiques de l'individu.

Une valeur générale de 0,5 mA est prise en considération dans ce rapport technique, quel que soit le temps, pour le seuil de réaction.

3.2 *Seuil de non-lâcher*

Le seuil de non-lâcher dépend de plusieurs paramètres, tels que la surface de contact, la forme et les dimensions des électrodes ainsi que des caractéristiques physiologiques de la personne.

Une valeur d'environ 10 mA est prise en considération dans ce rapport technique.

3.3 *Seuil de fibrillation ventriculaire*

Le seuil de fibrillation ventriculaire dépend autant de paramètres physiologiques (anatomie du corps, état des fonctions cardiaques, etc.) que de paramètres électriques (durée et parcours du courant, paramètres du courant, etc.)

En courant alternatif (50 Hz ou 60 Hz), le seuil de fibrillation décroît considérablement si la durée de passage du courant est prolongée au-delà d'un cycle cardiaque. Cet effet résulte de l'augmentation de l'hétérogénéité de l'état d'excitation du coeur dû aux extrasystoles produites par le courant.

Pour des durées de choc inférieures à 0,1 s, la fibrillation peut se produire pour des courants d'intensité supérieure à 500 mA si le choc se produit pendant la période vulnérable. Pour des chocs de même intensité et de durée supérieure à un cycle cardiaque, un arrêt cardiaque réversible peut se produire.

En adaptant les résultats des expériences effectuées sur des animaux aux êtres humains, une courbe c_1 (voir figure 14) a été établie pour un trajet du courant allant de la main gauche aux deux pieds, en dessous de laquelle la fibrillation n'est pas susceptible de se produire. Le seuil élevé, pour de courtes durées d'exposition entre 10 ms et 100 ms, se situe sur une droite allant de 500 mA à 400 mA. Sur la base d'informations sur des accidents électriques, le seuil inférieur pour des durées supérieures à 1 s se situe sur une droite allant de 50 mA pour une seconde à 40 mA pour des durées supérieures à 3 s. Les deux seuils sont reliés par une courbe continue.

L'évaluation statistique des expériences effectuées sur des animaux a permis le tracé des courbes c_2 et c_3 (voir figure 14) définissant des probabilités respectives de fibrillation de 5 % et de 50 %. Les courbes c_1, c_2 et c_3 s'appliquent pour un trajet du courant allant de la main gauche aux deux pieds.

3 Effects of sinusoidal alternating current in the range of 15 Hz to 100 Hz

This clause describes the effects of sinusoidal alternating current passing through the human body within the frequency range 15 Hz to 100 Hz.

NOTE – Unless otherwise specified, the current values defined hereinafter are r.m.s. values.

3.1 *Threshold of perception and threshold of reaction*

The thresholds depend on several parameters, such as the area of the body in contact with an electrode (contact area), the conditions of contact (dry, wet, pressure, temperature), and also on physiological characteristics of the individual.

A general value of 0,5 mA, independent of time, is assumed in this technical report for the threshold of reaction.

3.2 *Threshold of let-go*

The threshold of let-go depends on several parameters, such as the contact area, the shape and size of the electrodes and also on the physiological characteristics of the individual.

An average value of about 10 mA is assumed in this technical report.

3.3 *Threshold of ventricular fibrillation*

The threshold of ventricular fibrillation depends on physiological parameters (anatomy of the body, state of cardiac function, etc.) as well as on electrical parameters (duration and pathway of current flow, current parameters, etc.).

With sinusoidal a.c. (50 Hz or 60 Hz) there is a considerable decrease of the threshold of fibrillation if the current flow is prolonged beyond one cardiac cycle. This effect results from the increase in inhomogeneity of the excitatory state of the heart due to the current-induced extrasystoles.

For shock durations below 0,1 s, fibrillation may occur for current magnitudes above 500 mA, and is likely to occur for current magnitudes in the order of several amperes, only if the shock falls within the vulnerable period. For shocks of such intensities and durations longer than one cardiac cycle reversible cardiac arrest may be caused.

In adapting the results from animal experiments to human beings, a curve c_1 (see figure 14) was conventionally established for a current path left hand to both feet, below which fibrillation is unlikely to occur. The high level for short durations of exposure between 10 ms and 100 ms was chosen as a descending line from 500 mA to 400 mA. On the basis of information on electrical accidents, the lower level for durations longer than 1 s was chosen as a descending line from 50 mA at 1 s to 40 mA for durations longer than 3 s. Both levels were connected by a smooth curve.

By statistical evaluation of animal experiments, curve c_2 and curve c_3 (see figure 14) have been established defining a probability of fibrillation of 5 % and 50 % respectively. Curves c_1, c_2 and c_3 apply for a current path left hand to both feet.

3.4 *Autres effets du courant*

La fibrillation ventriculaire est considérée comme la cause principale de mort par choc électrique. Il existe aussi des cas de mort par asphyxie ou arrêt du coeur.

Des effets pathophysiologiques tels que contractions musculaires, difficultés de respiration, augmentation de la pression sanguine, perturbations dans la formation et la propagation des impulsions dans le coeur y compris la fibrillation auriculaire et l'arrêt provisoire du coeur peuvent se produire sans fibrillation ventriculaire. De tels effets ne sont pas mortels et sont habituellement réversibles, mais des marques de courant peuvent se produire.

Pour des courants de plusieurs ampères, des brûlures profondes provoquant des dommages sérieux et même la mort peuvent se produire.

3.5 *Descriptions des zones temps/courant* (voir figure 14)

Tableau 4 – Zones temps/courant en tension alternative 15 Hz à 100 Hz

Désignation de la zone	Limites de la zone	Effets physiologiques
AC-1	Jusqu'à 0,5 mA ligne a	Habituellement aucune réaction.
AC-2	De 0,5 mA jusqu'à la ligne b *	Habituellement, aucun effet physiologique dangereux.
AC-3	De la ligne b jusqu'à la courbe c_1	Habituellement aucun dommage organique. Probabilité de contractions musculaires et de difficultés de respiration pour des durées de passage du courant supérieures à 2 s. Des perturbations réversibles dans la formation et la propagation des impulsions dans le coeur, y compris la fibrillation auriculaire et des arrêts temporaires du coeur sans fibrillation ventriculaire, augmentant avec l'intensité du courant et le temps.
AC-4	Au-dessus de la courbe c_1	Augmentant avec l'intensité et le temps, des effets pathophysiologiques tels qu'arrêt du coeur, arrêt de la respiration, brûlures graves peuvent se produire en complément avec les effets de la zone 3.
AC-4.1	c_1-c_2	Probabilité de fibrillation ventriculaire augmentant jusqu'à 5 %.
AC-4.2	c_2-c_3	Probabilité de fibrillation ventriculaire jusqu'à environ 50 %.
AC-4.3	Au-delà de la courbe c_3	Probabilité de fibrillation ventriculaire supérieur à 50 %.

* Pour des durées de passage de courant inférieures à 10 ms, la limite du courant traversant le corps pour la ligne b reste constante et égale à 200 mA.

3.6 *Application du facteur de courant de coeur (F)*

Le facteur de courant de coeur permet de calculer les courants I_h pour des parcours autres que main gauche aux pieds, qui représentent le même danger de fibrillation ventriculaire que ceux correspondant au courant de référence I_{ref} entre main gauche et les deux pieds, donné sur la figure 14:

$$I_h = \frac{I_{ref}}{F}$$

3.4 *Other effects of current*

Ventricular fibrillation is considered to be the main cause of death by electrical shock. There is also some evidence of death due to asphyxia or cardiac arrest.

Pathophysiological effects such as muscular contractions, difficulty in breathing, rise in blood pressure, disturbances of formation and conduction of impulses in the heart including atrial fibrillation and transient cardiac arrest may occur without ventricular fibrillation. Such effects are not lethal and usually reversible but current marks can occur.

With currents of several amperes lasting more than seconds, deep-seated burns or other serious injuries which can be internal, and even death, are likely to occur.

3.5 *Description of the time/current zones* (see figure 14)

Table 4 – Time/current zones for a.c. 15 Hz to 100 Hz

Zone designation	Zone limits	Physiological effects
AC-1	Up to 0,5 mA line a	Usually no reaction.
AC-2	0,5 mA up to line b *	Usually no harmful physiological effects.
AC-3	Line b up to curve c_1	Usually no organic damage to be expected. Likelihood of cramplike muscular contractions and difficulty in breathing for durations of current-flow longer than 2 s. Reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time.
AC-4	Above curve c_1	Increasing with magnitude and time, dangerous pathophysiological effects such as cardiac arrest, breathing arrest and severe burns may occur in addition to the effects of zone 3.
AC-4.1	c_1-c_2	Probability of ventricular fibrillation increasing up to about 5 %.
AC-4.2	c_2-c_3	Probability of ventricular fibrillation up to about 50 %.
AC-4.3	Beyond curve c_3	Probability of ventricular fibrillation above 50 %.

* For durations of current-flow below 10 ms, the limit for the body current for line b remains constant at a value of 200 mA.

3.6 *Application of heart-current factor (F)*

The heart-current factor permits the calculation of currents I_h through paths other than left hand to feet which represent the same danger of ventricular fibrillation as that corresponding to I_{ref} left hand to feet given in figure 14:

$$I_h = \frac{I_{ref}}{F}$$

où:

I_{ref} est le courant main gauche aux deux pieds donné sur la figure 14;

I_h est le courant passant par le corps pour les trajets indiqués dans le tableau 5;

F est le facteur de courant de coeur indiqué dans le tableau 5.

NOTE – Le facteur de courant de coeur est à considérer comme une estimation approximative des dangers correspondant aux différents trajets du courant du point de vue de la fibrillation ventriculaire.

Pour les différents trajets du courant, le facteur de courant de coeur a la valeur indiquée dans le tableau 5.

Tableau 5 – Facteur de courant de coeur *F* pour différents trajets du courant

Trajet de courant	Facteur de courant de coeur *F*
Main gauche au pied gauche, au pied droit ou aux deux pieds	1,0
Deux mains aux deux pieds	1,0
Main gauche à la main droite	0,4
Main droite au pied gauche, au pied droit ou aux deux pieds	0,8
Dos à la main droite	0,3
Dos à la main gauche	0,7
Poitrine à la main droite	1,3
Poitrine à la main gauche	1,5
Siège à la main gauche, à la main droite ou aux deux mains	0,7

EXEMPLE: Un courant de 200 mA main à main a le même effet qu'un courant de 80 mA main gauche aux deux pieds.

where:

I_{ref} is the body current for the path left hand to feet given in figure 14;

I_h is the body current for paths given in table 5;

F is the heart-current factor given in table 5.

NOTE – The heart-current factor is to be considered as only a rough estimation of the relative danger of the various current paths with regard to ventricular fibrillation.

For the different current paths, the following heart-current factors are given in table 5.

Table 5 – Heart-current factor *F* for different current paths

Current path	Heart-current factor *F*
Left hand to left foot, right foot or both feet	1,0
Both hands to both feet	1,0
Left hand to right hand	0,4
Right hand to left foot, right foot or to both feet	0,8
Back to right hand	0,3
Back to left hand	0,7
Chest to right hand	1,3
Chest to left hand	1,5
Seat to left hand, right hand or to both hands	0,7

EXAMPLE: A current of 200 mA hand to hand has the same likelihood of producing ventricular fibrillation as a current of 80 mA left hand to both feet.

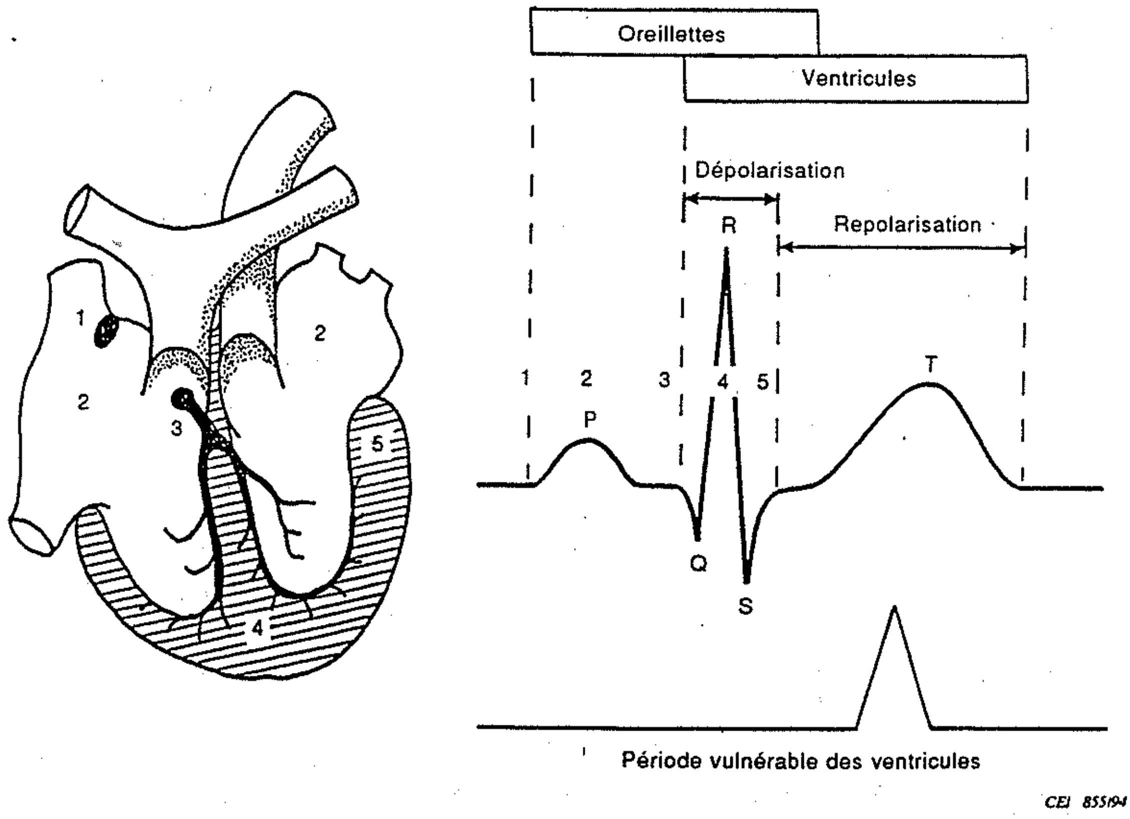


Figure 12 – Situation de la période vulnérable des ventricules pendant le cycle cardiaque. Les chiffres caractérisent les étapes consécutives de la repolarisation

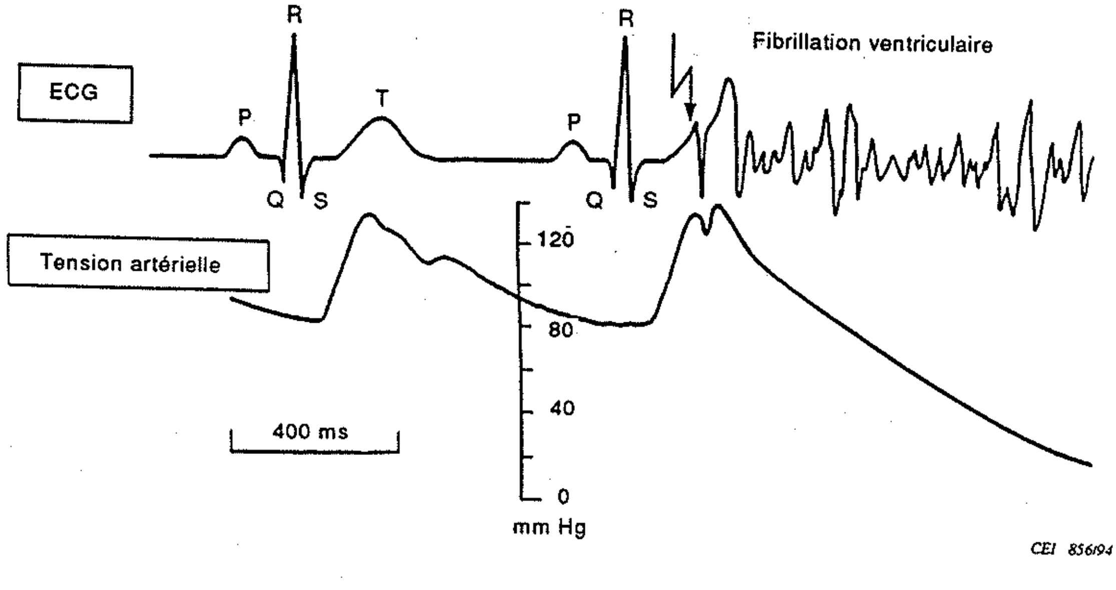


Figure 13 – Déclenchement de la fibrillation ventriculaire dans la période vulnérable. Effets sur l'électrocardiogramme (ECG) et la tension artérielle

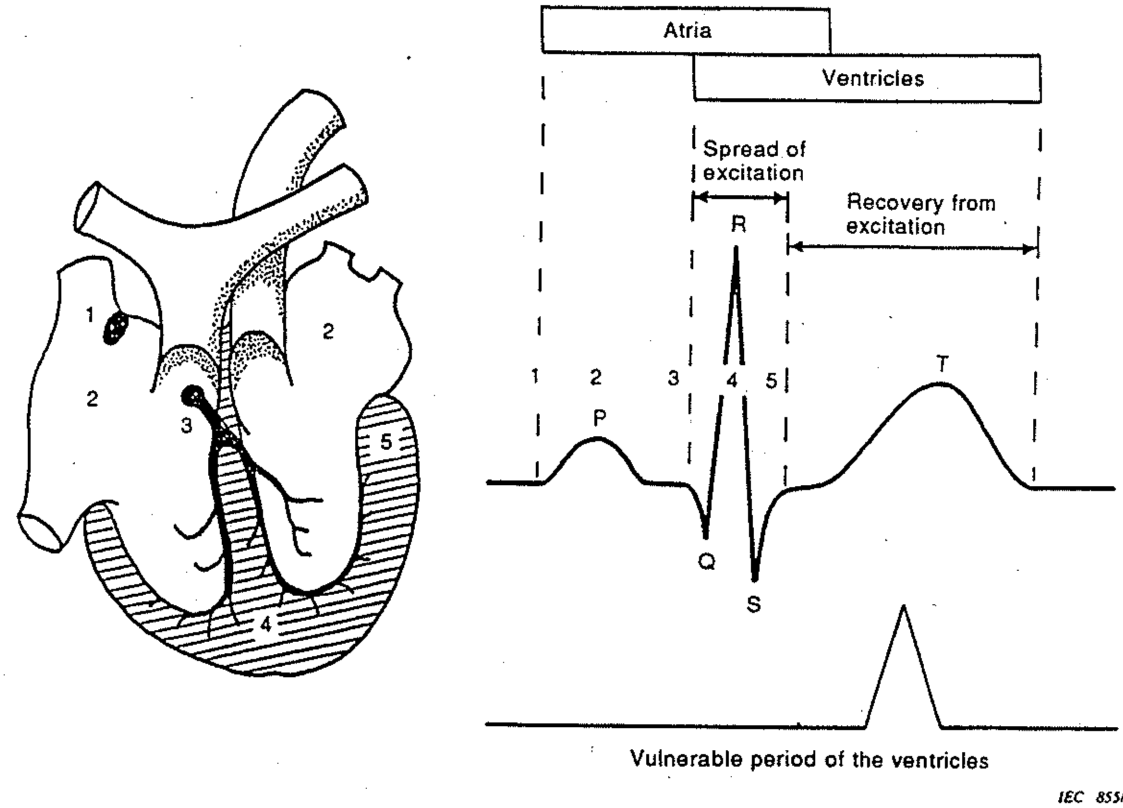


Figure 12 – Occurrence of the vulnerable period of ventricles during the cardiac cycle. The numbers designate the subsequent stages of propagation of the excitation

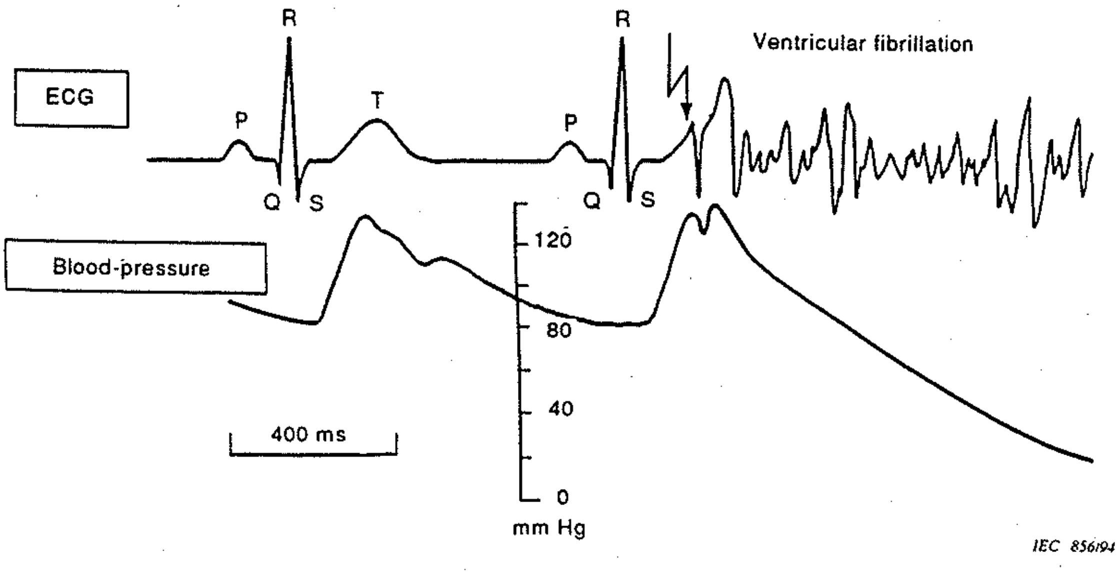
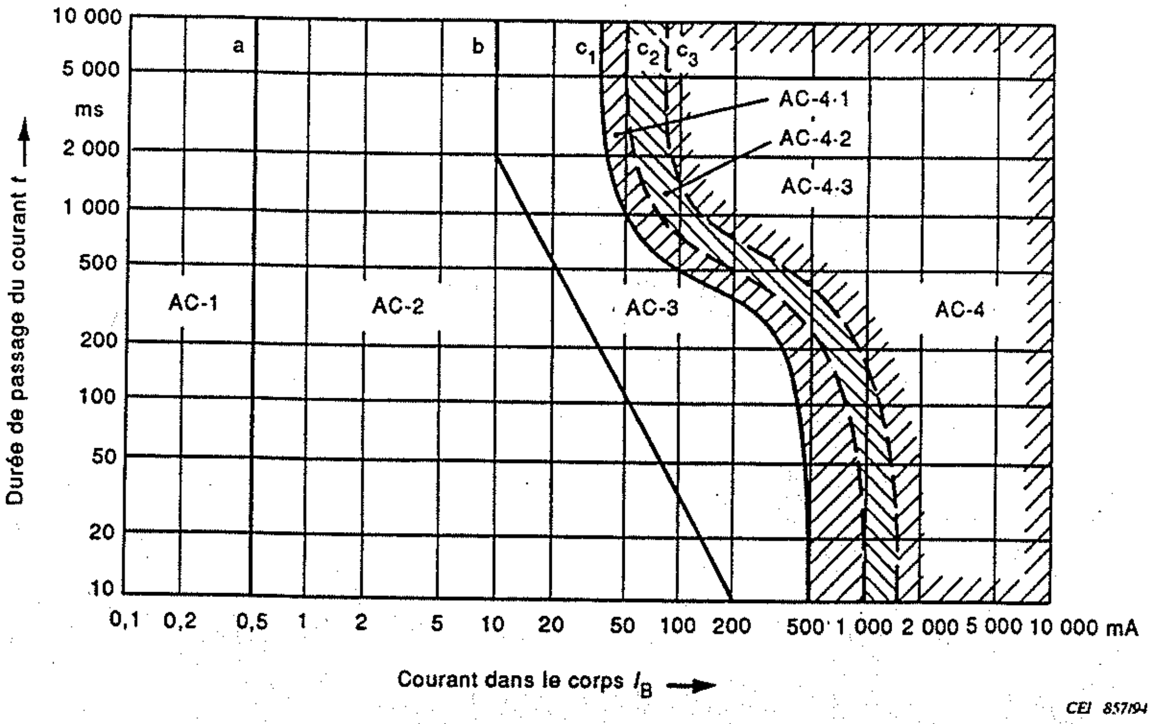
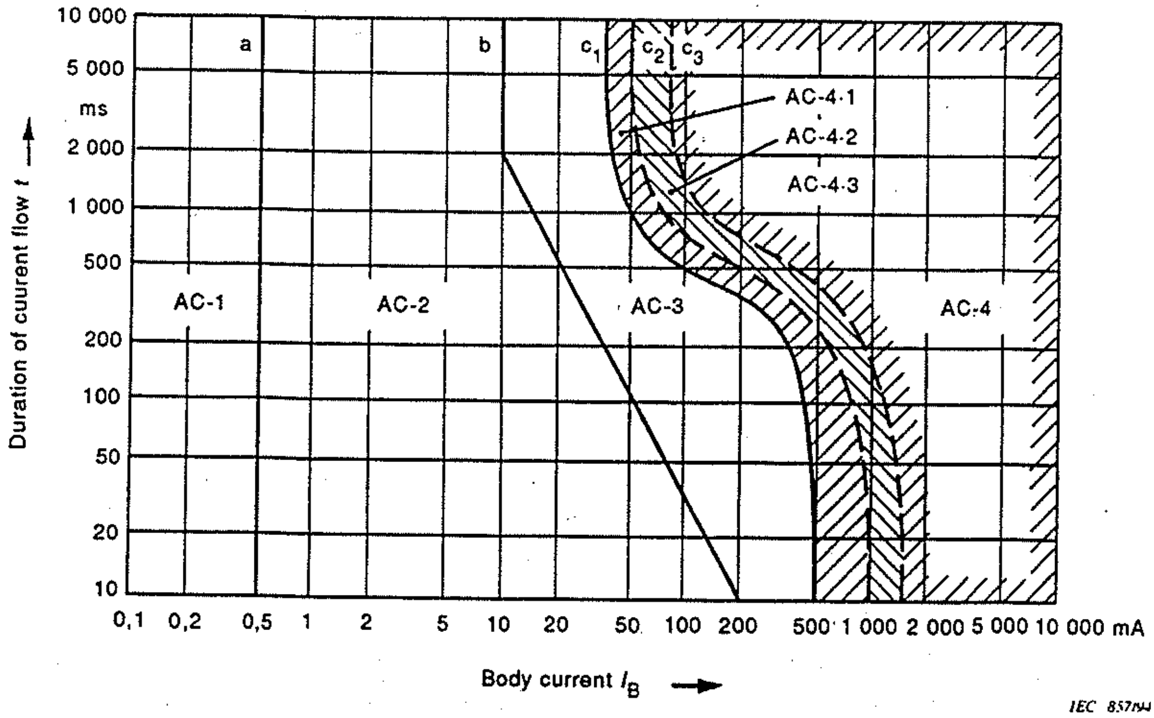


Figure 13 – Triggering of ventricular fibrillation in the vulnerable period. Effects on electrocardiogram (ECG) and blood-pressure



NOTE – En ce qui concerne la fibrillation ventriculaire, cette figure se rapporte aux effets du courant passant de la main gauche aux deux pieds. Pour d'autres parcours de courant, voir 3.6 et tableau 5. Les valeurs de seuil pour une durée de passage du courant inférieur à 0,2 s ne sont applicables qu'au passage du courant pendant la période vulnérable du cycle cardiaque.

Figure 14 – Zones temps/courant des effets des courants en tension alternative 15 Hz à 100 Hz
(Pour explications voir tableau 4)



NOTE – As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to both feet. For other current paths, see 3.6 and table 5. The threshold values for durations of current flow below 0,2 s apply only to current flowing during the vulnerable period of the cardiac cycle.

Figure 14 – Time/current zones of effects of a.c. currents 15 Hz to 100 Hz
(For explanations, see table 4)

4 Effets du courant continu

Cet article décrit les effets du courant continu passant à travers le corps humain.

NOTES

1 Le terme «courant continu» signifie un courant continu lisse. Toutefois, en ce qui concerne les effets de la fibrillation, les valeurs indiquées dans ce chapitre sont considérées comme sûres pour des courants continus dont le taux d'ondulation sinusoïdal n'est pas supérieur à 10 % en valeur efficace.

2 L'influence des ondulations est traitée dans le chapitre 5 de la CEI 479-2.

4.1 *Seuil de perception et seuil de réaction*

Les seuils dépendent de plusieurs paramètres tels que la surface de contact, les conditions de contact (sécheresse, humidité, pression, température), la durée de passage du courant ainsi que des caractéristiques physiologiques de l'individu. A la différence du courant alternatif, seuls l'établissement et l'interruption du courant sont perçus et aucune autre sensation n'est ressentie pendant le passage du courant au niveau du seuil de perception. Dans des conditions semblables à celles qui sont définies pour le courant alternatif, le seuil de perception est d'environ 2 mA.

4.2 *Seuil de non-lâcher*

A la différence du courant alternatif, il n'est pas possible de définir un seuil de non-lâcher en courant continu. Seuls l'établissement et l'interruption du courant provoquent des douleurs et des contractions musculaires.

4.3 *Seuil de fibrillation ventriculaire*

Comme il est décrit pour le courant alternatif (voir 3.3), le seuil de fibrillation ventriculaire produit par le courant continu dépend aussi bien de conditions physiologiques que de paramètres électriques.

L'information issue d'accidents électriques semble indiquer que le danger de fibrillation ventriculaire n'existe que pour les courants longitudinaux. Pour les courants transversaux l'expérimentation sur des animaux a montré que la fibrillation ventriculaire peut apparaître pour des intensités plus élevées.

Des expériences effectuées sur des animaux et des informations provenant d'accidents électriques montrent que le seuil de fibrillation ventriculaire pour un courant descendant est environ deux fois plus grand que pour un courant montant.

Pour des durées de choc supérieures à la durée du cycle cardiaque, le seuil de fibrillation en courant continu est plusieurs fois plus grand qu'en courant alternatif. Pour des durées de choc inférieures à 200 ms, le seuil de fibrillation est approximativement le même qu'en courant alternatif exprimé en valeur efficace.

Par analogie avec les zones temps/courant en courant alternatif (voir figure 14) des courbes ont été établies par adaptation des résultats obtenus sur des sujets humains. Elles sont valables pour un courant longitudinal montant. Sous la courbe c_1 (voir figure 15), la fibrillation n'est pas susceptible de se produire. Les courbes c_2 et c_3 (voir figure 15) définissent respectivement une probabilité de fibrillation de 5 % et de 50 %. Pour un courant longitudinal descendant, les courbes doivent être décalées vers des courants plus élevés par un facteur d'environ 2.

4 Effects of direct current

This clause describes the effects of direct current passing through the human body.

NOTES

1 The term "direct current" means ripple-free direct current. However, as regards fibrillation effects, the data given in this chapter are considered to be conservative for direct currents having a sinusoidal ripple content of not more than 10 % r.m.s.

2 The influence of ripple is dealt with in chapter 5 of IEC 479-2.

4.1 *Threshold of perception and threshold of reaction*

The thresholds depend on several parameters, such as the contact area, the conditions of contact (dryness, wetness, pressure, temperature), the duration of current flow and on the physiological characteristics of the individual. Unlike a.c., only making and breaking of current is felt and no other sensation is noticed during the current flow at the level of the threshold of perception. Under conditions comparable to those applied in studies with a.c., the threshold of reaction was found to be about 2 mA.

4.2 *Threshold of let-go*

Unlike a.c. there is no definable threshold of let-go for d.c. Only the making and breaking of current lead to painful and cramp-like contractions of the muscles.

4.3 *Threshold of ventricular fibrillation*

As described for a.c. (see 3.3), the threshold of ventricular fibrillation induced by d.c. depends on physiological as well as on electrical parameters.

Information derived from electrical accidents seems to indicate that the danger of ventricular fibrillation generally exists for longitudinal currents. For transverse currents, experiments on animals have, however, shown that at higher current intensities ventricular fibrillation may also occur.

Experiments on animals as well as information derived from electrical accidents show that the threshold of fibrillation for a downward current is about twice as high as for an upward current.

For shock durations longer than the cardiac cycle, the threshold of fibrillation for d.c. is several times higher than for a.c. For shock durations shorter than 200 ms, the threshold of fibrillation is approximately the same as for a.c. measured in r.m.s. values.

In comparison with the time/current zones for a.c. (see figure 14), curves have been constructed by adapting the results obtained from animal experiments to human beings. They apply to a longitudinal upward current. Below curve c_1 (see figure 15) fibrillation is unlikely to occur. Curve c_2 and curve c_3 (see figure 15) define a probability of fibrillation of 5 % and 50 % respectively. For a longitudinal downward current the curves have to be shifted to a higher current magnitude by a factor of about two.

4.4 *Autres effets du courant*

Au-dessus de 100 mA environ, une sensation de chaleur peut être ressentie dans les extrémités pendant le passage du courant. A l'intérieur de la zone de contact, des sensations douloureuses sont ressenties dans la peau.

Les courants transversaux d'intensité au plus égale à 300 mA passant à travers le corps humain pendant plusieurs minutes peuvent provoquer des arythmies cardiaques réversibles, des marques de courant, des brûlures, des vertiges et parfois l'inconscience. Au-dessus de 300 mA, l'inconscience se produit fréquemment.

Pour des courants de plusieurs ampères pendant plusieurs secondes des brûlures profondes, des blessures et même la mort sont susceptibles de se produire.

4.5 *Descriptions des zones temps/courant* (voir figure 15)

Tableau 6 – Zones temps/courant en courant continu

Désignation de la zone	Limites de la zone	Effets physiologiques
DC-1	Jusqu'à 2 mA ligne a	Habituellement pas d'effets de réaction. Légère sensation de picotement à l'établissement et à l'interruption du courant
DC-2	De 2 mA jusqu'à la ligne b *	Habituellement, pas d'effets physiologiques nocifs
DC-3	De la ligne b jusqu'à la courbe c_1	Habituellement pas de dégât organique. L'accroissement du courant et du temps est susceptible de provoquer des perturbations réversibles de formation et de conduction des impulsions dans le coeur
DC-4	Au-dessus de la courbe c_1	L'accroissement du courant et du temps provoque des effets patho-physiologiques dangereux, par exemple, des brûlures profondes surviennent en complément avec les effets de la zone 3
DC-4.1	c_1-c_2	Probabilité de fibrillation ventriculaire augmentant jusqu'à 5 %
DC-4.2	c_2-c_3	Probabilité de fibrillation ventriculaire augmentant jusqu'à 50 %
DC-4.3	Au-delà de la courbe c_3	Probabilité de fibrillation ventriculaire au-dessus de 50 %

* Pour des durées de passage de courant inférieures à 10 ms, la limite pour le courant passant à travers le corps pour la ligne b reste constante à une valeur égale à 200 mA.

4.4 *Other effects of current*

Above approximately 100 mA, a sensation of warmth may be felt in the extremities during the flow of the current. Within the contact area, painful sensations are felt in the skin.

Transverse currents up to 300 mA flowing through the human body for several minutes might, increasing with time and current, cause reversible cardiac dysrhythmias, current marks, burns, dizziness and sometimes unconsciousness. Above 300 mA, unconsciousness frequently occurs.

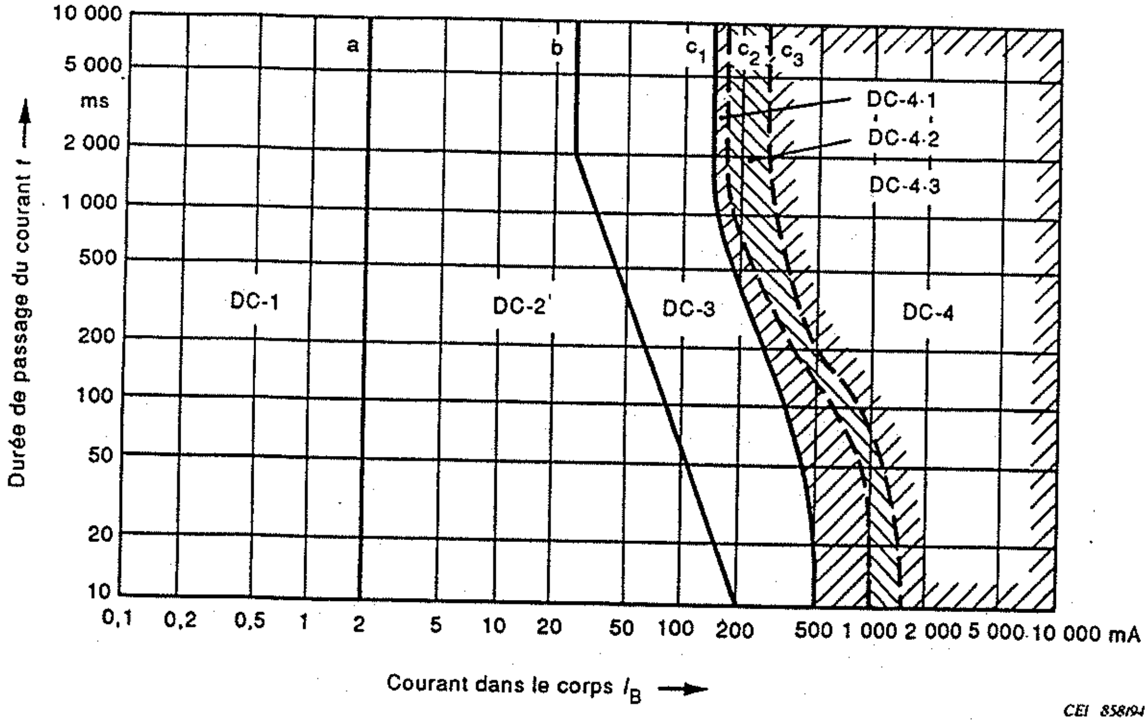
With currents of several amperes lasting more than seconds, deep-seated burns or other injuries, and even death, are likely to occur.

4.5 *Description of the time/current zones* (see figure 15)

Table 6 – Time/current zones for d.c.

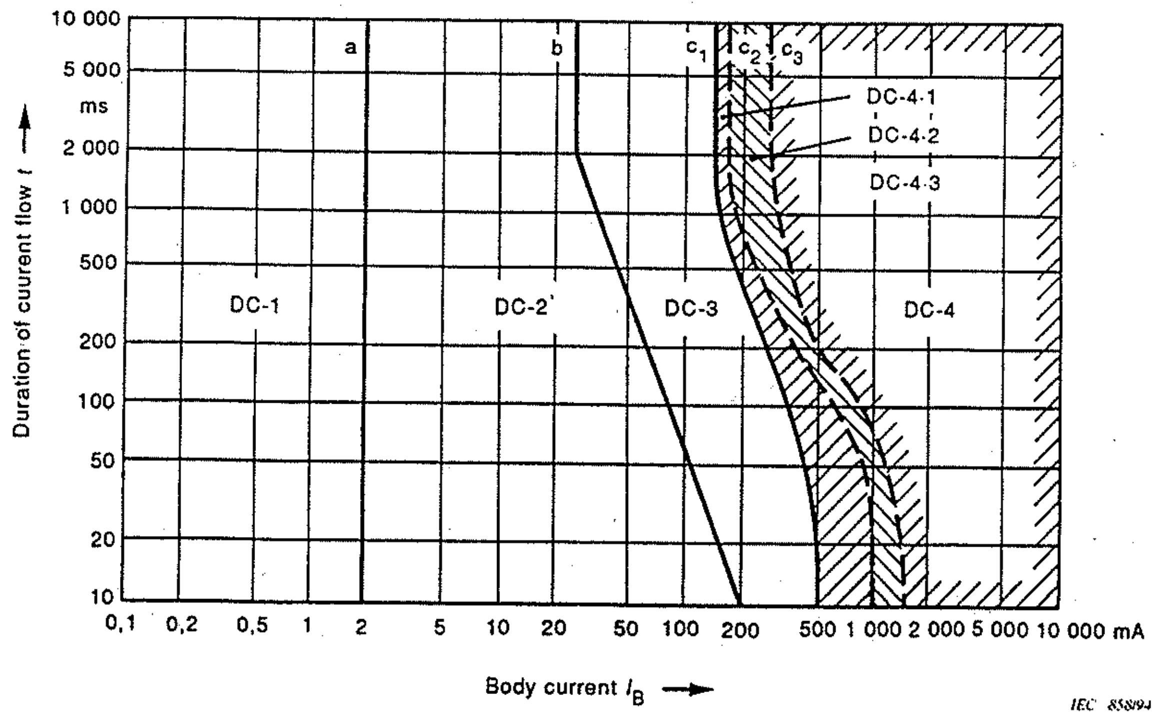
Zone designation	Zone limits	Physiological effects
DC-1	Up to 2 mA line a	Usually no reaction Slight pricking pain when switching on or off
DC-2	2 mA up to line b *	Usually no harmful physiological effects
DC-3	Line b up to curve c_1	Usually no organic damage to be expected. Increasing with current magnitude and time, reversible disturbances of formation and conduction of impulses in the heart may occur
DC-4	Above curve c_1	Increasing with current magnitude and time, dangerous pathophysiological effects, for example severe burns, are to be expected in addition to the effects of zone 3
DC-4.1	c_1-c_2	Probability of ventricular fibrillation increasing up to about 5 %
DC-4.2	c_2-c_3	Probability of ventricular fibrillation up to about 50 %
DC-4.3	Beyond curve c_3	Probability of ventricular fibrillation above 50 %

* For durations of current flow below 10 ms, the limit for the body current for line b remains constant at a value of 200 mA.



NOTE – Concernant la fibrillation ventriculaire, cette figure est relative aux effets d'un courant longitudinal avec un trajet main gauche aux deux pieds et pour un courant montant. Les valeurs de seuil pour une durée de passage du courant inférieur à 0,2 s ne sont applicables qu'au passage du courant pendant la période vulnérable du cycle cardiaque.

Figure 15 – Zone temps/courant des effets en courant continu
(Pour explications voir tableau 6)



NOTE – As regards ventricular fibrillation, this figure relates to the effects of a longitudinal current which flows in the path left hand to both feet and for upward current. The threshold values for durations of current flow below 0,2 s apply only to current flowing during the vulnerable period of the cardiac cycle.

Figure 15 – Time/current zones of effects of d.c. currents
(For explanations, see table 6)

Annexes

Introduction

Le chapitre 1 de la CEI 479 (2e édition, 1984) relatif à l'impédance électrique du corps humain ne contenait pas d'information sur l'impédance en courant alternatif à hautes fréquences, ni en courant continu. L'assujettissement de l'impédance à la zone de surface de contact n'était pas connue.

Tant que l'impédance interne était en cause, des données supplémentaires étaient recherchées pour les divers trajets dans le corps humain afin d'être capable de calculer les impédances pour des trajets de courant particuliers (par exemple, de l'avant-bras au tronc du corps) pouvant se produire lors d'accidents électriques.

D'autre part, un diagramme simple de l'impédance interne du corps humain est nécessaire et permet des estimations pour des accidents fréquents avec divers trajets de courant, par exemple des deux mains au tronc du corps.

Le chapitre 1 a donc été revu et l'information nécessaire a été ajoutée en divisant l'article 2.5. (Valeurs de l'impédance totale du corps (Z_T)) en:

2.5.1 Courant alternatif sinusoïdal 50/60 Hz

2.5.2 Courant alternatif sinusoïdal jusqu'à des fréquences de 20 kHz

2.5.3 Courant continu

2.5.4 Effets du courant sur la peau

2.7 Sujétion des impédances du corps à la surface de contact en courant alternatif 50/60 Hz et en courant continu.

Les mesures à diverses fréquences se sont avérées difficiles. En raison du décroissement rapide de l'impédance totale du corps même à 25 V à des fréquences supérieures à 500 Hz, les sensations sont désagréables et même à 25 V, très peu de sujets ont été testés jusqu'à 20 kHz. Cinquante sujets ont été testés à une tension de contact de 10 V avec des fréquences jusqu'à 20 kHz ainsi qu'en courant continu avec une tension de contact de 25 V.

En raison des sensations désagréables et du danger possible inhérent aux expérimentations, des mesures ont été réalisées sur un seul adulte avec des surfaces de contact importantes main à main et en courant continu jusqu'à 200 V. Le même sujet a été testé avec diverses zones de surface de contact main à main et entre bouts des doigts en courant alternatif 50 Hz jusqu'à 200 V.

Les séries de mesures entre bouts des doigts (index droit et gauche) et entre pouces droit et gauche ont été répétées en courant continu jusqu'à 200 V. Ces mesures prouvent qu'au-dessus d'environ 150 V, les impédances totales du corps en courant alternatif 50 Hz diffèrent de manière peu significative de la résistance totale du corps en courant continu.

Toutes les mesures sont brièvement décrites dans les annexes.

Annexes

Introduction

Chapter 1 of IEC 479 (2nd edition 1984) on the electrical impedance of the human body contained neither information on the impedance for alternating current of higher frequencies nor for direct current. Also the dependence of the impedance on the surface area of contact was not known.

As far as the internal impedance was concerned, more data was wanted for the various paths of the human body in order to be able to calculate impedances for special current paths (e.g. from the upper arm to the trunk of the body) which occasionally do occur in electrical accidents.

On the other hand, a simple diagram for the internal impedance of the human body is needed which allows estimations for frequently occurring accidents with various current paths, for example, both hands to the trunk of the body.

Chapter 1 had therefore to be rewritten and the required information was added by subdividing clause 2.5. (Values of the total impedance of the human body (Z_T)) as follows:

2.5.1 Sinusoidal alternating current 50/60 Hz

2.5.2 Sinusoidal alternating current with frequencies up to 20 kHz

2.5.3 Direct current

2.5.4 Effect of current on the skin

2.7 Dependence of the body impedance on the surface area of contact for a.c. 50/60 Hz and for d.c.

The measurements with various frequencies proved to be difficult. Due to the rapidly decreasing total body impedance, even at 25 V with frequencies above 500 Hz, the sensations are unpleasant and so at 25 V only a few persons have been measured up to 20 kHz. Fifty persons have been measured at a touch voltage of 10 V with frequencies up to 20 kHz and also with direct current of 25 V.

Due to the unpleasant sensations and the possibly inherent danger within the experiments, measurements have only been carried out with one adult using large contact areas hand to hand and d.c. up to 200 V. With the same person, measurements with various surface areas of contact hand to hand and between fingertips were also made with a.c. 50 Hz up to 200 V.

The series of measurements between fingertips (right and left forefingers) and between the balls of the thumbs of right and left hands were then repeated with d.c. up to 200 V. These measurements proved that above approximately 150 V the total body impedance at 50 Hz a.c. differs only insignificantly from the total body resistance for direct current.

All measurements are briefly described in the annexes.

Annexe A
(normative)

Mesures effectuées sur des sujets vivants et sur des cadavres et exploitation statistique des résultats

Afin d'obtenir des valeurs réalistes de l'impédance totale du corps humain de sujets vivants, la procédure suivante a été utilisée:

1) Des mesures ont été effectuées sur 50 personnes vivantes à une tension de contact de 15 V et sur 100 personnes à 25 V avec un trajet du courant main à main et des électrodes cylindriques importantes (environ 8 000 mm^2) dans des conditions sèches.

Les valeurs de l'impédance totale du corps humain pour 5 %, 50 % et 95 % de la population ont été déterminées par deux méthodes statistiques indépendantes qui ont donné sensiblement les mêmes résultats.

Les mesures ont été effectuées 0,1 s après l'application de la tension.

2) Des mesures ont été effectuées sur une personne vivante, dans les conditions du point 1) ci-dessus, avec des tensions de contact jusqu'à 150 V et en outre avec des durées de choc allant jusqu'à 0,03 s pour des tensions de contact jusqu'à 200 V.

3) Des mesures ont été effectuées sur un grand nombre de cadavres dans des conditions analogues au point 1) ci-dessus, avec un trajet du courant main à main et main à pied avec de grandes électrodes (environ 9 000 mm^2) pour des tensions de contact de 25 V à 5 000 V dans des conditions sèches et mouillées. Les valeurs de l'impédance totale du corps humain pour 5 %, 50 % et 95 % de la population ont été déterminées comme au point 1).

Les mesures ont été effectuées 3 s après l'application de la tension.

4) Les mesures de l'impédance totale des cadavres (point 3) ci-dessus) pour des tensions de contact jusqu'à 220 V ont montré des valeurs de l'impédance de la peau trop élevées et ont été modifiées en adaptant les courbes aux valeurs mesurées sur des personnes vivantes.

Annex A
(normative)

Measurements made on living and dead human beings and the statistical analysis of the results

In order to obtain realistic values for the total body impedances of living human beings, the following procedure was applied:

1) Measurements were made on 50 living persons at a touch voltage of 15 V and on 100 living persons at 25 V with a current path hand to hand with large cylinder electrodes (approximately 8 000 mm^2) in dry conditions.

The values for the total body impedances for a percentile rank of 5 %, 50 % and 95 % were determined by two independent statistical methods which gave nearly the same results.

The measurements were made 0,1 s after applying the voltage.

2) The total body impedance of one living person was measured under the conditions of item 1) above with touch voltages up to 150 V and, in addition, with shock durations up to 0,03 s for touch voltages up to 200 V.

3) Measurements were made on a large number of corpses under conditions similar to item 1) above for current paths hand to hand and hand to foot with large electrodes (approximately 9 000 mm^2) for touch voltages of 25 V to 5 000 V in dry and wet conditions. The values for the total body impedances for a percentile rank of 5 %, 50 % and 95 % were determined as in item 1).

The measurements were made 3 s after applying the voltage.

4) The total body impedances measured with corpses (item 3) above) which for touch voltages up to 220 V showed excessively high skin impedances were modified by adjusting the curves to the values measured on living persons.

Annexe B
(normative)

Influence de la fréquence sur l'impédance totale du corps humain (Z_T)

Afin d'obtenir des valeurs réalistes de l'influence de la fréquence sur l'impédance totale Z_T de sujets humains, la procédure suivante a été utilisée:

1) Des mesures ont été effectuées sur 10 personnes vivantes à une tension de contact de 10 V pour des fréquences de 25 Hz à 20 kHz avec un trajet de courant main à main et des électrodes cylindriques importantes (environ 8 000 mm^2) dans des conditions sèches.

Les valeurs de l'impédance totale du corps humain pour 5 %, 50 % et 95 % de la population ont été déterminées par des méthodes statistiques.

2) En raison d'effets musculaires importants des mesures ont été effectuées sur une seule personne vivante sous une tension de contact de 25 V pour des fréquences de 25 Hz à 2 kHz dans les conditions décrites au point 1) ci-dessus.

Les mesures des points 1) et 2) ont été effectuées 0,05 s après application de la tension.

Les résultats de ces mesures sont montrés en figures 6 et 7.

3) Pour 50 % de la population, la figure 6 à une tension de contact de 10 V et les valeurs du tableau 1 à 50 Hz et des tensions de contact de 25 V à 1 000 V ont été utilisées pour la figure 8. Cette figure montre l'assujettissement de l'impédance totale du corps humain à la fréquence pour une plage de 50 Hz à 2 kHz pour 50 % de la population à des tensions de contact variant de 10 V à 1 000 V en courant alternatif avec une ligne droite entre les valeurs asymptotiques de 750 Ω à 50 Hz et de 600 Ω à 2 kHz.

Les courbes pour des tensions de contact de 50 V à 1 000 V (lignes pointillées figure 8) ont été tracées par analogie avec les courbes à 10 V et 25 V qui sont fondées sur les mesures décrites aux points 1) et 2).

Annex B
(normative)

Influence of frequency on the total body impedance (Z_T)

In order to obtain realistic values for the influence of frequency on the total impedance Z_T of living human beings, the following procedure was applied:

1) Measurements were made on 10 living human beings at a touch voltage of 10 V for frequencies from 25 Hz to 20 kHz with a current path hand to hand with large cylinder electrodes (approximately 8 000 mm^2) in dry conditions.

The values for the total body impedances for a percentile rank of 5 %, 50 % and 95 % were determined by statistical methods.

2) Due to strong muscular effects measurements were made only on one living human being at a touch voltage of 25 V for frequencies from 25 Hz to 2 kHz under the conditions described in item 1) above.

The measurements of item 1) and item 2) were made 0,05 s after applying the voltage.

The results of these measurements are shown in figures 6 and 7.

3) For a percentile rank of 50 %, figure 6 for a touch voltage of 10 V, and the values of table 1 for 50 Hz and touch voltages from 25 V to 1 000 V were used for figure 8. This figure shows the dependence of the total body impedance on the frequency for a range from 50 Hz to 2 kHz for a percentile rank of 50 % of a population for touch voltages from 10 V to 1 000 V a.c. with a straight line between the asymptotic values of 750 Ω at 50 Hz and 600 Ω at 2 kHz.

The curves for touch voltages of 50 V to 1 000 V (dashed lines in figure 8) have been drawn in analogy to the curves for 10 V and 25 V which are based on the measurements described under items 1) and 2).

Annexe C
(normative)

Résistance totale du corps (R_T) en courant continu

Afin d'obtenir des valeurs réalistes de la résistance totale du corps R_T de sujets humains, la procédure suivante a été réalisée:

1) Des mesures ont été effectuées sur 50 personnes vivantes à une tension de contact de 10 V en courant continu pur avec un trajet de courant main à main et des électrodes cylindriques importantes (environ 8 000 mm^2) dans des conditions sèches.

Les valeurs de la résistance totale du corps R_T pour 5 %, 50 % et 95 % de la population ont été déterminées par des méthodes statistiques.

2) Les valeurs asymptotiques des impédances totales du corps en courant alternatif 50 Hz à des tensions de contact supérieures à 1 000 V et les valeurs à 220 V conformes au tableau 1 ont été utilisées pour ajuster les courbes de la résistance totale du corps R_T en courant continu pour des tensions de contact de 25 V à 220 V en courant continu (voir figure 5).

Les valeurs de la résistance totale du corps R_T en courant continu déterminées par la méthode décrite ci-dessus sont données dans le tableau 2.

Les mesures sur 50 sujets vivants à une tension de contact de 25 V ont été réalisées en augmentant lentement la tension jusqu'à 25 V en quelques secondes afin d'éviter des sensations douloureuses.

NOTE – Au-dessus de 1 000 V, il doit être considéré que l'influence de l'impédance de la peau est négligeable et par conséquent Z_T et R_T ont pratiquement les mêmes valeurs.

Annex C
(normative)

Total body resistance (R_T) for direct current

In order to obtain realistic values for the total body resistance R_T of living human beings, the following procedure was applied:

1) Measurements were made on 50 living persons at a touch voltage of 10 V pure d.c. with a current path hand to hand with large cylinder electrodes (approximately 8 000 mm^2) in dry conditions.

The values for the total body resistance R_T for a percentile rank of 5 %, 50 % and 95 % were determined by statistical methods.

2) The asymptotic values for the total body impedances for a.c. 50 Hz, at touch voltages above 1 000 V, and the values of 220 V according to table 1 were used to adjust the curves to the total body resistance R_T for d.c. for touch voltages between 25 V and 220 V, d.c. (see figure 5).

The values for the total body resistance R_T for direct current determined by the method described above are given in table 2.

The measurements on 50 living persons at a touch voltage of 25 V were made after slowly increasing the voltage to the value of 25 V within a few seconds, in order to avoid painful sensations.

NOTE – Above 1 000 V it may be assumed that the influence of the skin impedance is negligible and therefore Z_T and R_T have practically the same values.

Annexe D
(normative)

Mesures de l'assujettissement de l'impédance totale du corps humain (Z_T) à la surface de contact

1) En raison de sensations douloureuses et d'un certain risque à des tensions de contact élevées, les mesures ont été réalisées seulement sur un adulte masculin, dont l'impédance du corps, comparée à celle d'une population de 100 sujets vivants sous une tension de contact de 25 V en courant alternatif 50 Hz, s'avérait proche de la moyenne de la population. Par conséquent, il peut être supposé que les valeurs données aux figures 10 et 11 correspondent approximativement à la moyenne ou aux valeurs probables de 50 % de la population de sujets vivants.

2) Les impédances totales du corps ont été mesurées à des tensions de contact de 25 V à 200 V en courant alternatif 50 Hz avec un trajet de courant main à main dans des conditions sèches. Les mesures ont été effectuées en fin de durée de passage du courant. Les surfaces des zones de contact utilisées sont indiquées dans le tableau 3.

Les conditions suivantes pour le trajet du courant et les durées de passage de courant ont été utilisées:

Essai de série A: Surface de contact 8 000 mm^2, électrodes serrées avec les deux mains, durée du passage du courant 0,1 s.

Essai de série B: Surface de contact 1 000 mm^2, électrodes serrées avec les deux mains, durée du passage du courant: quelques secondes jusqu'à 75 V et 0,1 s au-dessus de 75 V.

Essai de série C Surface de contact 100 mm^2, électrodes pressées contre le milieu des paumes de mains, durée du passage du courant: quelques secondes jusqu'à 75 V et 0,1 s au-dessus de 75 V.

Essai de série D: Surface de contact 10 mm^2, électrodes pressées contre le milieu des paumes de mains, durée du passage du courant quelques secondes jusqu'à 100 V et 0,1 s à 0,3 s au-dessus de 100 V.

Essai de série E Surface de contact 1 mm^2, électrodes pressées contre le milieu des paumes de mains, durée du passage du courant: quelques secondes jusqu'à 150 V et 0,1 s à 0,2 s au-dessus de 150 V (à 220 V, le claquage de la peau a été observé).

3) L'impédance totale du corps a été mesurée dans une plage de tensions de contact de 25 V à 200 V, en courant alternatif 50 Hz et en courant continu entre les extrémités des doigts droit et gauche (surface de contact d'environ 250 mm^2). Les mesures ont été effectuées 20 ms après mise sous tension. En courant alternatif, la tension est appliquée au passage à zéro de la tension de contact.

Les résultats sont représentés en figure 11, les valeurs en courant continu se rapprochent de celles en courant alternatif avec des tensions de contact croissantes.

De la figure 11, il s'en déduit aussi que l'impédance additionnelle d'un doigt (surface de contact d'environ 250 mm^2) comparée avec un trajet de courant à l'origine de la paume de la main (zone de surface de contact d'environ 8 000 mm^2) à 200 V en courant alternatif 50 Hz est d'environ 1 000 Ω. Ceci est conforme aux mesures précédentes sur des cadavres.

Annex D
(normative)

Measurements of the dependence of the total impedance of the human body (Z_T) on the surface area of contact

1) Due to painful sensations and a certain risk at higher touch voltages, the measurements have been carried out only on one male adult whose body impedance when compared with the body impedance of a population of 100 living persons at a touch voltage of 25 V 50 Hz a.c., proved to be near the average of the population. It may therefore be assumed that the values shown in figures 10 and 11 correspond approximately to the average or the 50 % probability values of a population of living persons.

2) The total body impedances were measured for touch voltages from 25 V up to 200 V 50 Hz a.c. with a current path hand to hand in dry conditions. The measurements were made at the end of the duration of current flow. The surface areas of contact used are shown in table 3.

The following conditions for the current path and durations of current flow have been used:

Test series A: Contact area 8 000 mm^2, electrodes grasped with both hands, duration of current flow 0,1 s.

Test series B: Contact area 1 000 mm^2, electrodes grasped with both hands, duration of current flow several seconds up to 75 V, 0,1 s above 75 V.

Test series C: Contact area 100 mm^2, electrodes pressed against the middle of the palms, duration of current flow several seconds up to 75 V, 0,1 s above 75 V.

Test series D: Contact area 10 mm^2, electrodes pressed against the middle of the palms, duration of current flow several seconds up to 100 V, 0,1 s up to 0,3 s above 100 V.

Test series E: Contact area 1 mm^2, electrodes pressed against the middle of the palms, duration of current flow several seconds up to 150 V, 0,1 s up to 0,2 s above 150 V (at 220 V breakdown of the skin was observed).

3) The total body impedance was measured for a touch voltage range of 25 V to 200 V, a.c. 50 Hz and d.c. between the tips of the right and left forefingers (surface area of contact approximately 250 mm^2). The measurements were made 20 ms after applying the voltage. For a.c., the voltage was applied at zero crossing of the touch voltage.

The results are shown in figure 11, the d.c. values approaching the a.c. values with rising touch voltages.

From figure 11 it also follows that the additional impedance of one forefinger (surface area of contact approximately 250 mm^2) compared with a current path beginning in the palm of the hand (surface area of contact approximately 8 000 mm^2) at 200 V, 50 Hz a.c., is approximately 1 000 Ω. This is in conformity with earlier measurements made on corpses.

Annexe E/Annex E
(informative)

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364-5-53 (1994)	Chapter 53: Switchgear and controlgear.
364-5-537 (1981)	Chapiter 53: Switchgear and controlgear. Section 537: Devices for isolation and switching. Amendment No. 1 (1989)
364-5-54 (1980)	Chapter 54: Earthing arrangements and protective conductors. Amendment No. 1 (1982).
364-5-56 (1980)	Chapter 56: Safety services.
364-6-61 (1986)	Part 6: Verification. Chapter 61: Initial verification. Amendment 1 (1993).
364-7-701 (1984)	Part 7: Requirements for special installations or locations. Section 701: Locations containing a bath tub or shower basin.
364-7-702 (1983)	Section 702: Swimming pools.

(continued)

Publications de la CEI préparées par le Comité d'Etudes n° 64 *(suite)*

364-7-703 (1984)	Section 703: Locaux contenant des radiateurs pour saunas.
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479-1 (1994)	Partie 1: Aspects généraux.
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536-2 (1992)	Partie 2: Directives pour des prescriptions en matière de protection contre les chocs électriques.
1140 (1992)	Protection contre les chocs électriques. Aspects communs pour les installations et les matériels.
1200:– Guide pour les installations électriques.	
1200-52 (1993)	Partie 52: Choix et mise en oeuvre des matériels électriques – Canalisations.

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364-7-703 (1984)	Section 703: Locations containing sauna heaters.
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364-7-706 (1983)	Section 706: Restrictive conducting locations.
364-7-707 (1984)	Section 707: Earthing requirements for the insta[l]lation of data processing equipment.
364-7-708 (1988)	Section 708: Electrical installations in carav[an] parks and caravans. Amendment 1 (1993).
364-7-709 (1994)	Marinas and pleasure craft.
449 (1973)	Voltage bands for electrical installations [of] buildings. Amendment No. 1 (1979).
479: – Effects of current passing through the human body.	
479-1 (1994)	Part 1: General aspects.
479-2 (1987)	Part 2: Special aspects.
536 (1976)	Classification of electrical and electronic equi[p]ment with regard to protection against elect[ric] shock.
536-2 (1992)	Part 2: Guidelines to requirements for protecti[on] against electric shock.
1140 (1992)	Protection against electric shock. Common aspe[cts] for installation and equipment.
1200:- Electrical installation guide.	
1200-52 (1993)	Part 52: Selection and erection of electrical equi[p]ment – Wiring systems.

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

Effets du courant passant par le corps humain

Deuxième partie: Aspects particuliers
Chapitre 4: Effets du courant alternatif de fréquence supérieure à 100 Hz
Chapitre 5: Effets des courants de formes d'onde spéciales
Chapitre 6: Effets des courants d'impulsion unique de courte durée

Effects of current passing through the human body

Part 2: Special aspects
Chapter 4: Effects of alternating current with frequencies above 100 Hz
Chapter 5: Effects of special waveforms of current
Chapter 6: Effects of unidirectional single impulse currents of short duration

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Révision de la présente publication

Le contenu technique des publications de la CEI est constamment revu par la Commission afin d'assurer qu'il reflète bien l'état actuel de la technique.

Les renseignements relatifs à ce travail de révision, à l'établissement des éditions révisées et aux mises à jour peuvent être obtenus auprès des Comités nationaux de la CEI et en consultant les documents ci-dessous:

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En ce qui concerne la terminologie générale, le lecteur se reportera à la Publication 50 de la CEI: Vocabulaire Electrotechnique International (VEI), qui est établie sous forme de chapitres séparés traitant chacun d'un sujet défini, l'Index général étant publié séparément. Des détails complets sur le VEI peuvent être obtenus sur demande.

Les termes et définitions figurant dans la présente publication ont été soit repris du VEI, soit spécifiquement approuvés aux fins de cette publication.

Symboles graphiques et littéraux

Pour les symboles graphiques, symboles littéraux et signes d'usage général approuvés par la CEI, le lecteur consultera:

- la Publication 27 de la CEI: Symboles littéraux à utiliser en électrotechnique;
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The terms and definitions contained in the present publication have either been taken from the IEV or have been specifically approved for the purpose of this publication.

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For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to:

- IEC Publication 27: Letter symbols to be used in electrical technology;
- IEC Publication 617: Graphical symbols for diagrams.

The symbols and signs contained in the present publication have either been taken from IEC Publications 27 or 617, or have been specifically approved for the purpose of this publication.

IEC publications prepared by the same Technical Committee

The attention of readers is drawn to the back cover, which lists IEC publications issued by the Technical Committee which has prepared the present publication.

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PRÉFACE

Le présent rapport a été établi par le Comité d'Etudes n° 64 de la CEI: Installations électriques des bâtiments.

Cette deuxième édition remplace la première édition de la Publication 479 de la CEI, parue en 1974.

Le texte de ce rapport est issu des documents suivants:

Règle des Six Mois	Rapports de vote
64(BC)149 64(BC)150 64(BC)155	64(BC)157 64(BC)158 64(BC)163

Pour de plus amples renseignements, consulter les rapports de vote correspondants mentionnés dans le tableau ci-dessus.

La nouvelle version de la Publication 479 est divisée en deux parties, chacune divisée en trois chapitres.

Première partie: Aspects généraux:

Chapitre 1: Impédance électrique du corps humain.
Chapitre 2: Effets du courant alternatif de fréquence comprise entre 15 Hz et 100 Hz.
Chapitre 3: Effets du courant continu.

Deuxième partie: Aspects particuliers:

Chapitre 4: Effets du courant alternatif de fréquence supérieure à 100 Hz.
Chapitre 5: Effets des courants de formes d'onde spéciales.
Chapitre 6: Effets des courants d'impulsion unique de courte durée.

Les publications suivantes de la CEI sont citées dans le présent rapport:

Publications n^{os} 50(551) (1982): Vocabulaire Electrotechnique International (VEI), Chapitre 551: Electronique de puissance.
50(801) (1984): Chapitre 801: Acoustique et électroacoustique.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF CURRENT PASSING THROUGH THE HUMAN BODY

Part 2: Special aspects

Chapter 4: Effects of alternating current with frequencies above 100 Hz
Chapter 5: Effects of special waveforms of current
Chapter 6: Effects of unidirectional single impulse currents of short duration

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by the Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.
3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This report has been prepared by IEC Technical Committee No. 64: Electrical Installations of Buildings.

This second edition replaces the first edition of IEC Publication 479, published in 1974.

The text of this report is based on the following documents:

Six Months' Rule	Reports on Voting
64(CO)149 64(CO)150 64(CO)155	64(CO)157 64(CO)158 64(CO)163

Further information can be found in the relevant Reports on Voting indicated in the table above.

The new edition of Publication 479 is divided into two parts each containing three chapters:

Part 1: General aspects:

- Chapter 1: Electrical impedance of the human body.
- Chapter 2: Effects of alternating current in the range of 15 Hz to 100 Hz.
- Chapter 3: Effects of direct current.

Part 2: Special aspects:

- Chapter 4: Effects of alternating current with frequencies above 100 Hz.
- Chapter 5: Effects of special waveforms of current.
- Chapter 6: Effects of unidirectional single impulse currents of short duration.

The following IEC publications are quoted in this report:

Publications Nos. 50(551) (1982): International Electrotechnical Vocabulary (IEV), Chapter 551: Power Electronics.
50(801) (1984): Chapter 801: Acoustics and Electro-acoustics.

EFFETS DU COURANT PASSANT PAR LE CORPS HUMAIN

Deuxième partie: Aspects particuliers

CHAPITRE 4: EFFETS DU COURANT ALTERNATIF DE FRÉQUENCE SUPÉRIEURE À 100 Hz

1. Généralités

L'énergie électrique sous la forme de courant alternatif de fréquence supérieure à 50/60 Hz est de plus en plus utilisée dans les matériels électriques modernes, par exemple dans les avions (400 Hz), les outils portatifs et le soudage électrique (essentiellement jusqu'à 450 Hz), l'électrothérapie (essentiellement entre 4000 Hz et 5000 Hz), les alimentations de puissance (de 20 kHz à 1 MHz).

Peu de valeurs expérimentales sont disponibles pour ce chapitre, de sorte que les informations données sont à considérer seulement comme provisoires, mais elles peuvent être utilisées pour l'estimation des risques dans les plages des fréquences considérées (voir bibliographie, page 44). L'attention est également appelée sur le fait que l'impédance de la peau décroît sensiblement de façon inversement proportionnelle à la fréquence pour des tensions de contact de l'ordre de quelques dizaines de volts, de sorte que l'impédance de la peau à 500 Hz est environ le dixième de celle à 50 Hz et peut être négligée dans beaucoup de cas. Cela est encore plus vrai pour les fréquences supérieures. C'est ainsi que l'impédance du corps humain à de telles fréquences est limitée à son impédance interne Z_i (voir chapitre 1).

2. Domaine d'application

Le présent chapitre décrit les effets des courants alternatifs sinusoïdaux dans les plages de fréquence suivantes:

- supérieure à 100 Hz et inférieure ou égale à 1000 Hz (voir article 4);
- supérieure à 1000 Hz et inférieure ou égale à 10000 Hz (voir article 5);
- supérieure à 10000 Hz (voir article 6).

3. Définitions

En plus de celles qui sont données dans la première partie, la définition suivante s'applique dans le cadre du présent chapitre:

3.1 *Facteur de fréquence F_f*

Rapport du seuil à la fréquence f au seuil à la fréquence de 50/60 Hz pour les effets physiologiques considérés.

Note. – Les facteurs de fréquence pour la perception, le non-lâcher et la fibrillation ventriculaire sont différents.

4. Effets du courant alternatif de fréquence comprise entre 100 Hz et 1000 Hz inclus

4.1 *Seuil de perception*

Le facteur de fréquence pour le seuil de perception est indiqué sur la figure 9, page 10.

4.2 *Seuil de non-lâcher*

Le facteur de fréquence pour le seuil de non-lâcher est indiqué sur la figure 10, page 10.

EFFECTS OF CURRENT PASSING THROUGH THE HUMAN BODY

Part 2: Special aspects

CHAPTER 4: EFFECTS OF ALTERNATING CURRENT WITH FREQUENCIES ABOVE 100 Hz

1. General

Electric energy in the form of alternating current of higher frequencies than 50/60 Hz is increasingly used in modern electrical equipment, for example aircraft (400 Hz), power tools and electric welding (mostly up to 450 Hz), electrotherapy (using mostly 4000 Hz to 5000 Hz), switching mode power supplies (20 kHz to 1 MHz).

Little experimental data is available for this chapter, so that the information given herein should be considered as provisional only but may be used for the evaluation of risks in the ranges of frequencies concerned (see bibliography, page 44). Attention is also drawn to the fact, that the impedance of human skin decreases approximately inversely proportional to the frequency for touch voltages in the order of some tens of volts, so that the skin impedance at 500 Hz is only about one tenth of the skin impedance at 50 Hz and may be neglected in many cases. This holds even more true for higher frequencies. The impedance of the human body at such frequencies is therefore reduced to its internal impedance Z_i (see Chapter 1).

2. Scope

This chapter describes the effects of sinusoidal alternating current within the frequency ranges:

- above 100 Hz up to and including 1000 Hz (see Clause 4);
- above 1000 Hz up to and including 10000 Hz (see Clause 5);
- above 10000 Hz (see Clause 6).

3. Definitions

In addition to the definitions given in Part 1, the following definition applies:

3.1 *Frequency factor F_f*

Ratio of the threshold current for the relevant physiological effects at the frequency f to the threshold current at 50/60 Hz.

Note. – The frequency factor differs for perception, let-go and ventricular fibrillation.

4. Effects of alternating current in the frequency range above 100 Hz up to and including 1000 Hz

4.1 *Threshold of perception*

For the threshold of perception the frequency factor is given in Figure 9, page 11.

4.2 *Threshold of let-go*

For the threshold of let-go the frequency factor is given in Figure 10, page 11.

4.3 *Seuil de fibrillation ventriculaire*

Pour des durées de choc supérieures à celle du cycle cardiaque, le facteur de fréquence pour le seuil de fibrillation et des trajets de courant longitudinaux à travers le tronc du corps est indiqué sur la figure 11, page 12.

Pour des durées de choc inférieures à celle du cycle cardiaque, aucune valeur expérimentale n'est disponible.

5. Effets du courant alternatif de fréquence comprise entre 1000 Hz et 10000 Hz inclus

5.1 *Seuil de perception*

Le facteur de fréquence pour le seuil de perception est indiqué sur la figure 12, page 12.

5.2 *Seuil de non-lâcher*

Le facteur de fréquence pour le seuil de non-lâcher est indiqué sur la figure 13, page 12.

5.3 *Seuil de fibrillation ventriculaire*

A l'étude.

6. Effets du courant alternatif de fréquence supérieure à 10000 Hz

6.1 *Seuil de perception*

Pour les fréquences comprises entre 10 kHz et 100 kHz, le seuil de perception s'élève approximativement de 10 mA à 100 mA (valeurs efficaces).

Pour les fréquences supérieures à 100 kHz, la sensation de picotement caractéristique pour la perception aux fréquences inférieures devient une sensation de chaleur pour les courants de l'ordre de quelques centaines de milliampères.

6.2 *Seuil de non-lâcher*

Pour les fréquences supérieures à 100 kHz, aucune valeur expérimentale n'est disponible pour le seuil de non-lâcher et aucun incident n'est connu.

6.3 *Seuil de fibrillation ventriculaire*

Pour les fréquences supérieures à 100 kHz, aucune valeur expérimentale n'est disponible pour le seuil de fibrillation ventriculaire et aucun incident n'est connu.

6.4 *Autres effets*

Pour les fréquences supérieures à 100 kHz, des brûlures peuvent se produire pour des courants de quelques ampères selon la durée de passage du courant.

4.3 *Threshold of ventricular fibrillation*

For shock-durations longer than the cardiac cycle, the frequency factor for the threshold of fibrillation for longitudinal current paths through the trunk of the body is given in Figure 11, page 13.

For shock-durations shorter than the cardiac cycle no experimental data is available.

5. Effects of alternating current in the frequency range above 1000 Hz up to and including 10 000 Hz

5.1 *Threshold of perception*

For the threshold of perception the frequency factor is given in Figure 12, page 13.

5.2 *Threshold of let-go*

For the threshold of let-go the frequency factor is given in Figure 13, page 13.

5.3 *Threshold of ventricular fibrillation*

Under consideration.

6. Effects of alternating current in the frequency range above 10 000 Hz

6.1 *Threshold of perception*

For frequencies between 10 kHz and 100 kHz the threshold rises approximately from 10 mA to 100 mA (r. m s. values).

For frequencies above 100 kHz the tingling sensation characteristic for the perception at lower frequencies changes into a sensation of warmth for current intensities in the order of some hundred milliamperes.

6.2 *Threshold of let-go*

For frequencies above 100 kHz there is neither experimental data nor reported incidents concerning the threshold of let-go.

6.3 *Threshold of ventricular fibrillation*

For frequencies above 100 kHz there is neither experimental data nor reported incidents concerning the threshold of ventricular fibrillation.

6.4 *Other effects*

Burns may occur at frequencies above 100 kHz and current magnitudes in the order of amperes depending on the duration of the current flow.

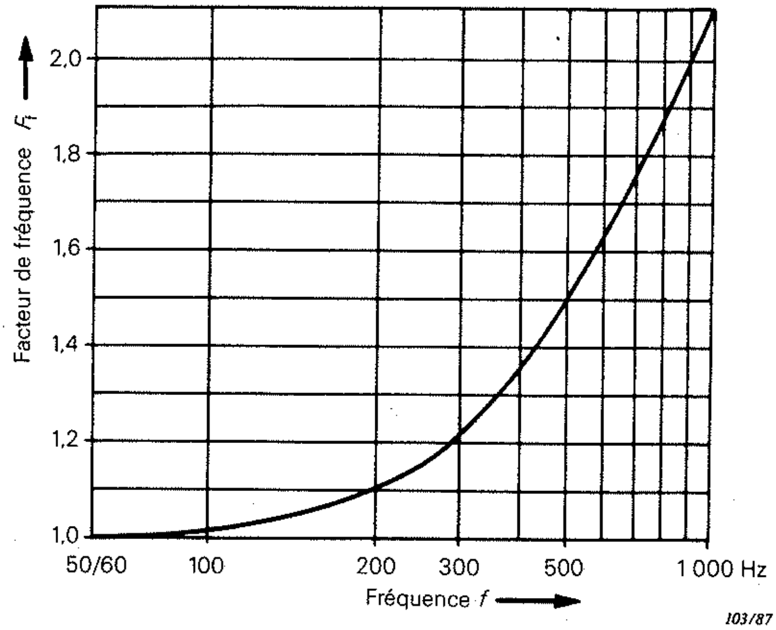

FIG. 9. – Variation du seuil de perception pour les fréquences comprises entre 50/60 Hz et 1000 Hz.

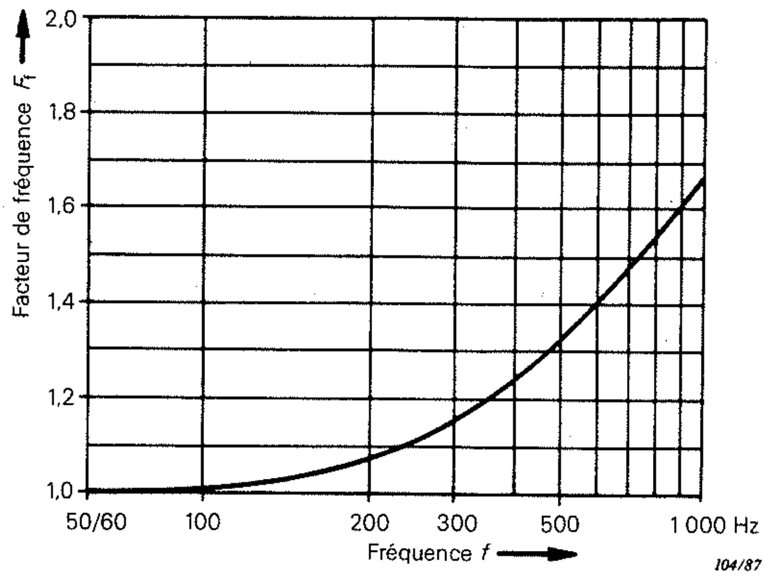

FIG. 10. – Variation du seuil de non-lâcher pour les fréquences comprises entre 50/60 Hz et 1000 Hz.

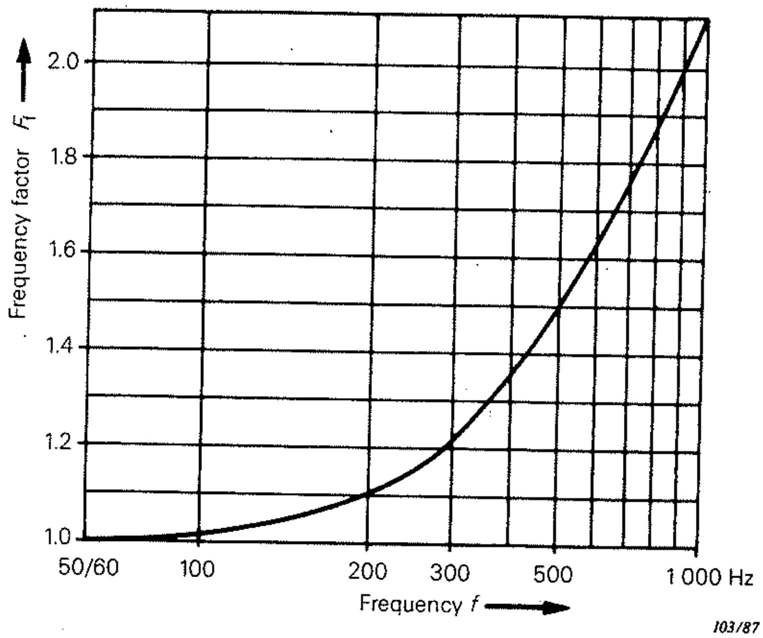

FIG. 9. – Variation of the threshold of perception within the frequency range 50/60 Hz to 1 000 Hz.

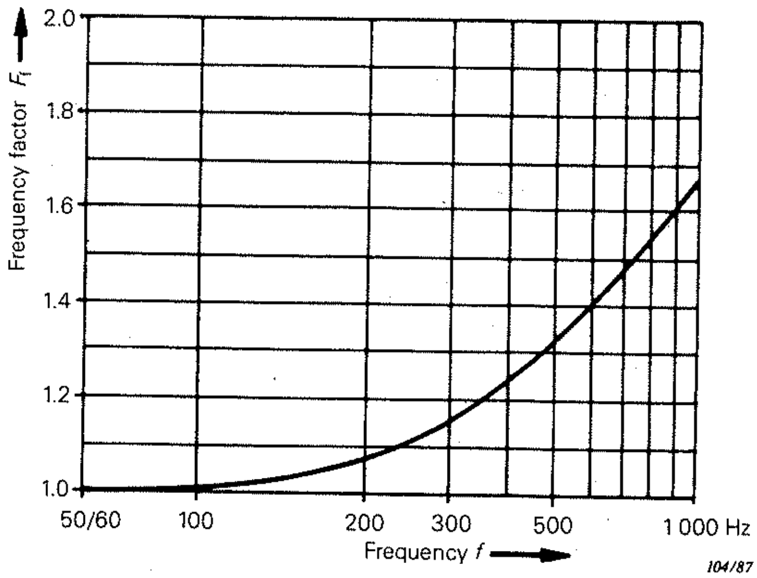

FIG. 10. – Variation of the threshold of let-go within the frequency range 50/60 Hz to 1 000 Hz.

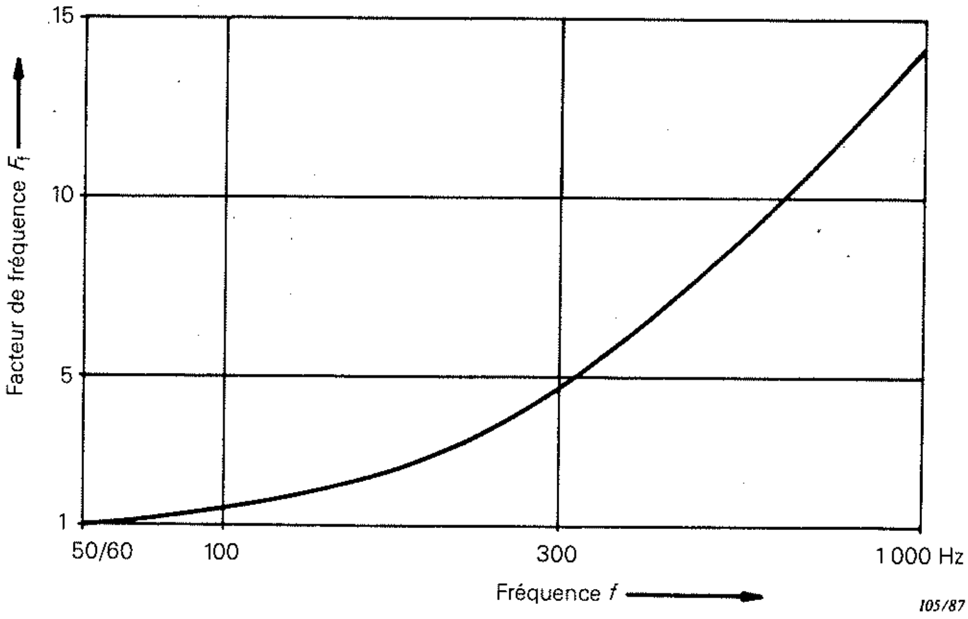

Fig. 11. – Variation du seuil de fibrillation ventriculaire pour les fréquences comprises entre 50/60 Hz et 1000 Hz, des durées de choc supérieures à celle d'un cycle cardiaque et des trajets de courant longitudinaux à travers le tronc du corps.

Note. – Pour des durées de choc inférieures à celle d'un cycle cardiaque, d'autres courbes sont à l'étude.

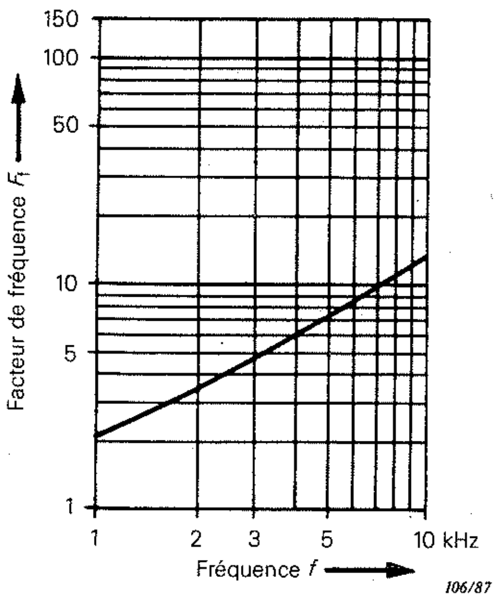

Fig. 12. – Variation du seuil de perception pour les fréquences comprises entre 1000 Hz et 10000 Hz.

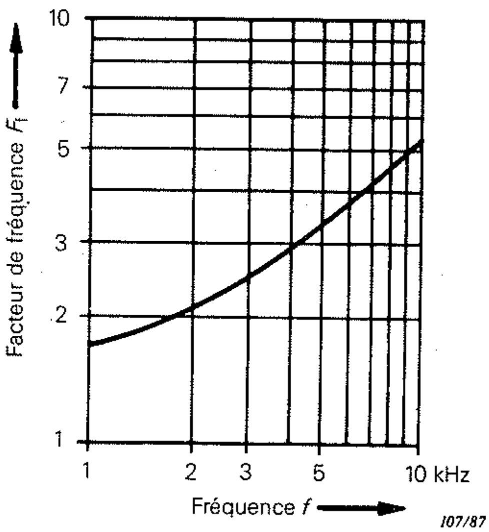

Fig. 13. – Variation du seuil de non-lâcher pour les fréquences comprises entre 1000 Hz et 10000 Hz.

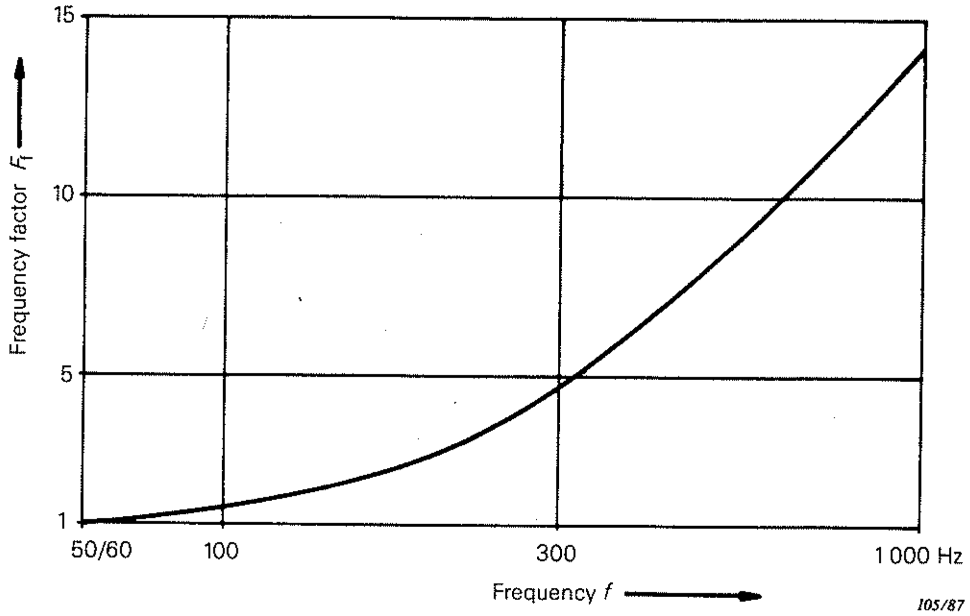

Fig. 11. – Variation of the threshold of ventricular fibrillation within the frequency range 50/60 Hz to 1000 Hz, shock-durations longer than one heart period and longitudinal current paths through the trunk of the body.

Note. – For shock-durations shorter than one heart period, other curves are under consideration.

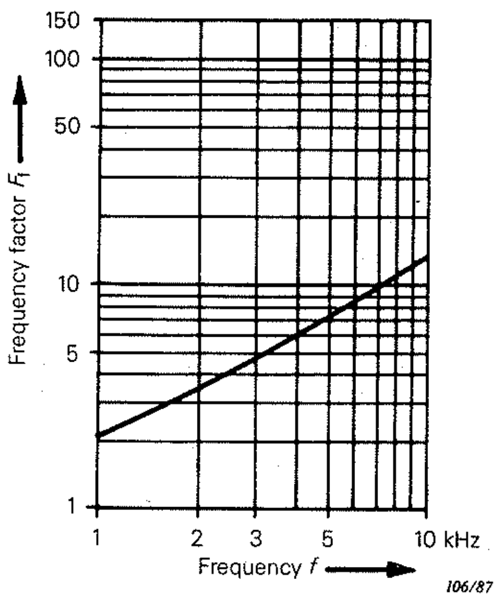

Fig. 12. – Variation of the threshold of perception within the frequency range 1000 Hz to 10000 Hz.

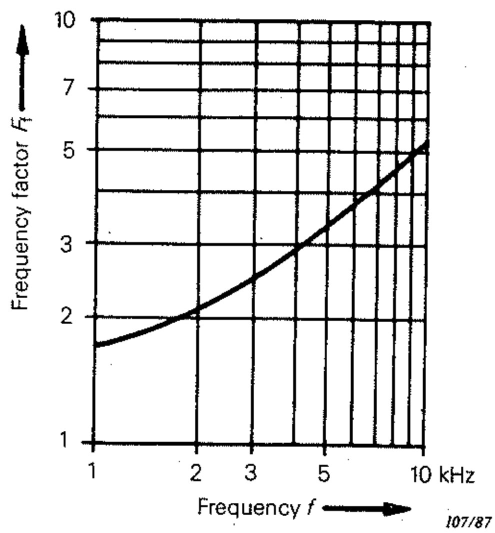

Fig. 13. – Variation of the threshold of let-go within the frequency range 1000 Hz to 10000 Hz.

CHAPITRE 5: EFFETS DES COURANTS DE FORMES D'ONDE SPÉCIALES

1. Généralités

L'intérêt croissant porté aux courants de formes d'onde spéciales constitués de courant alternatif avec composante continue s'explique par le développement des applications des commandes électroniques, commandes qui créent de tels types de courants, particulièrement en cas de défaut d'isolement. Cela est également le cas de matériels utilisant des courants alternatifs avec contrôle de l'angle de phase et commande synchrone par trains d'alternance.

Comme l'on peut s'y attendre, les effets de tels courants sur le corps humain sont intermédiaires entre ceux du courant alternatif et ceux de courant continu et il est possible de déterminer les valeurs de courant équivalentes du point de vue du risque de fibrillation ventriculaire.

2. Domaine d'application

Le présent chapitre décrit les effets du courant électrique passant par le corps humain:

- pour des courants alternatifs sinusoïdaux avec composante continue,
- pour des courants alternatifs sinusoïdaux avec contrôle de l'angle de phase,
- pour des courants alternatifs sinusoïdaux avec commande synchrone par trains d'alternance.

Note. – D'autres formes d'onde sont à l'étude.

Les informations indiquées sont valables pour les fréquences en courant alternatif comprises entre 15 Hz et 100 Hz.

3. Définitions

En plus de celles qui sont données dans la première partie, les définitions suivantes s'appliquent dans le cadre du présent chapitre:

3.1 *Contrôle de phase*

Procédé consistant à modifier l'instant de la période à partir duquel commence la conduction du courant.

3.2 *Contrôle de l'angle de phase* (angle de retard)

Intervalle de temps, exprimé en mesure angulaire, pendant lequel le point de départ de la conduction du courant est retardé par le réglage de phase.

3.3 *Commande synchrone par trains d'alternance* (réglage par trains d'ondes)

Opération consistant à faire varier le rapport entre le nombre de périodes pendant lesquelles il y a conduction de courant et le nombre de périodes pendant lesquelles il n'y a pas conduction de courant.

3.4 *Facteur p de commande par trains d'alternance* (facteur de réglage par trains d'ondes)

Rapport du nombre de périodes de conduction à la somme des nombres de périodes de conduction et de non-conduction (voir figure 17, page 24).

4. Effets du courant alternatif avec composante continue

4.1 *Formes d'onde et fréquences*

La figure 14, page 22, montre des formes d'onde caractéristiques dont traite le présent article. Le courant alternatif pur et le courant continu lisse sont représentés ainsi que les formes d'onde combinées des différents rapports du courant alternatif au courant continu. On distingue les courants suivants:

CHAPTER 5: EFFECTS OF SPECIAL WAVEFORMS OF CURRENT

1. General

The increasing interest in special waveforms of current derived from alternating current and direct current is evidenced by the rising number of applications of electronic controls causing such types of current particularly in the case of an insulation fault. This holds true also for equipment using alternating currents with phase control and multicycle control.

As is to be expected the effects of such currents on the human body are between those caused by direct and by alternating current; therefore equivalent current magnitudes with regard to ventricular fibrillation can be established.

2. Scope

This chapter describes the effects of current passing through the human body for:

- alternating sinusoidal current with d. c. components,
- alternating sinusoidal current with phase control,
- alternating sinusoidal current with multicycle control.

Note. – Other waveforms are under consideration.

The information given is deemed applicable for alternating current frequencies from 15 Hz up to 100 Hz.

3. Definitions

In addition to the definitions given in Part 1, the following ones apply for the purpose of this chapter:

3.1 *Phase control*

The process of varying the instant within the cycle at which current conduction begins.

3.2 *Phase control angle* (current delay angle)

The time expressed in angular measure by which the starting instant of current conduction is delayed by phase control.

3.3 *Multicycle control*

The process of varying the ratio of the number of cycles which include current conduction to the number of cycles in which no current conduction occurs.

3.4 *Multicycle control factor p*

The ratio between the number of conducting cycles and the sum of conducting and non-conducting cycles in the case of multicycle control (see Figure 17, page 25).

4. Effects of alternating current with d. c. components

4.1 *Waveforms and frequencies*

Figure 14, page 23, shows typical waveforms which are dealt with in this clause. Pure d. c. and pure a. c. are represented as well as combined waveforms of various ratios a. c. to d. c. The following current magnitudes have to be distinguished:

I_{eff} = valeur efficace du courant de la forme d'onde résultante,

I_p = valeur de crête du courant de la forme d'onde résultante,

I_{pp} = valeur entre crêtes du courant de la forme d'onde résultante,

I_{ev} = valeur efficace du courant sinusoïdal équivalent, du point de vue du risque de fibrillation ventriculaire, à la forme d'onde considérée.

Note. – Le courant I_{ev} est utilisé au lieu du courant I_B de la figure 5 du chapitre 2 pour estimer les risques de fibrillation ventriculaire.

4.2 *Seuil de perception*

Le seuil de perception dépend de plusieurs paramètres, tels que la surface du corps en contact avec une électrode (surface de contact), les conditions de contact (sèches, humides, pression, température), ainsi que des caractéristiques physiologiques de l'individu.

Les valeurs du seuil de perception sont à l'étude.

4.3 *Seuil de non-lâcher*

Le seuil de non-lâcher dépend de plusieurs paramètres, tels que la surface de contact, la forme et les dimensions des électrodes, ainsi que des caractéristiques physiologiques de l'individu.

Les valeurs du seuil de non-lâcher sont à l'étude.

4.4 *Seuil de fibrillation ventriculaire*

4.4.1 *Formes d'onde avec des rapports spécifiques entre la composante alternative et la composante continue*

Le risque de fibrillation est approximativement le même qu'avec un courant alternatif équivalent I_{ev} ayant les caractéristiques suivantes:

a) Pour des durées de choc supérieures à environ 1,5 fois la durée du cycle cardiaque, I_{ev} est la valeur efficace d'un courant ayant la même valeur entre crêtes I_{pp} que le courant de la forme d'onde considérée:

$$I_{ev} = \frac{I_{pp}}{2\sqrt{2}}$$

b) Pour des durées de choc inférieures à environ 0,75 fois la durée du cycle cardiaque, I_{ev} est la valeur efficace d'un courant ayant la même valeur de crête I_p que le courant de la forme d'onde considérée:

$$I_{ev} = \frac{I_p}{\sqrt{2}}$$

Note. – Cette relation est de moins en moins applicable pour des rapports entre les composantes alternatives et continues de plus en plus petits. Pour des chocs en courant continu lisse d'une durée inférieure à 0,1 s, le seuil est égal à la valeur efficace correspondante du courant alternatif (voir figure 5 et figure 8, respectivement au chapitre 2 et au chapitre 3).

c) Pour des durées de choc comprises entre 0,75 et 1,5 fois la durée du cycle cardiaque, le paramètre de référence passe de la valeur de crête à la valeur entre crêtes.

Note. – Les détails sur la nature de ce passage feront l'objet d'études complémentaires.

4.4.2 *Exemples de courant alternatif redressé*

La figure 15, page 22, montre les formes d'onde pour des systèmes à simple ou double alternance. Pour ces formes d'onde, la valeur de crête du courant est identique à sa valeur entre crêtes.

I_{rms} = r. m. s. value of the current of the resultant waveform,

I_p = peak value of the current of the resultant waveform,

I_{pp} = peak-to-peak value of the current of the resultant waveform,

I_{ev} = r. m. s. value of a sinusoidal current presenting the same risk as regards ventricular fibrillation as the waveform concerned.

Note. – The current I_{ev} is used instead of the current I_B in Figure 5 of Chapter 2 to estimate the risk of ventricular fibrillation.

4.2 *Threshold of perception*

The threshold of perception depends on several parameters such as the area of the body in contact with an electrode (contact area), the conditions of contact (dry, wet, pressure, temperature) and also on physiological characteristics of the individual.

Values for the threshold of perception are under consideration.

4.3 *Threshold of let-go*

The threshold of let-go depends on several parameters, such as the contact area, the shape and size of the electrodes and also on the physiological characteristics of the individual.

Values for the threshold of let-go are under consideration.

4.4 *Threshold of ventricular fibrillation*

4.4.1 *Waveforms consisting of specific ratios of alternating to direct current*

The fibrillation hazard may be taken as being approximately the same as with an equivalent alternating current I_{ev} having the following characteristics:

a) For shock durations longer than approximately 1.5 times the period of the cardiac cycle, I_{ev} is the r. m. s. value of a current having the same peak-to-peak value I_{pp} as the current of the waveform concerned:

$$I_{ev} = \frac{I_{pp}}{2\sqrt{2}}$$

b) For shock durations shorter than approximately 0.75 times the period of the cardiac cycle, I_{ev} is the r. m. s. value of a current having the same peak value I_p as the current of the waveform concerned:

$$I_{ev} = \frac{I_p}{\sqrt{2}}$$

Note. – This correlation is the less applicable the smaller the ratio a. c. to d. c. becomes. For pure d. c. shocks of a duration less than 0.1 s the threshold is equal to the corresponding r. m. s. value of the alternating current (see Figure 5 and Figure 8 in Chapter 2 and Chapter 3 respectively).

c) In the duration range from 0.75 to 1.5 times the period of the cardiac cycle the amplitude parameter changes from peak value to peak-to-peak value.

Note. – The details of the nature of the transition that takes place are subject to further studies.

4.4.2 *Examples of rectified alternating current*

Figure 15, page 23, shows the waveforms for half wave and full wave rectification. For these waveforms the peak value of the current is identical with its peak-to-peak value.

Le courant alternatif équivalent I_{ev} est déterminé:

a) Pour des durées supérieures à 1,5 fois la durée du cycle cardiaque, par:

$$I_{ev} = \frac{I_{pp}}{2\sqrt{2}} = \frac{I_p}{2\sqrt{2}}$$

Ainsi, pour les systèmes à simple alternance, I_{ev} se rapporte à la valeur efficace du courant redressé I_{eff} par la relation:

$$I_{ev} = \frac{I_{eff}}{\sqrt{2}}$$

et, pour les systèmes à double alternance, par la relation:

$$I_{ev} = \frac{I_{eff}}{2}$$

b) Pour des durées inférieures à 0,75 fois la durée du cycle cardiaque:

$$I_{ev} = \frac{I_{pp}}{\sqrt{2}} = \frac{I_p}{\sqrt{2}}$$

Ainsi, pour les systèmes à simple alternance, I_{ev} se rapporte à la valeur efficace du courant redressé I_{eff} par la relation:

$$I_{ev} = \sqrt{2}\, I_{eff}$$

et, pour les systèmes à double alternance par la relation:

$$I_{ev} = I_{eff}$$

5. Effets du courant alternatif avec contrôle de l'angle de phase

5.1 *Formes d'onde et fréquences*

La figure 16, page 24, montre les formes d'onde pour des commandes symétriques et asymétriques.

5.2 *Seuil de perception et seuil de non-lâcher*

Comme décrit précédemment aux paragraphes 4.2 et 4.3, ces seuils dépendent de plusieurs paramètres.

Les valeurs de courant produisant une sensation ou empêchant le lâcher sont sensiblement les mêmes qu'en courant alternatif pour la même valeur de crête I_p. Lorsque l'angle de contrôle de phase est supérieur à 120°, les valeurs de crête augmentent du fait de la diminution du temps de passage du courant.

5.3 *Seuil de fibrillation ventriculaire*

Les seuils sont différents suivant que la commande est symétrique ou asymétrique.

5.3.1 *Commande symétrique*

Le risque de fibrillation est approximativement le même qu'avec un courant alternatif équivalent I_{ev} ayant les caractéristiques suivantes:

a) pour des durées de choc supérieures à environ 1,5 fois la durée du cycle cardiaque, I_{ev} a la même valeur efficace que le courant de la forme d'onde considérée;

The equivalent alternating current I_{ev} is determined:

a) For durations longer than 1.5 times the period of the cardiac cycle by:

$$I_{ev} = \frac{I_{pp}}{2\sqrt{2}} = \frac{I_p}{2\sqrt{2}}$$

Hence for half wave rectification I_{ev} is related to the r. m. s. value of the rectified current I_{rms} by:

$$I_{ev} = \frac{I_{rms}}{\sqrt{2}}$$

and for full wave rectification by:

$$I_{ev} = \frac{I_{rms}}{2}$$

b) For durations shorter than 0.75 times the period of the cardiac cycle:

$$I_{ev} = \frac{I_{pp}}{\sqrt{2}} = \frac{I_p}{\sqrt{2}}$$

Hence for half wave rectification I_{ev} is related to the r. m. s. value of the rectified current I_{rms} by:

$$I_{ev} = \sqrt{2}\, I_{rms}$$

and for full wave rectification by:

$$I_{ev} = I_{rms}$$

5. Effects of alternating current with phase control

5.1 *Waveforms and frequencies*

Figure 16, page 25, shows the waveforms for symmetrical and asymmetrical control.

5.2 *Threshold of perception and threshold of let-go*

As described in the preceding Sub-clauses 4.2 and 4.3, these thresholds depend on different parameters.

The effect of the current in producing sensation or inhibiting let-go is about equal to a pure a. c. with the same peak value I_p. For phase control angles above 120° the peak values increase as a consequence of the decreasing duration of the current flow.

5.3 *Threshold of ventricular fibrillation*

The thresholds differ for symmetrical and asymmetrical waveforms.

5.3.1 *Symmetrical control*

The fibrillation hazard may be taken as being approximately the same as with equivalent alternating current I_{ev} having the following characteristics:

a) for shock-durations longer than approximately 1.5 times the period of the cardiac cycle, I_{ev} has the same r. m.s. value as the current of the relevant waveform concerned;

b) pour des durées de choc inférieures à environ 0,75 fois la durée du cycle cardiaque, I_{ev} est la valeur efficace d'un courant ayant la même valeur de crête que le courant de la forme d'onde considérée;

Note. – Lorsque l'angle de contrôle de phase est supérieur à 120°, il est possible que le seuil de fibrillation soit augmenté.

c) pour les durées de choc comprises entre 0,75 et 1,5 fois la durée du cycle cardiaque, le paramètre de référence passe de la valeur de crête à la valeur efficace.

Note. – Les détails sur la nature de cette variation feront l'objet d'études complémentaires.

5.3.2 *Commande asymétrique*

Le risque de fibrillation est approximativement le même qu'avec un courant alternatif équivalent I_{ev} ayant les caractéristiques suivantes:

a) pour des durées de choc supérieures à environ 1,5 fois la durée du cycle cardiaque, les valeurs sont à l'étude;

b) pour des durées de choc inférieures à environ 0,75 fois la durée du cycle cardiaque, I_{ev} est la valeur efficace d'un courant ayant la même valeur de crête que le courant de la forme d'onde considérée.

Notes 1. – Lorsque l'angle de contrôle de phase est supérieur à 120°, il est possible que le seuil de fibrillation soit augmenté.

2. – Les courants dus à des commandes asymétriques (voir VEI 551-05-19)* peuvent comporter également des composantes continues.

6. Effets du courant alternatif avec commande synchrone par trains d'alternance

6.1 *Formes d'onde et fréquences*

La figure 17, page 24, montre les formes d'onde pour un facteur p égal à 0,67.

6.2 *Seuil de perception et seuil de non-lâcher*

Comme décrit précédemment aux paragraphes 4.2, 4.3, 5.2 et 5.3, ces seuils dépendent de plusieurs paramètres.

Les seuils de perception et de non-lâcher sont à l'étude.

6.3 *Seuil de fibrillation ventriculaire*

Suivant la durée du choc et le facteur de commande, les courants alternatifs avec commande par trains d'alternance sont aussi ou moins dangereux que les courants alternatifs de même durée de choc et de même intensité.

La figure 18, page 26, montre le seuil de fibrillation ventriculaire mesuré sur des porcs pour différents facteurs de commande.

6.3.1 Pour des durées de choc supérieures à environ 1,5 fois la durée du cycle cardiaque, le seuil dépend du facteur de commande p. Pour p voisin de 1, le seuil a la même valeur efficace que pour un courant alternatif sinusoïdal de même durée. Pour p voisin de 0,1, la valeur efficace du courant pendant la période de conduction $I_{1\,eff}$ a la même valeur que celle d'un courant alternatif d'une durée inférieure à 0,75 fois la durée du cycle cardiaque.

Note. – Pour des valeurs intermédiaires de p, le seuil de fibrillation augmente à partir du niveau inférieur indiqué sur la figure 5 de la première partie jusqu'au niveau supérieur indiqué pour des durées de choc inférieures à 0,1 s.

6.3.2 Pour des durées de choc inférieures à environ 0,75 fois la durée du cycle cardiaque, la valeur efficace du courant pendant la période de conduction $I_{1\,eff}$ a la même valeur que celle d'un courant alternatif sinusoïdal de même durée.

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* Publication 50 (551) de la CEI: Vocabulaire Electrotechnique International (VEI), Chapitre 551: Electronique de puissance.

b) for shock-durations shorter than approximately 0.75 times the period of the cardiac cycle, I_{ev} is the r. m. s. value of a current having the same peak value as the current of the relevant waveform concerned;

Note. – For phase control angles above 120° a rise of the threshold of fibrillation is to be expected.

c) in the duration range from 0.75 to 1.5 times the period of the cardiac cycle, the amplitude parameter changes from peak to r. m. s. value.

Note. – The details of the nature of the transition that takes place are subject to further studies.

5.3.2 *Asymmetrical control*

The fibrillation hazard may be taken as being approximately the same as with an equivalent alternating current I_{ev} having the following characteristics:

a) for shock-durations longer than approximately 1.5 times the period of the cardiac cycle: Under consideration.

b) for shock-durations shorter than approximately 0.75 times the period of the cardiac cycle, I_{ev} is the r. m. s. value of a current having the same peak value as the current of the relevant waveform concerned.

Notes 1. – For phase control angles above 120° a rise of the threshold of fibrillation is to be expected.

2. – Currents caused by asymmetrical control (see IEV 551-05-19) * may also have d. c. components.

6. Effects of alternating current with multicycle control

6.1 *Waveforms and frequencies*

Figure 17, page 25, shows the waveforms for a degree of power control of p = 0.67.

6.2 *Threshold of perception and threshold of let-go*

As described in the preceding Sub-clauses 4.2, 4.3, 5.2 and 5.3, these thresholds depend on different parameters.

The threshold of perception and threshold of let-go are under consideration.

6.3 *Threshold of ventricular fibrillation*

Depending on the duration of shock and on the degree of power control alternating currents with multicycle control are equally or less dangerous than a. c. of the same shock duration and current magnitude.

Figure 18, page 27, shows the threshold of ventricular fibrillation measured on pigs for various degrees of power control.

6.3.1 For shock-durations longer than approximately 1.5 times the period of the cardiac cycle, the threshold depends on the degree of power control p. For p near unity it has the same r. m. s. value as a sinusoidal alternating current of the same duration. For p near 0.1 the r. m. s. value of the current during current conduction $I_{1\,rms}$ is the same as the threshold for alternating current of a duration below 0.75 times the period of the cardiac cycle.

Note. – For intermediate values of p, the fibrillation threshold rises from the low level shown in Figure 5 of Part 1 to the high level indicated for shock-durations below 0.1 s.

6.3.2 For shock-durations shorter than approximately 0.75 times the period of the cardiac cycle the r. m. s. value of the current during current conduction $I_{1\,rms}$ is the same as that for a sinusoidal alternating current of the same duration.

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* IEC Publication 50 (551): International Electrotechnical Vocabulary (IEV), Chapter 551: Power Electronics.

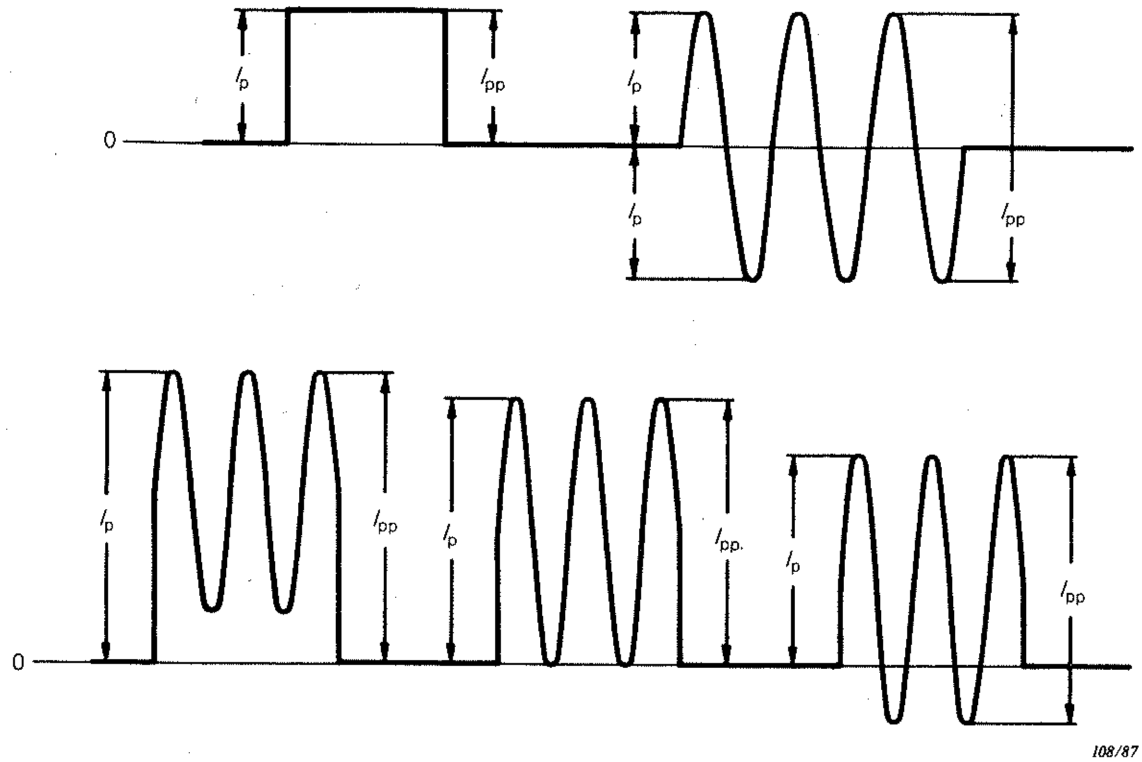


FIG. 14. – Formes d'onde de courant.

a) simple alternance

b) double alternance

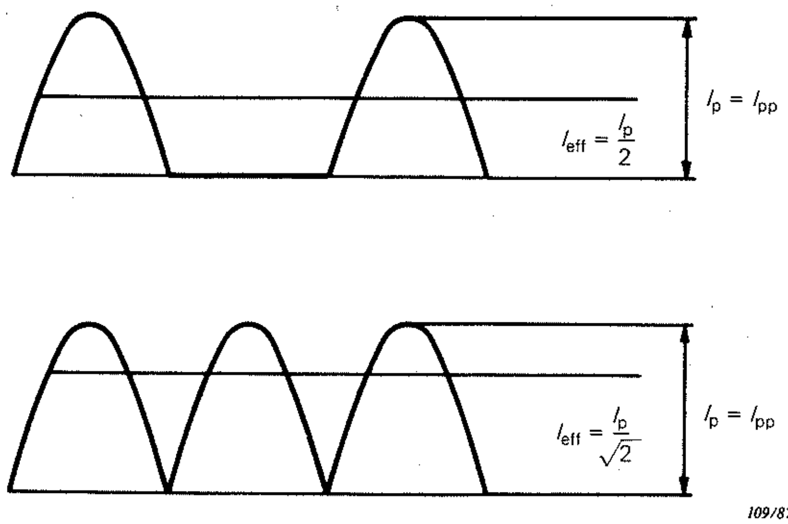


FIG. 15. – Formes d'onde de courant alternatif redressé.

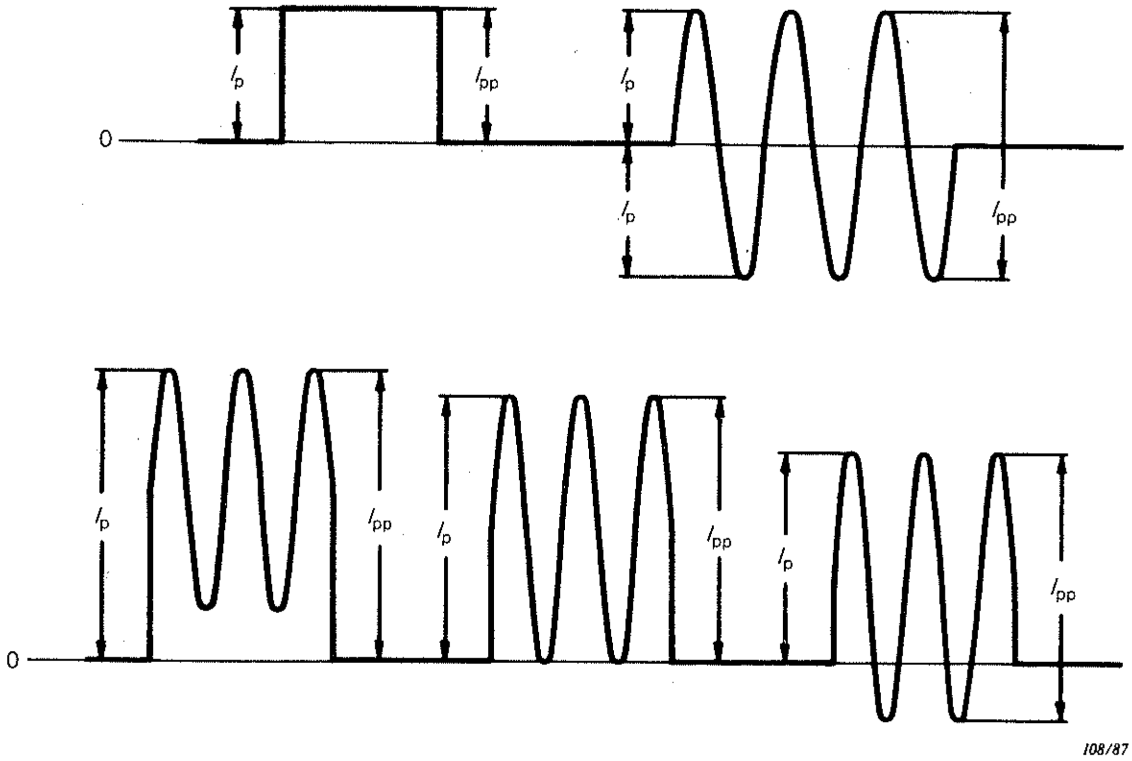


FIG. 14. – Waveforms of currents.

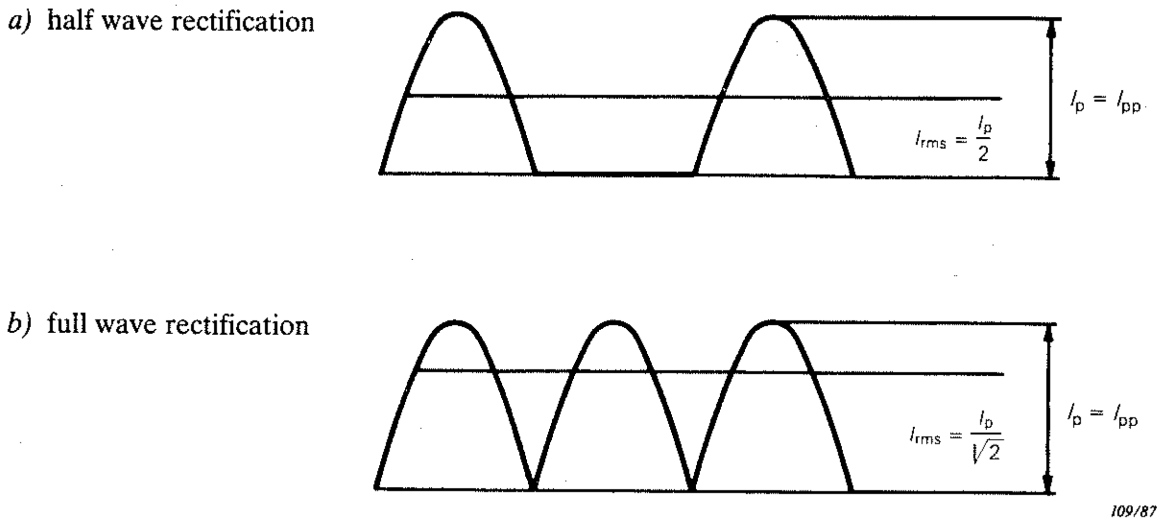
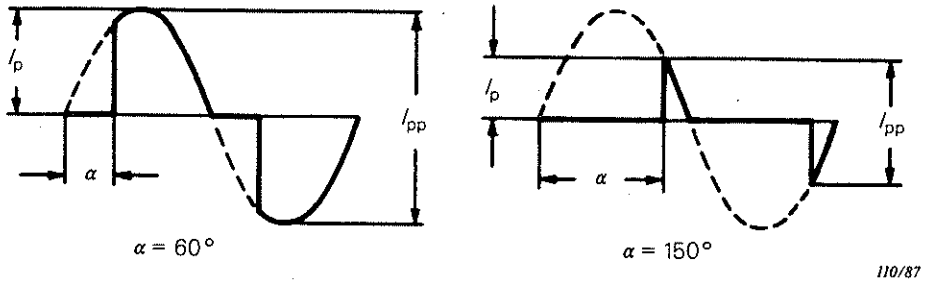


FIG. 15. – Waveforms of rectified alternating currents.

a) contrôle symétrique



b) contrôle asymétrique

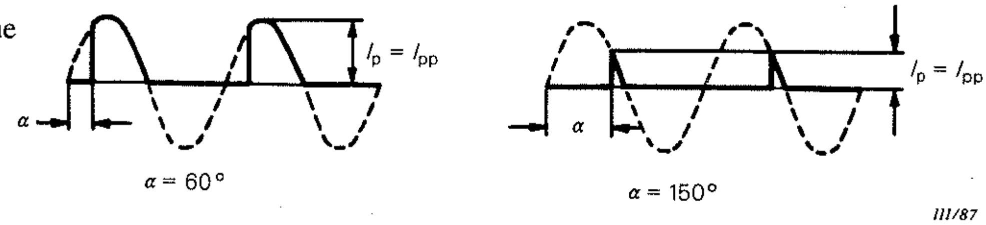
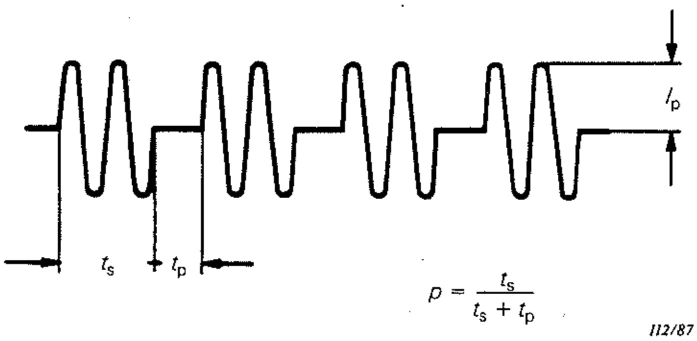


FIG. 16. – Formes d'onde de courant alternatif avec contrôle de l'angle de phase.



t_s = temps de conduction

t_p = temps de non-conduction

$t_s + t_p$ = période de fonctionnement

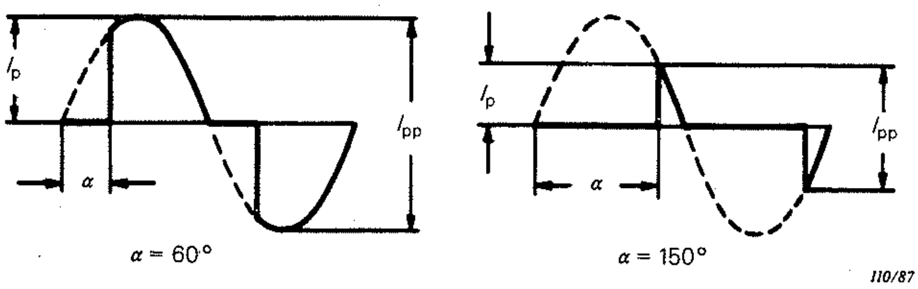
p = facteur de commande

FIG. 17. – Formes d'onde de courant alternatif avec commande synchrone par trains d'alternance.

$$I_{1\,\mathrm{eff}} = \frac{I_p}{\sqrt{2}}$$ = valeur efficace du courant pendant la période de conduction

Note. – Le courant $I_{1\,\mathrm{eff}}$ ne doit pas être confondu avec la valeur efficace du courant pendant la période de fonctionnement $I_{2\,\mathrm{eff}} = I_{1\,\mathrm{eff}}\sqrt{\mathrm{p}}$.

a) symmetrical control



b) asymmetrical control

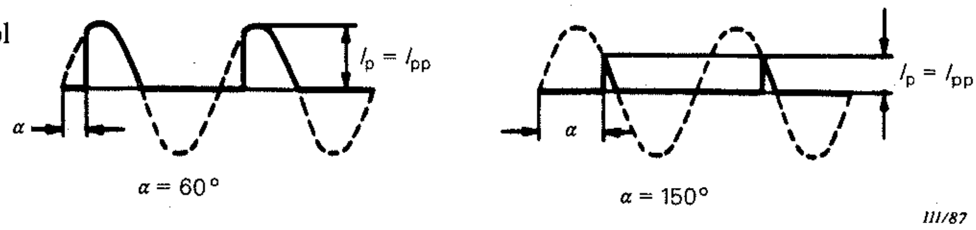
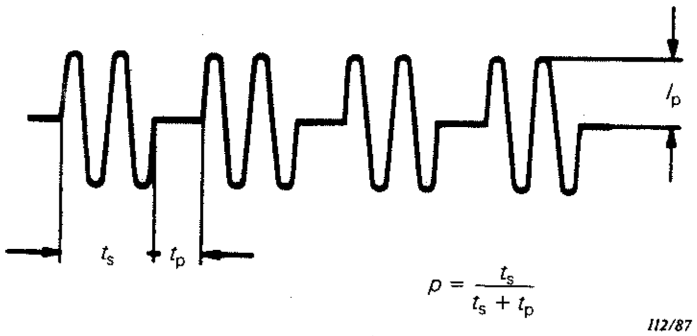


FIG. 16. – Waveforms of alternating currents with phase control.



t_s = conducting time
t_p = non-conducting time

$t_s + t_p$ = working period
p = degree of power control

FIG. 17. – Waveforms of alternating currents with multicycle control.

$$I_{1\,\mathrm{rms}} = \frac{I_p}{\sqrt{2}} = \text{r. m. s. value of current during current conduction}$$

Note. – $I_{1\,\mathrm{rms}}$ is not to be confused with the r. m. s. value of current during working period $I_{2\,\mathrm{rms}} = I_{1\,\mathrm{rms}} \sqrt{p}$.

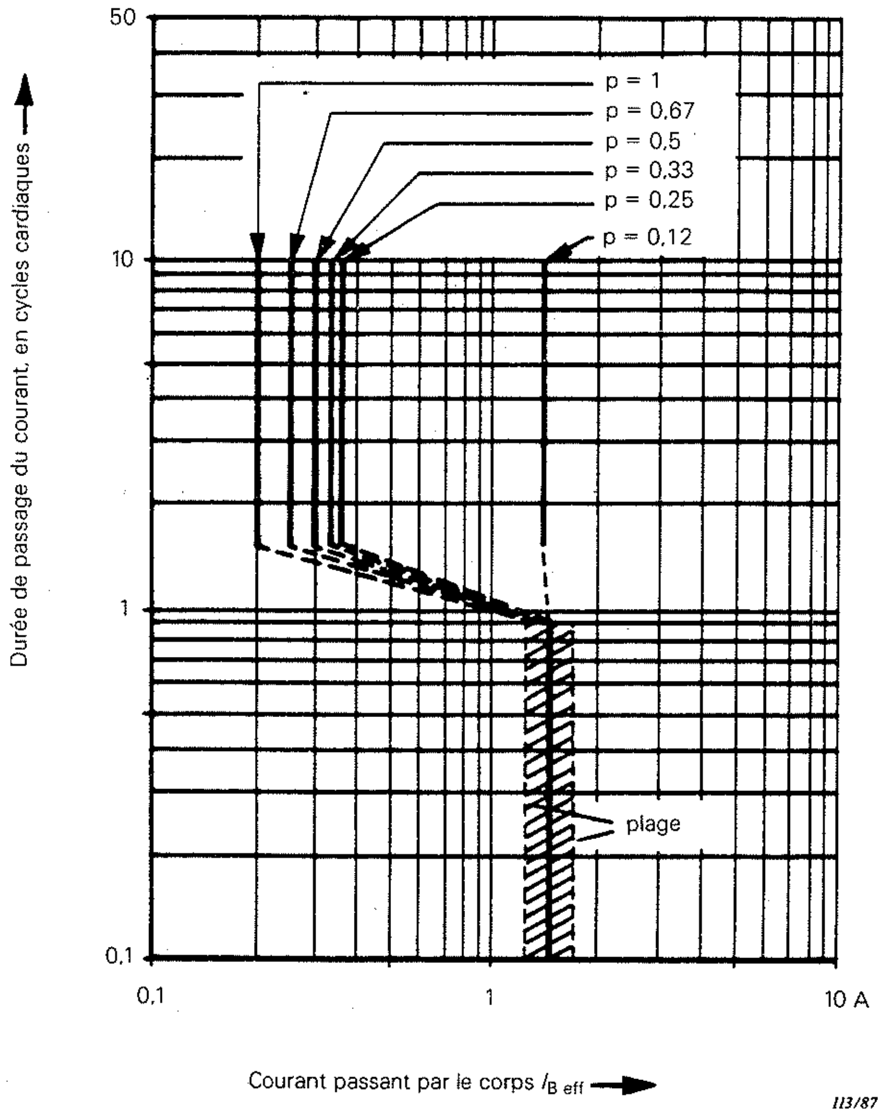


FIG. 18. – Seuil de fibrillation ventriculaire (valeurs moyennes) pour des courants alternatifs avec commande par trains d'alternance pour différents facteurs de commande (résultats d'expériences sur de jeunes porcs).

Note. – Le courant passant par le corps $I_{B\ eff}$ est la valeur efficace du courant pendant la période de conduction $I_{1\ eff}$.

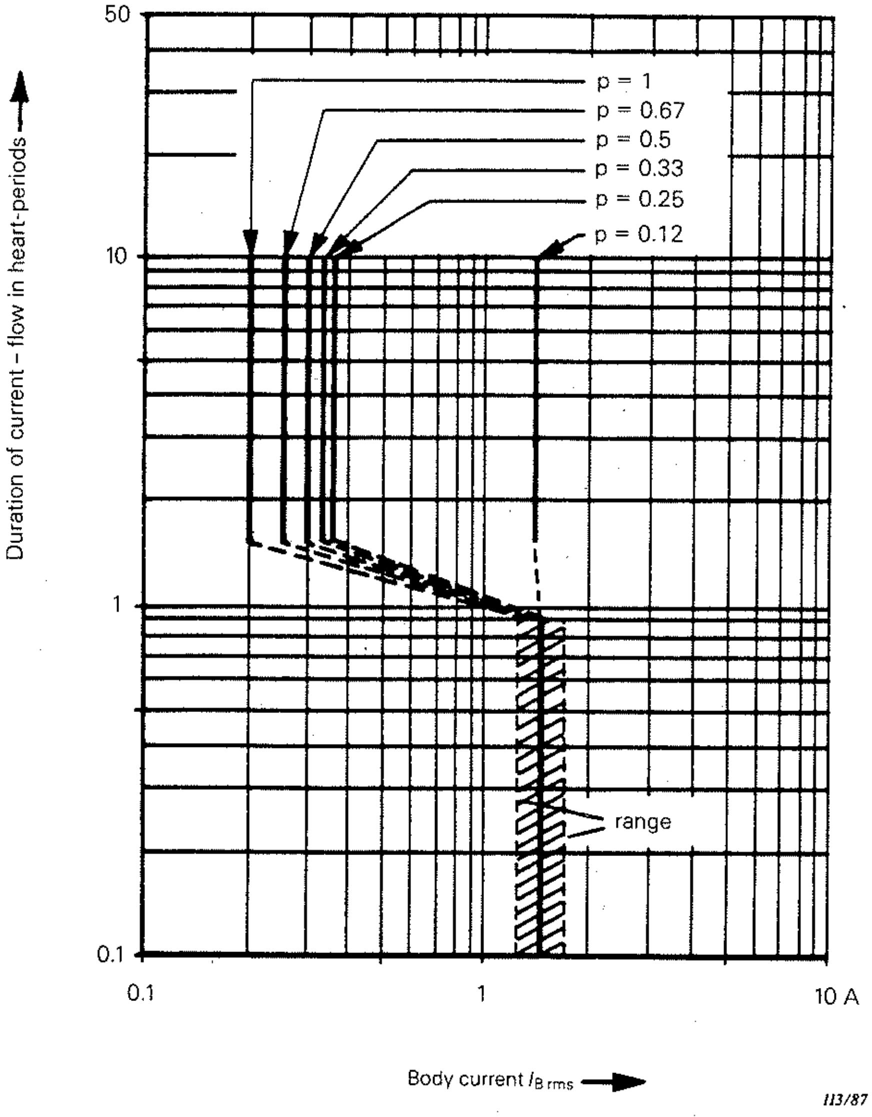


FIG. 18. – Threshold of ventricular fibrillation (average values) for alternating current with multicycle control for various degrees of power control (results of experiments with young pigs).

Note. – Body current $I_{B\,rms}$ is the r.m.s. value of the current during current conduction $I_{1\,rms}$.

CHAPITRE 6: EFFETS DES COURANTS D'IMPULSION UNIQUE DE COURTE DURÉE

1. Généralités

Les courants d'impulsion unique de courte durée de forme rectangulaire ou sinusoïdale ou de décharges de condensateurs peuvent être une source de danger en cas de défaut d'isolement dans un appareil électrique contenant des composants électriques ou en cas de contact avec les parties actives de tels appareils. C'est pourquoi il est important de définir les limites de danger pour de tels courants.

Pour une durée de choc de 10 ms, les effets décrits dans ce chapitre correspondent à ceux qui sont indiqués dans les chapitres 2 à 5, de sorte que la Publication 479 traite de l'ensemble des durées de choc depuis 0,1 ms jusqu'à 10 s pour pratiquement toutes les formes d'onde de courant qui présentent un intérêt technique. Le contenu du présent chapitre est basé sur l'hypothèse déduite de recherches scientifiques, selon laquelle le facteur principal pour provoquer la fibrillation ventriculaire pour les différentes formes de courants d'impulsion est la valeur It ou I^2t pour des chocs de durée au plus égale à 10 ms (voir bibliographie, page 44).

2. Domaine d'application

Le présent chapitre décrit les effets du courant passant par le corps humain pour des courants d'impulsion unique de forme rectangulaire ou sinusoïdale ou résultant de décharges de condensateurs.

Note. – Les effets d'impulsions successives sont à l'étude.

Les valeurs indiquées sont applicables pour des durées d'impulsion de 0,1 ms jusqu'à et y compris 10 ms. Pour des durées d'impulsion supérieures à 10 ms, les valeurs indiquées sur la figure 5 du chapitre 2 sont applicables.

3. Définitions

En plus de celles qui sont données dans les chapitres 2 à 5, les définitions suivantes s'appliquent dans le cadre du présent chapitre:

3.1 *Energie spécifique de fibrillation F_e (Ws/Ω ou A^2s)*

Valeur minimale I^2t de l'impulsion de courte durée qui, dans des conditions données (trajet du courant, phase cardiaque), provoque avec une certaine probabilité la fibrillation ventriculaire.

Note. – F_e est déterminée par la forme de l'impulsion comme l'intégrale

$$\int_0^{t_i} i^2 dt.$$

F_e multipliée par la résistance du corps donne l'énergie dissipée dans le corps humain pendant l'impulsion.

3.2 *Charge spécifique de fibrillation F_q (C ou As)*

Valeur minimale It de l'impulsion de courte durée qui, dans des conditions données (trajet du courant, phase cardiaque) provoque avec une certaine probabilité la fibrillation ventriculaire.

Note. – F_q est déterminée par la forme de l'impulsion comme l'intégrale

$$\int_0^{t_i} i dt.$$

CHAPTER 6: EFFECTS OF UNIDIRECTIONAL SINGLE IMPULSE CURRENTS OF SHORT DURATION

1. General

Unidirectional single impulse currents of short duration in the form of rectangular and sinusoidal impulses or capacitor discharges may be a source of danger in the case of an insulation fault of an electric appliance containing electronic components or when touching live parts of such equipment. It is therefore important to establish the danger limits for these types of currents.

For a shock-duration of 10 ms the effects described in this chapter correspond to those given in Chapters 2 to 5 so that IEC Publication 479 covers the whole range of shock-durations from 0.1 ms to 10 s for nearly all current waveforms which are of technical interest. The content of this chapter is based on the assumption derived from scientific research that the principal factor for the initiation of ventricular fibrillation for the various forms of unidirectional impulse currents is the It or the I^2t value as for shocks of up to 10 ms duration (see Bibliography, page 44).

2. Scope

This chapter describes the effects of current passing through the human body in the form of single unidirectional rectangular impulses, sinusoidal impulses and impulses resulting from capacitor discharges.

Note. – The effects of sequences of impulses are under consideration.

The values specified are deemed to be applicable for impulse durations from 0.1 ms up to and including 10 ms. For impulse durations longer than 10 ms the values given in Figure 5 of Chapter 2 apply.

3. Definitions

In addition to the definitions given in Chapters 2 to 5, the following ones apply for the purpose of this chapter:

3.1 *Specific fibrillating energy F_e (Ws/Ω or A^2s)*

The minimum I^2t value of a unidirectional impulse of short duration which under given conditions (current-path, heart-phase) causes ventricular fibrillation with a certain probability.

Note. – F_e is determined by the form of the impulse as the integral

$$\int_0^{t_i} i^2 \mathrm{d}t.$$

F_e multiplied by the body resistance gives the energy dissipated in the human body during the impulse.

3.2 *Specific fibrillating charge F_q (C or As)*

The minimum It value of a unidirectional impulse of short duration which under given conditions (current-path, heart-phase) causes ventricular fibrillation with a certain probability.

Note. – F_q is determined by the form of the impulse as the integral

$$\int_0^{t_i} i \mathrm{d}t.$$

3.3 *Constante de temps*

Temps nécessaire pour que l'amplitude initiale d'une grandeur d'un champ qui décroît selon une loi exponentielle soit multipliée par le facteur $\frac{1}{e}$ = 0,3679 (VEI 801-01-44). *

3.4 *Durée de choc d'une décharge de condensateur (t_i)*

Temps séparant le début de la décharge du moment où le courant de décharge est descendu à 5% de sa valeur de crête.

Note. – Lorsque la constante de temps de la décharge d'un condensateur est égale à T, la durée de choc de la décharge est égale à 3 T. L'énergie de l'impulsion est pratiquement entièrement dissipée pendant la durée de choc.

3.5 *Seuil de perception*

Valeur minimale de la quantité d'électricité qui, dans des conditions données, provoque une sensation dans la personne qu'elle traverse.

3.6 *Seuil de douleur*

Valeur maximale de la quantité d'électricité (It) ou de l'énergie spécifique (I^2t) qu'une personne peut supporter volontairement en tenant une grande électrode dans la main sans ressentir de douleur.

3.7 *Douleur*

Sensation suffisamment désagréable pour qu'elle ne soit pas acceptée une deuxième fois par la personne qui y est exposée.

Note. – Comme exemples de douleurs, on peut citer un choc électrique supérieur au seuil de douleur décrit au paragraphe 4.3, la piqûre d'une abeille ou la brûlure d'une cigarette.

4. Effets des courants d'impulsion de courte durée

4.1 *Formes d'onde*

La figure 19, page 38, montre la forme des courants d'impulsions rectangulaires, sinusoïdales ou de décharges de condensateurs. Il y a lieu de distinguer les courants suivants:

I_{DC} = intensité du courant d'impulsion rectangulaire,

$I_{AC\,eff}$ = valeur efficace du courant d'impulsion sinusoïdale,

$I_{AC\,(p)}$ = valeur de crête du courant d'impulsion sinusoïdale,

$I_{C\,eff}$ = valeur efficace du courant de décharge d'un condensateur pour une durée de 3 T,

$I_{C\,(p)}$ = valeur de crête du courant de décharge d'un condensateur.

Note. – Si U_c est la tension du condensateur au début de la décharge à travers le corps humain et R_i la résistance initiale du corps, $I_{C\,(p)}$ est égal à:

$$I_{C\,(p)} = \frac{U_c}{R_i}$$

4.2 *Evaluation de l'énergie spécifique de fibrillation F_e*

Pour les formes d'impulsions prises en considération dans ce chapitre, l'énergie F_e est égale à:

a) Pour les impulsions rectangulaires, $F_e = I_{DC}^2 t_i$

b) Pour les impulsions sinusoïdales, $F_e = \frac{I_{AC\,(p)}^2}{2} t_i = I_{AC\,eff}^2 t_i$

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* Publication 50 (801) de la CEI: Vocabulaire Electrotechnique International (VEI), Chapitre 801: Acoustique et électroacoustique.

3.3 *Time constant*

The time required for the amplitude of an exponentially decaying field quantity to decrease to $\frac{1}{e} = 0.3679$ times an initial amplitude (IEV 801-01-44). *

3.4 *Shock-duration of a capacitor discharge* (t_i)

The time interval from the beginning of the discharge to the time when the discharge current has fallen to 5% of its peak value.

Note. – When the time constant of the capacitor discharge is given by T the shock-duration of the capacitor discharge is equal to 3 T. During the shock-duration of the capacitor discharge practically all the energy of the impulse is dissipated.

3.5 *Threshold of perception*

The minimum value for the charge of electricity which under given conditions causes any sensation to the person through whom it is flowing.

3.6 *Threshold of pain*

The maximum value of charge (It) or specific energy (I^2t) that can be applied as an impulse to a person holding a large electrode in the hand without causing pain.

3.7 *Pain*

An unpleasant experience such that it is not readily accepted a second time by the subject submitted to it.

Note. – Examples are an electric shock above the threshold of pain described in Sub-clause 4.3, the sting of a bee or burn of a cigarette.

4. Effects of unidirectional impulse currents of short duration

4.1 *Waveforms*

Figure 19, page 39, shows the forms of currents for rectangular impulses, sinusoidal impulses and for capacitor discharges. The following current magnitudes have to be distinguished:

I_{DC} = magnitude of the current of the rectangular impulse,

$I_{AC\,rms}$ = r. m. s. value of the current of the sinusoidal impulse,

$I_{AC\,(p)}$ = peak value of the current of the sinusoidal impulse,

$I_{C\,rms}$ = r. m. s. value of the current of the capacitor discharge for a duration of 3 T,

$I_{C\,(p)}$ = peak value of the capacitor discharge.

Note. – If U_c is the voltage of the capacitor at the beginning of the discharge through the human body and R_i the initial body resistance, $I_{C\,(p)}$ is determined by:

$$I_{C\,(p)} = \frac{U_c}{R_i}$$

4.2 *Determination of specific fibrillating energy* F_e

The specific fibrillating energy F_e for the different forms of impulses dealt with in this chapter, is determined:

a) For rectangular impulses by $F_e = I_{DC}^2 t_i$

b) For sinusoidal impulses by $F_e = \frac{I_{AC\,(p)}^2}{2} t_i = I_{AC\,rms}^2 t_i$

* IEC Publication 50 (801): International Electrotechnical Vocabulary (IEV), Chapter 801: Acoustics and Electro-acoustics.

c) Pour une décharge de condensateur de constante de temps T:

$$F_e = I_{C\,(p)}^2 \frac{T}{2} = I_{C\,eff}^2 t_i$$

A titre de comparaison, la figure 20, page 38, montre des courants pour des impulsions rectangulaire, sinusoïdale et une décharge de condensateur avec la constante de temps T pour une même énergie spécifique de fibrillation F_e et la même durée de choc t_i. Dans ce cas, les relations suivantes existent:

$$I_{DC} = \frac{I_{AC\,(p)}}{\sqrt{2}} = \frac{I_{C\,(p)}}{\sqrt{6}}$$

Note. – La relation $I_{DC} = \frac{I_{C\,(p)}}{\sqrt{6}}$ est établie comme suit:

$$F_e = I_{C\,(p)}^2 \int_0^{\infty} e^{-\frac{2t}{T}} \, dt = I_{C\,(p)}^2 \frac{T}{2}$$

$$I_{C\,eff}^2\, 3\,T = I_{DC}^2\, 3\,T = I_{C\,(p)}^2 \frac{T}{2}$$

$$I_{C\,eff} = I_{DC} = I_{C\,(p)} \frac{1}{\sqrt{6}}$$

4.3 *Seuil de perception et seuil de douleur de décharges de condensateurs*

Les seuils dépendent de la forme des électrodes, de la charge de l'impulsion et de sa valeur de crête. La figure 21, page 40, montre le seuil de perception et le seuil de douleur en fonction de la quantité d'électricité et de la tension de charge du condensateur pour une personne tenant de larges électrodes avec des mains sèches.

Le seuil de douleur est, en terme d'énergie spécifique, de l'ordre de 50 à 100 · 10^{-6} A^2s pour des passages de courant à travers les extrémités et de grandes surfaces de contact.

4.4 *Seuil de fibrillation ventriculaire*

Le seuil de fibrillation ventriculaire dépend de la forme, de la durée et de l'intensité du courant de l'impulsion, de la phase cardiaque à laquelle l'impulsion commence, du trajet du courant dans le corps humain et des caractéristiques physiologiques de la personne.

Des expériences effectuées sur des animaux ont montré que:

– pour des impulsions de courte durée, la fibrillation ventriculaire ne se produit en général que si l'impulsion a lieu pendant la période vulnérable du cycle cardiaque;
– la charge spécifique de fibrillation F_q ou l'énergie spécifique de fibrillation F_e détermine le début de la fibrillation ventriculaire pour des impulsions unidirectionnelles de durée de choc inférieure à 10 ms.

Les seuils de fibrillation ventriculaire sont indiqués sur la figure 22, page 42. Pour une probabilité de fibrillation de 50%, F_q est de l'ordre de 0,005 As et F_e passe d'environ 0,01 A^2s pour une durée d'impulsion t_i de 4 ms à 0,02 A^2s pour une durée d'impulsion t_i de 1 ms.

4.5 *Exemples*

Afin de montrer l'application pratique des relations décrites dans le présent chapitre, deux exemples sont donnés. Le premier concerne une décharge de condensateur avec une constante de temps T = 1 ms et une durée de choc t_i égale à 3 T soit 3 ms, c'est-à-dire dans le domaine d'application de cette partie. Dans le deuxième exemple, la constante de temps T est de 10 ms, soit une durée de choc t_i de 30 ms pour laquelle les limites de fibrillation ventriculaire sont celles de la figure 5 du chapitre 2.

c) For a capacitor discharge with a time-constant T by

$$F_e = I_{C(p)}^2 \frac{T}{2} = I_{C\,rms}^2 t_i$$

Figure 20, page 39, compares the current magnitudes for rectangular impulses, sinusoidal impulses and a capacitor discharge with the time constant T having the same specific fibrillating energy F_e and the same shock-duration t_i. In this case the following relationships exist:

$$I_{DC} = \frac{I_{AC(p)}}{\sqrt{2}} = \frac{I_{C(p)}}{\sqrt{6}}$$

Note. – The relationship $I_{DC} = \frac{I_{C(p)}}{\sqrt{6}}$ is derived as follows:

$$F_e = I_{C(p)}^2 \int_0^{\infty} e^{-\frac{2t}{T}} dt = I_{C(p)}^2 \frac{T}{2}$$

$$I_{C\,rms}^2\, 3\,T = I_{DC}^2\, 3\,T = I_{C(p)}^2 \frac{T}{2}$$

$$I_{C\,rms} = I_{DC} = I_{C(p)} \frac{1}{\sqrt{6}}$$

4.3 *Threshold of perception and threshold of pain for capacitor discharge*

The thresholds depend on the form of the electrodes, on the charge of the impulse and on its peak current value. Figure 21, page 41, shows the threshold of perception and the threshold of pain as a function of the charge and the charging voltage of the capacitor for a person holding large electrodes with dry hands.

The threshold of pain in terms of specific energy is in the order of 50 to 100 $\cdot\, 10^{-6}$ A^2s for current paths through the extremities and large contact areas.

4.4 *Threshold of ventricular fibrillation*

The threshold of ventricular fibrillation depends on the form, duration and magnitude of the current of the impulse, the heart phase in which the impulse starts, the current path in the human body and on the physiological characteristics of the person.

Experiments on animals show:

- that for impulses of short duration ventricular fibrillation in general results only if the impulse falls within the vulnerable period of the cardiac cycle;
- that the specific fibrillating charge F_q or the specific fibrillating energy F_e determines the initiation of ventricular fibrillation for unidirectional impulses for shock-durations shorter than 10 ms.

Thresholds for ventricular fibrillation are shown in Figure 22, page 43. For 50% probability of fibrillation, F_q is of the order of 0.005 As and F_e rises from about 0.01 A^2s at an impulse duration t_i = 4 ms to 0.02 A^2s for t_i = 1 ms.

4.5 *Examples*

In order to explain the practical application of the relationships described in this chapter, two examples are given. The first example deals with a capacitor discharge with a time constant of T = 1 ms and a shock-duration $t_i = 3\,T$ = 3 ms and is within the scope of this part. In the second example, the time constant is T = 10 ms, i.e. t_i = 30 ms which means that the limits for ventricular fibrillation are those given in Figure 5 of Chapter 2.

Exemple 1

Effets de décharges de condensateur sur le corps humain:

Condensateur C = 1 µF, tensions de charge 10 V, 100 V, 1000 V et 10000 V.

Trajet du courant: main–pied, résistance initiale du corps humain R_i estimée à 1000 Ω.*

Constante de temps T = 1 ms, soit une durée de choc $t_i = 3\,T$ = 3 ms.

Energie spécifique de fibrillation $F_e = I^2_{C\,eff} t_i \approx \dfrac{W_C}{R_i}$

Effets des chocs:

Tension de charge U_c (V)	10	100	1000	10000
Courant de décharge Valeur de crête $I_{C\,(p)}$ (A)	0,01	0,1	1	10
Courant de décharge Valeur efficace (A) $I_{C\,eff} = \dfrac{I_{C\,(p)}}{\sqrt{6}}$	0,004	0,04	0,4	4
Charge spécifique F_q (As)	$0{,}01 \cdot 10^{-3}$	$0{,}1 \cdot 10^{-3}$	10^{-3}	$10 \cdot 10^{-3}$
Energie de décharge W_C (Ws)	$0{,}05 \cdot 10^{-3}$	$5 \cdot 10^{-3}$	0,5	50
Energie spécifique de fibrillation F_e (R_i = 1000 Ω) (A^2s)	$0{,}048 \cdot 10^{-6}$	$4{,}8 \cdot 10^{-6}$	$0{,}48 \cdot 10^{-3}$	$48 \cdot 10^{-3}$
Effets physiologiques	faibles	désagréables	douloureux	fibrillation ventriculaire possible

* La valeur de R_i de 1000 Ω est choisie arbitrairement à des fins de calcul seulement pour cet exemple. A ne pas confondre avec la valeur de R_i correspondant à un pourcentage de probabilité de 5% indiquée dans l'article 6 du chapitre 1.

Example 1

Effects of capacitor discharge on the human body:

Capacitor C = 1 μF, charging voltages 10 V, 100 V, 1000 V and 10000 V.

Current-path: hand–foot, initial body resistance assumed to be $R_i = 1000\,\Omega$.*

Time constant $T = 1$ ms, i. e. shock-duration $t_i = 3\,T = 3$ ms.

Specific fibrillating energy $F_e = I^2_{C\,rms} t_i \approx \dfrac{W_C}{R_i}$

Effects of shocks:

Charging voltage U_c (V)	10	100	1000	10000
Discharge current Peak value $I_{C\,(p)}$ (A)	0.01	0.1	1	10
Discharge current r. m. s. value (A) $I_{C\,rms} = \dfrac{I_{C\,(p)}}{\sqrt{6}}$	0.004	0.04	0.4	4
Specific charge F_q (As)	$0.01 \cdot 10^{-3}$	$0.1 \cdot 10^{-3}$	10^{-3}	$10 \cdot 10^{-3}$
Discharge energy W_C (Ws)	$0.05 \cdot 10^{-3}$	$5 \cdot 10^{-3}$	0.5	50
Specific fibrillating energy F_e ($R_i = 1000\,\Omega$) (A^2s)	$0.048 \cdot 10^{-6}$	$4.8 \cdot 10^{-6}$	$0.48 \cdot 10^{-3}$	$48 \cdot 10^{-3}$
Physiological effects	slight	disagreeable	painful	ventricular fibrillation likely

* The value of R_i of 1000 Ω has been arbitrarily chosen for the purpose of this example. Not to be confused with the value of R_i for 5% percentile rank of Clause 6 of Chapter 1.

Exemple 2

Effets de décharges de condensateur sur le corps humain:

Condensateur C = 20 µF, tensions de charge 10 V, 100 V, 1000 V et 10000 V.

Trajet du courant: main–tronc, résistance initiale du corps R_i estimée à 500 Ω.*

Constante de temps $T = 10$ ms, soit une durée de choc $t_i = 3\ T = 30$ ms.**

Effets des chocs:

Tension de charge U_c (V)	10	100	1000	10000
Courant de décharge Valeur de crête $I_{C(p)}$ (A)	0,02	0,2	2	20
Courant de décharge Valeur efficace (A) $I_{C\,eff} = \frac{I_{C\,(p)}}{\sqrt{6}}$	0,008	0,08	0,8	8
Charge spécifique F_q (As)**	$0{,}2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$20 \cdot 10^{-3}$	$200 \cdot 10^{-3}$
Energie de décharge W_C (Ws)	$1 \cdot 10^{-3}$	0,1	10	1000
Energie spécifique de fibrillation F_e (A^2s)**	–	–	–	–
Effets physiologiques	faibles	douloureux	dangereux, mais fibrillation ventriculaire improbable	dangereux et fibrillation ventriculaire possible

* La valeur de R_i de 500 Ω est choisie arbitrairement à des fins de calcul seulement pour cet exemple. A ne pas confondre avec la valeur de R_i correspondant à un pourcentage de probabilité de 5% indiquée dans l'article 6 du chapitre 1.

** Comme la durée de choc t_i est supérieure à 10 ms, les seuils de fibrillation sont à reprendre de la figure 5 du chapitre 2.

Example 2

Effects of capacitor discharge on the human body:

Capacitor C = 20 μF, charging voltage 10 V, 100 V, 1000 V and 10000 V.

Current-path: hand–trunk of body, initial body resistance assumed to be $R_i = 500\,\Omega$.*

Time constant $T = 10$ ms, i. e. shock-duration $t_i = 3\,T = 30$ ms.**

Effects of shocks:

Charging voltage U_c (V)	10	100	1000	10000
Discharge current Peak value $I_{C(p)}$ (A)	0.02	0.2	2	20
Discharge current r. m. s. value (A) $I_{C\,rms} = \frac{I_{C\,(p)}}{\sqrt{6}}$	0.008	0.08	0.8	8
Specific charge F_q (As)**	$0.2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$20 \cdot 10^{-3}$	$200 \cdot 10^{-3}$
Discharge energy W_C (Ws)	$1 \cdot 10^{-3}$	0.1	10	1000
Specific fibrillating energy F_e (A^2s)**	–	–	–	–
Physiological effects	slight	painful	dangerous, but ventricular fibrillation unlikely	dangerous, and ventricular fibrillation likely

* The value of R_i of 500 Ω has been arbitrarily chosen for the purpose of this example. Not to be confused with the value of R_i for the 5% percentile rank of Clause 6 of Chapter 1.

** As the shock duration t_i is longer than 10 ms, fibrillation thresholds are to be taken from Figure 5 in Chapter 2.

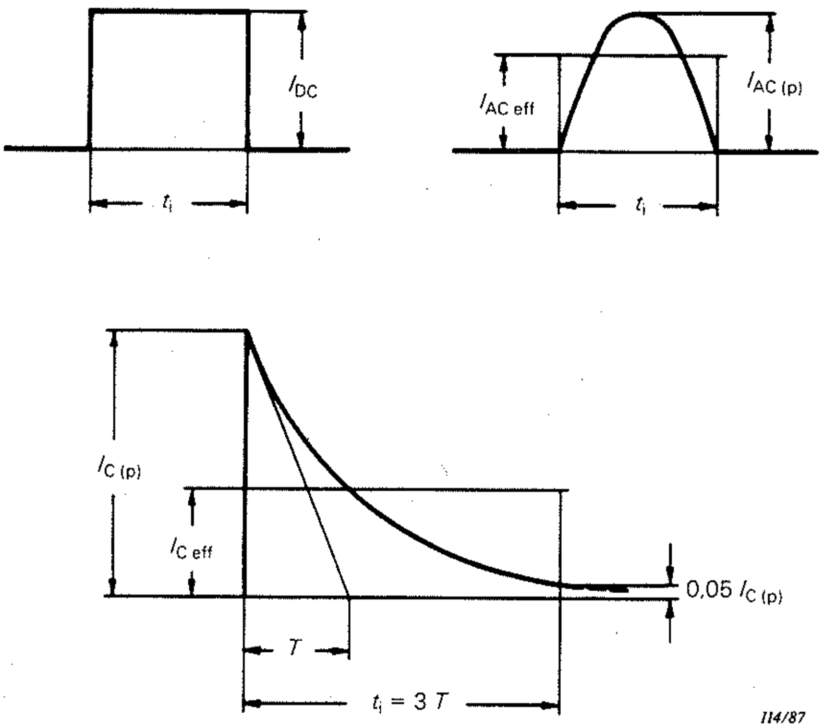

FIG. 19. – Formes des courants pour des impulsions rectangulaires, sinusoïdales et pour des décharges de condensateur.

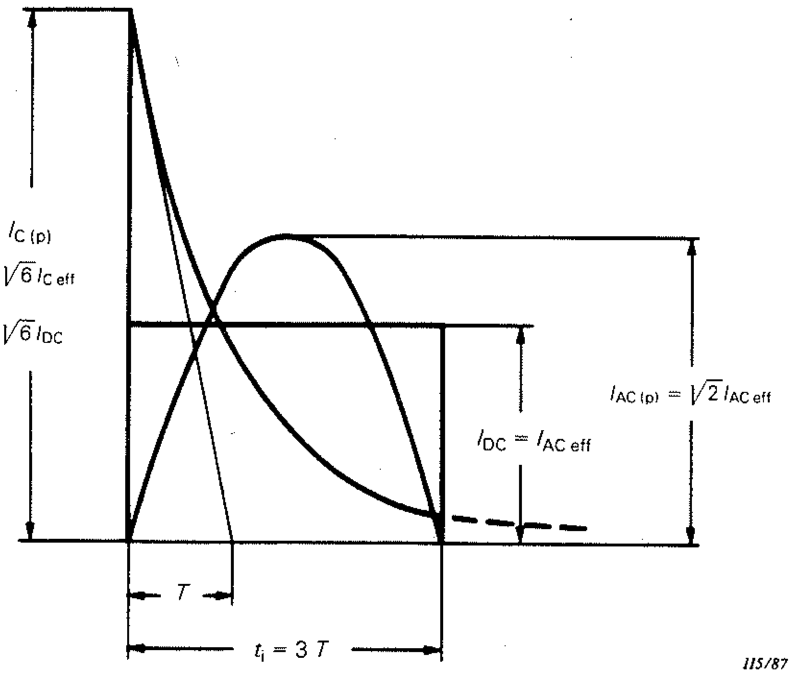

FIG. 20. – Impulsions rectangulaire, sinusoïdale et décharge de condensateur, ayant la même énergie spécifique de fibrillation et la même durée de choc.

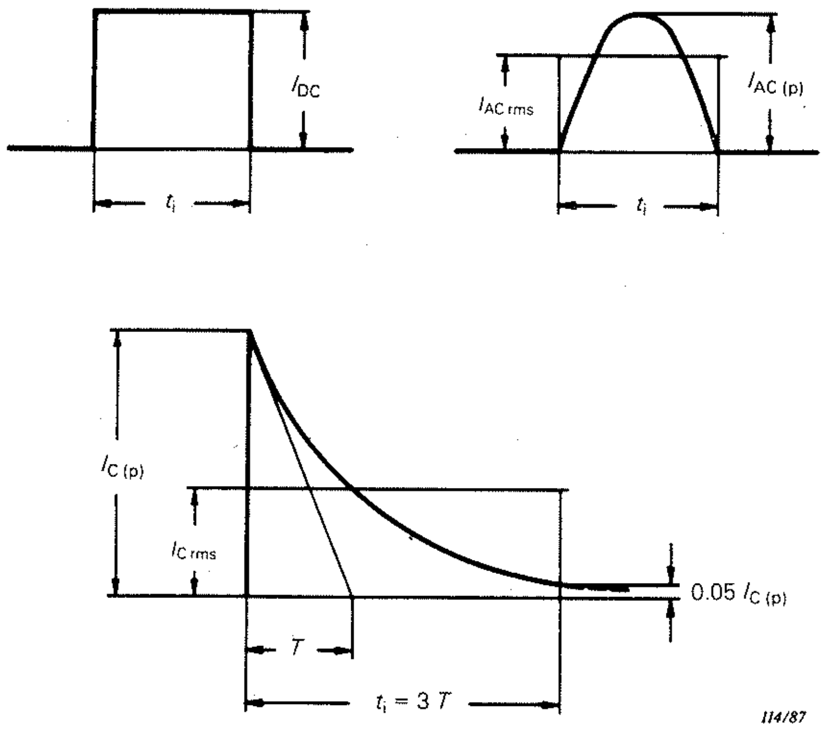

FIG. 19. – Forms of current for rectangular impulses, sinusoidal impulses and for capacitor discharges.

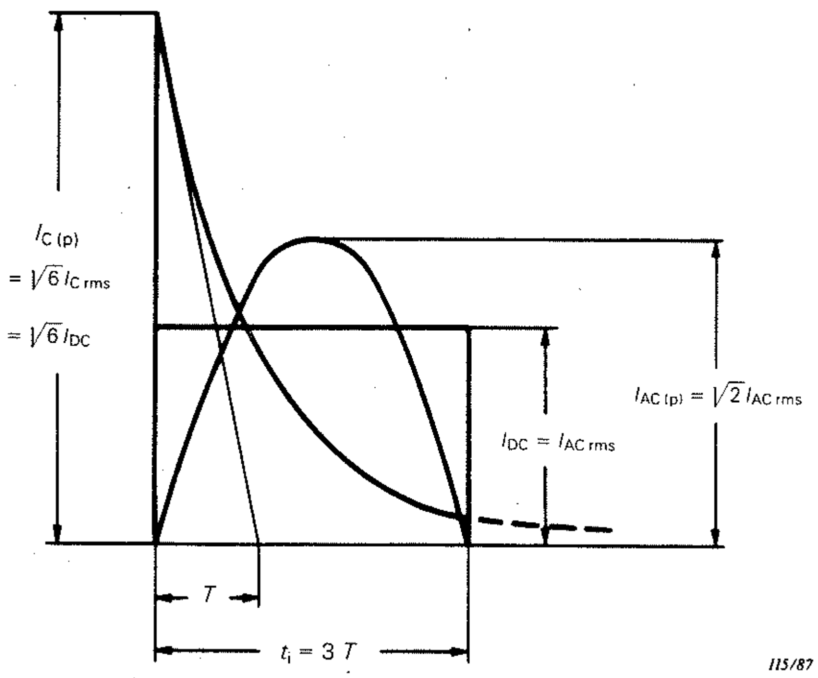

FIG. 20. – Rectangular impulse, sinusoidal impulse and capacitor discharge having the same specific fibrillating energy and the same shock-duration.

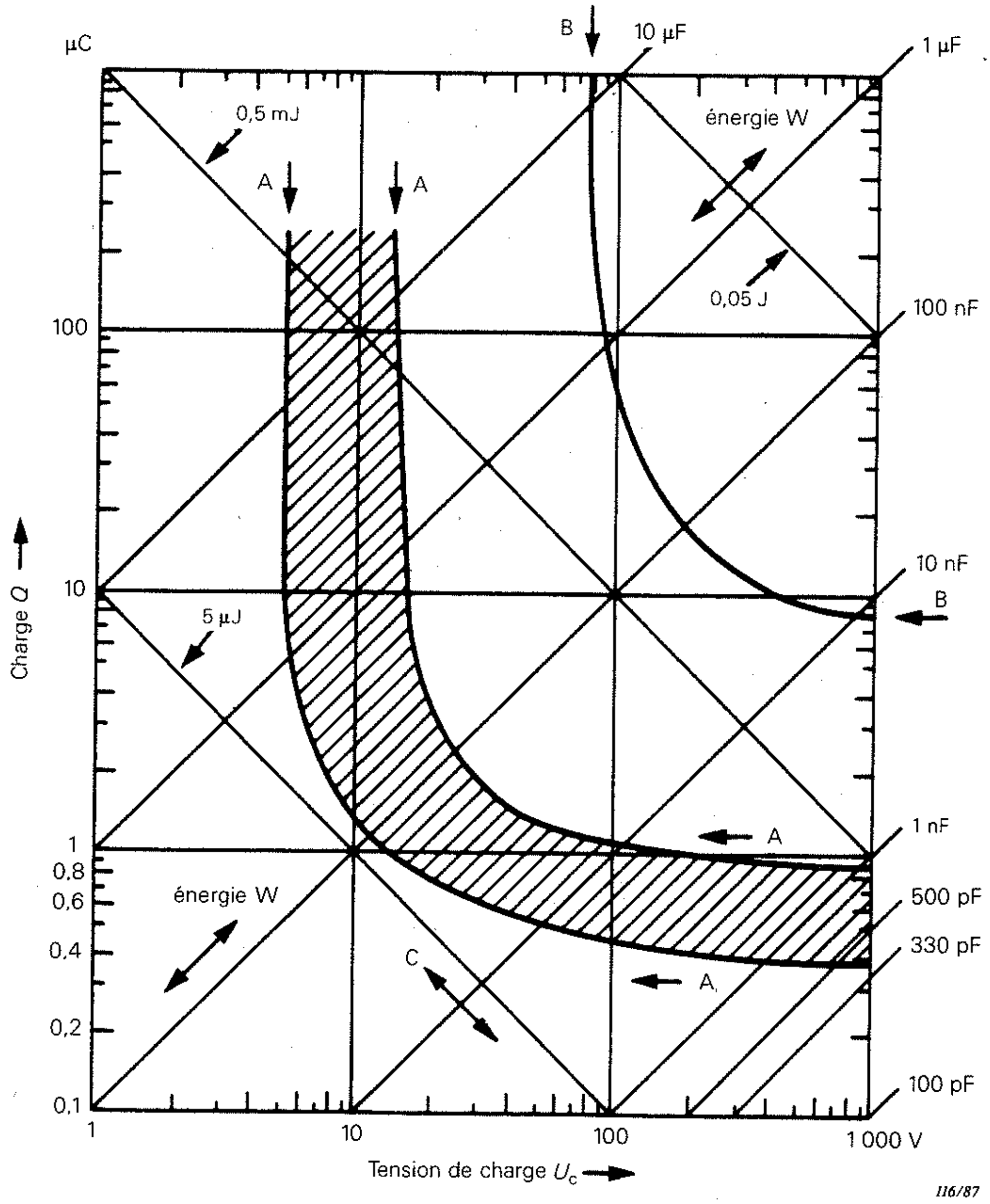

FIG. 21. – Seuil de perception et seuil de douleur pour des décharges de condensateur (mains sèches, grandes surfaces de contact).

Zone A: Seuil de perception. Courbe B: Seuil typique de douleur.

Note. – Les échelles des diagonales indiquent les valeurs de capacité (C) et d'énergie (W). A l'intersection des valeurs de tension de charge et de capacité, les valeurs de charge et d'énergie d'impulsion peuvent être lues sur les axes appropriés.

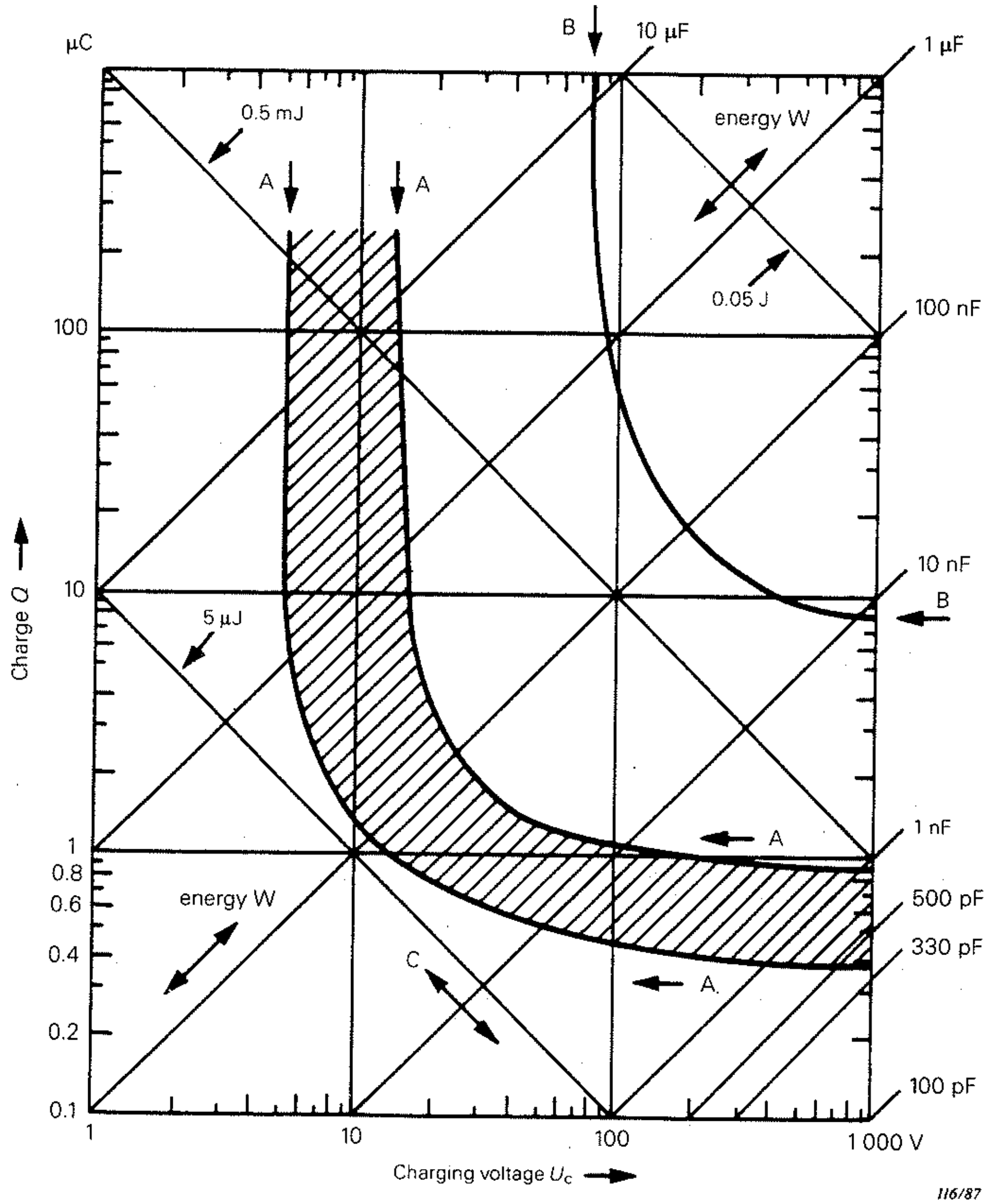

FIG. 21. – Threshold of perception and threshold of pain for capacitor discharges (dry hands, large contact areas).

Zone A: Threshold of perception. Curve B: Typical threshold of pain.

Note. – The diagonal axes are scaled for capacitance (C) and energy (W). From the intersection of the co-ordinates for charging voltage and capacitance the charge and the energy of the impulse can be read on the appropriate axes.

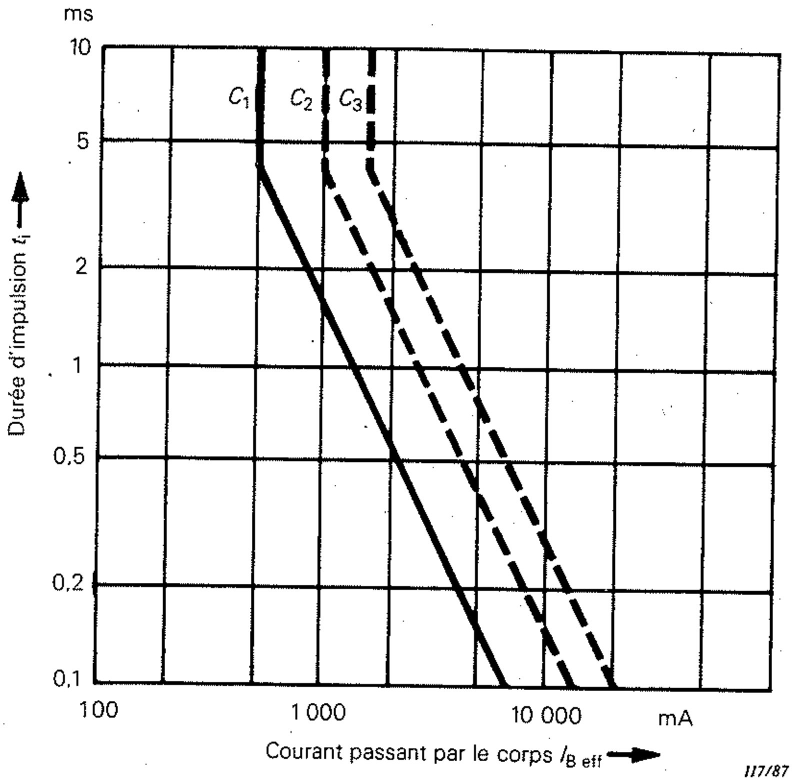

FIG. 22. – Seuils de fibrillation ventriculaire.

Les courbes indiquent les probabilités des risques de fibrillation dus au courant traversant le corps humain entre la main gauche et les deux pieds. Pour d'autres trajets de courant, voir l'article 5 et le tableau III du chapitre 2.

au-dessous de C_1:	pas de fibrillation,
au-dessus de C_1 jusqu'à C_2:	faible risque de fibrillation (jusqu'à 5% de probabilité),
au-dessus de C_2 jusqu'à C_3:	risque moyen de fibrillation (jusqu'à 50% de probabilité),
au-dessus de C_3:	risque important de fibrillation (plus de 50% de probabilité).

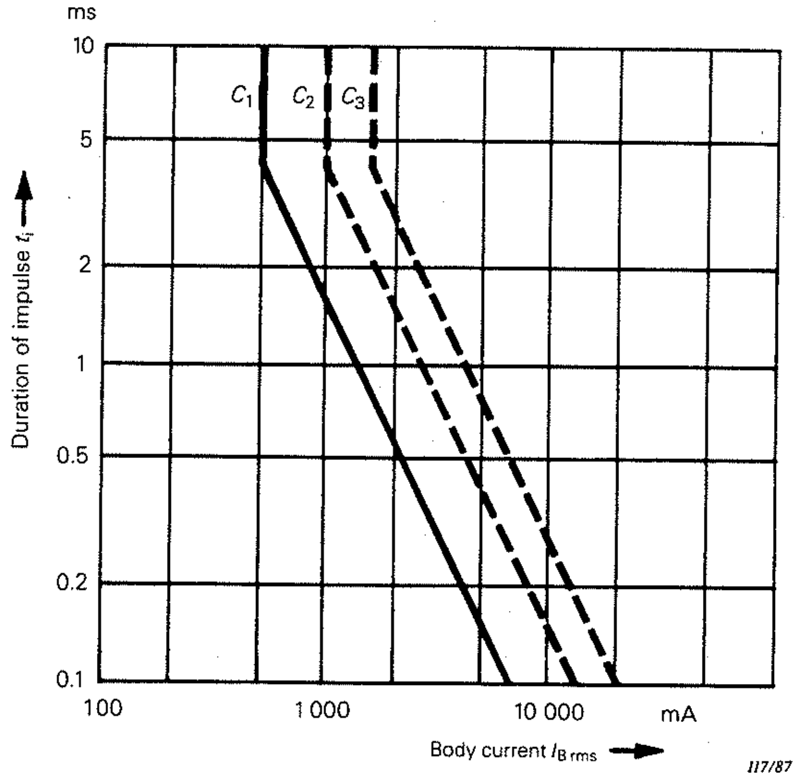

FIG. 22. – Threshold of ventricular fibrillation.

The curves indicate the probability of fibrillation risks for current flowing in the path left hand to feet. For other current paths, see Clause 5 and Table III of Chapter 2.

below C_1:	no fibrillation,
above C_1 up to C_2:	low risk of fibrillation (up to 5% probability),
above C_2 up to C_3:	average risk of fibrillation (up to 50% probability),
above C_3:	high risk of fibrillation (more than 50% probability).

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* Cette liste n'est pas exhaustive. Une bibliographie plus complète a été publiée par UNIPÈDE (Union internationale des producteurs et distributeurs d'énergie électrique).

* This list is not exhaustive. A more comprehensive bibliography has been published by UNIPEDE (Union Internationale des Producteurs et Distributeurs d'Énergie Electrique).

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364-7-706 (1983)	Section 706: Restrictive conducting locations.
364-7-707 (1984)	Section 707: Earthing requirements for the installation of data processing equipment.
449 (1973)	Voltage bands for electrical installations of buildings. Amendment No. 1 (1979).

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479: — Effects of current passing through the human body.

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585: — Electrical installation guide.

585-1 (1977)	Caravans, boats and yachts.

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IEEE Std 80-2000
(Revision of
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IEEE Guide for Safety in AC Substation Grounding

Sponsor

Substations Committee
of the
IEEE Power Engineering Society

Approved 30 January 2000

IEEE-SA Standards Board

Abstract: Outdoor ac substations, either conventional or gas-insulated, are covered in this guide. Distribution, transmission, and generating plant substations are also included. With proper caution, the methods described herein are also applicable to indoor portions of such substations, or to substations that are wholly indoors. No attempt is made to cover the grounding problems peculiar to dc substations. A quantitative analysis of the effects of lightning surges is also beyond the scope of this guide.
Keywords: ground grids, grounding, substation design, substation grounding

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Introduction

(This introduction is not part of IEEE Std 80-2000, IEEE Guide for Safety in AC Substation Grounding.)

This fourth edition represents the second major revision of this guide since its first issue in 1961. Major modifications include the further extension of the equations for calculating touch and step voltages to include L-shaped and T-shaped grids; the introduction of curves to help determine current division; modifications to the derating factor curves for surface material; changes in the criteria for selection of conductors and connections; additional information on resistivity measurement interpretation; and the discussion of multilayer soils. Other changes and additions were made in the areas of gas-insulated substations, the equations for the calculation of grid resistance, and the annexes. The fourth edition continues to build on the foundations laid by three earlier working groups: AIEE Working Group 56.1 and IEEE Working Groups 69.1 and 78.1.

The work of preparing this standard was done by Working Group D7 of the Distribution Substation Subcommittee and was sponsored by the Substation Committee of the IEEE Power Engineering Society. At the time this guide was completed, the Substation Grounding Safety Working Group, D7, had the following membership:

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This fourth edition of IEEE Std 80 is dedicated to the memory of J. G. Sverak, who, through his technical knowledge and expertise, developed the touch and step voltage equations and the grid resistance equations used in the 1986 edition of this guide. His leadership, humor, and perseverance as Chair of Working Group 78.1 led to the expansion of substation grounding knowledge in IEEE Std 80-1986.

The following members of the balloting committee voted on this standard:

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Contents

IEEE Guide for Safety in AC Substation Grounding

1. Overview

1.1 Scope

This guide is primarily concerned with outdoor ac substations, either conventional or gas-insulated. Distribution, transmission, and generating plant substations are included. With proper caution, the methods described herein are also applicable to indoor portions of such substations, or to substations that are wholly indoors.[1]

No attempt is made to cover the grounding problems peculiar to dc substations. A quantitative analysis of the effects of lightning surges is also beyond the scope of this guide.

1.2 Purpose

The intent of this guide is to provide guidance and information pertinent to safe grounding practices in ac substation design.

The specific purposes of this guide are to

a) Establish, as a basis for design, the safe limits of potential differences that can exist in a substation under fault conditions between points that can be contacted by the human body.
b) Review substation grounding practices with special reference to safety, and develop criteria for a safe design.
c) Provide a procedure for the design of practical grounding systems, based on these criteria.
d) Develop analytical methods as an aid in the understanding and solution of typical gradient problems.

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[1]Obviously, the same ground gradient problems that exist in a substation yard should not be present within a building. This will be true provided the floor surface either assures an effective insulation from earth potentials, or else is effectively equivalent to a conductive plate or close mesh grid that is always at substation ground potential, including the building structure and fixtures.

Therefore, even in a wholly indoor substation it may be essential to consider some of the possible hazards from perimeter gradients (at building entrances) and from transferred potentials described in Clause 8. Furthermore, in the case of indoor gas-insulated facilities, the effect of circulating enclosure currents may be of concern, as discussed in Clause 10.

The concept and use of safety criteria are described in Clause 1 through Clause 8, practical aspects of designing a grounding system are covered in Clause 9 through Clause 13, and procedures and evaluation techniques for the grounding system assessment (in terms of safety criteria) are described in Clause 14 through Clause 20. Supporting material is organized in Annex A through Annex G.

This guide is primarily concerned with safe grounding practices for power frequencies in the range of 50–60 Hz. The problems peculiar to dc substations and the effects of lightning surges are beyond the scope of this guide. A grounding system designed as described herein will, nonetheless, provide some degree of protection against steep wave front surges entering the substation and passing to earth through its ground electrodes.[2] Other references should be consulted for more information about these subjects.

1.3 Relation to other standards

The following standards provide information on specific aspects of grounding:

— IEEE Std 81-1983[3] and IEEE Std 81.2-1991 provide procedures for measuring the earth resistivity, the resistance of the installed grounding system, the surface gradients, and the continuity of the grid conductors.

— IEEE Std 142-1991, also known as the IEEE Green Book, covers some of the practical aspects of grounding, such as equipment grounding, cable routing to avoid induced ground currents, cable sheath grounding, static and lightning protection, indoor installations, etc.

— IEEE Std 367-1996 provides a detailed explanation of the asymmetrical current phenomenon and of the fault current division, which to a large degree parallels that given herein. Of course, the reader should be aware that the ground potential rise calculated for the purpose of telecommunication protection and relaying applications is based on a somewhat different set of assumptions concerning the maximum grid current, in comparison with those used for the purposes of this guide.

— IEEE Std 665-1995 provides a detailed explanation of generating station grounding practices.

— IEEE Std 837-1989 provides tests and criteria to select connections to be used in the grounding system that will meet the concerns described in Clause 11.

2. References

This guide should be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

Accredited Standards Committee C2-1997, National Electrical Safety Code® (NESC®).[4]

IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (Part 1).[5]

IEEE Std 81.2-1992, IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems (Part 2).

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[2]The greater impedance offered to steep front surges will somewhat increase the voltage drop in ground leads to the grid system, and decrease the effectiveness of the more distant parts of the grid. Offsetting this in large degree is the fact that the human body apparently can tolerate far greater current magnitudes in the case of lightning surges than in the case of 50 Hz or 60 Hz currents.

[3]Information on references can be found in Clause 2.

[4]The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[5]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).

IEEE Std 367-1996, IEEE Recommended Practice for Determining the Electric Power Substation Ground Potential Rise and Induced Voltage from a Power Fault.

IEEE Std 487-1992, IEEE Recommended Practice for the Protection of Wire-Line and Communication Facilities Serving Electric Power Stations.

IEEE Std 525-1992 (Reaff 1999), IEEE Guide for the Design and Installation of Cable Systems in Substations.

IEEE Std 665-1995, IEEE Guide for Generating Station Grounding.

IEEE Std 837-1989 (Reaff 1996), IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.

IEEE Std 1100-1999, IEEE Recommended Practice for Powering and Grounding Electronic Equipment (IEEE Emerald Book).

IEEE Std C37.122-1993, IEEE Standard for Gas-Insulated Substations.

IEEE Std C37.122.1-1993, IEEE Guide for Gas-Insulated Substations.

3. Definitions

Most of the definitions given herein pertain solely to the application of this guide. No further references will be made to any of the definitions stated below, unless necessary for clarity. All other definitions are placed within the text of individual clauses. For additional definitions refer to *The IEEE Standard Dictionary of Electrical and Electronics Terms* [B86].[6]

3.1 auxiliary ground electrode: A ground electrode with certain design or operating constraints. Its primary function may be other than conducting the ground fault current into the earth.

3.2 continuous enclosure: A bus enclosure in which the consecutive sections of the housing along the same phase conductor are bonded together to provide an electrically continuous current path throughout the entire enclosure length. Cross-bondings, connecting the other phase enclosures, are made only at the extremities of the installation and at a few selected intermediate points.

3.3 dc offset: Difference between the symmetrical current wave and the actual current wave during a power system transient condition. Mathematically, the actual fault current can be broken into two parts, a symmetrical alternating component and a unidirectional (dc) component. The unidirectional component can be of either polarity, but will not change polarity, and will decrease at some predetermined rate.

3.4 decrement factor: An adjustment factor used in conjunction with the symmetrical ground fault current parameter in safety-oriented grounding calculations. It determines the rms equivalent of the asymmetrical current wave for a given fault duration, t_f, accounting for the effect of initial dc offset and its attenuation during the fault.

[6]The numbers in brackets correspond to those of the bibliography in Annex A.

3.5 effective asymmetrical fault current: The rms value of asymmetrical current wave, integrated over the interval of fault duration (see Figure 1).

$$I_F = D_f \times I_f \tag{1}$$

where

I_F is the effective asymmetrical fault current in A
I_f is the rms symmetrical ground fault current in A
D_f is the decrement factor

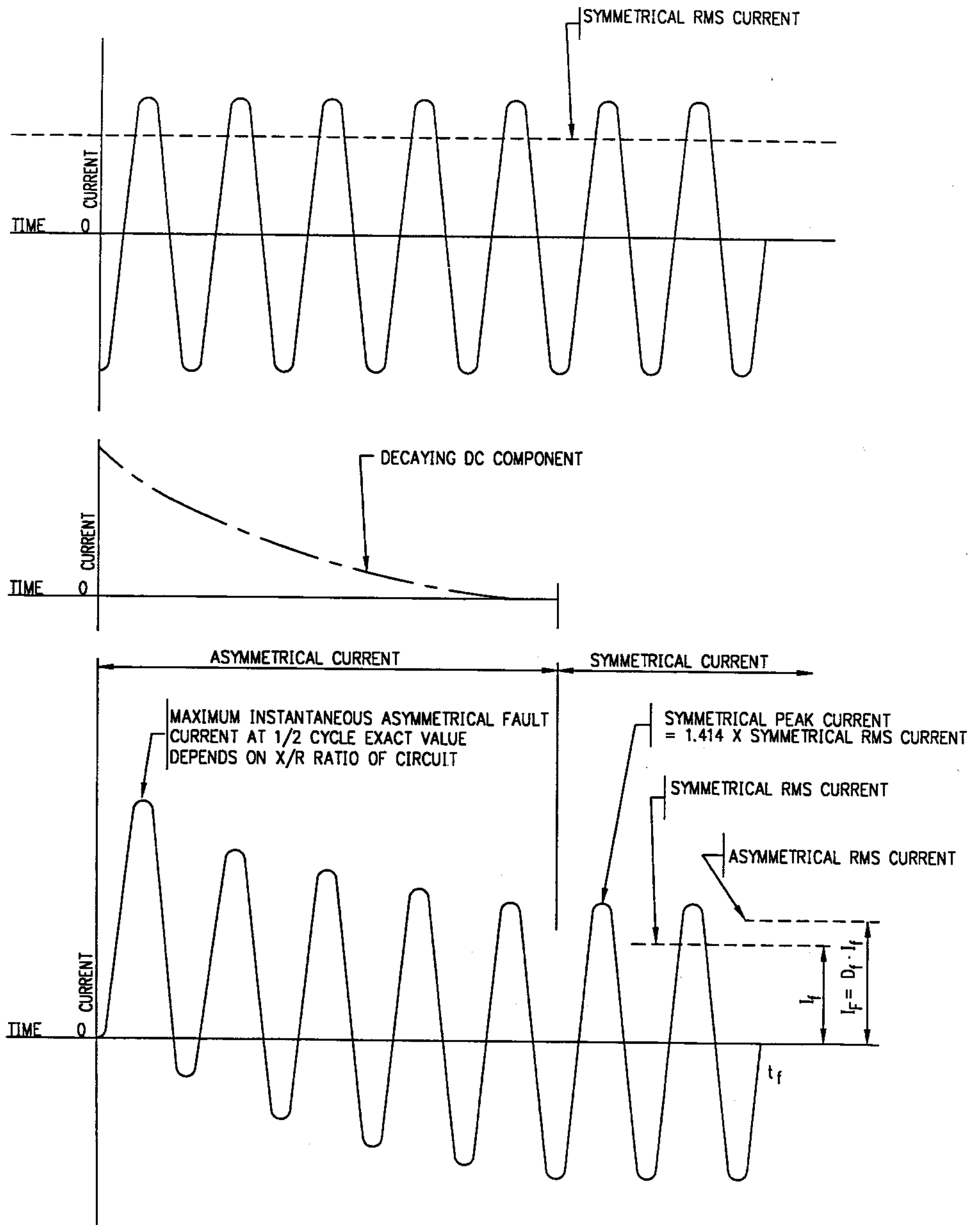


Figure 1—Relationship between actual values of fault current and values of I_F, I_f, and D_f for fault duration t_f

3.6 enclosure currents: Currents that result from the voltages induced in the metallic enclosure by the current(s) flowing in the enclosed conductor(s).

3.7 fault current division factor: A factor representing the inverse of a ratio of the symmetrical fault current to that portion of the current that flows between the grounding grid and surrounding earth.

$$S_f = \frac{I_g}{3I_0} \tag{2}$$

where

S_f is the fault current division factor
I_g is the rms symmetrical grid current in A
I_0 is the zero-sequence fault current in A

NOTE—In reality, the current division factor would change during the fault duration, based on the varying decay rates of the fault contributions and the sequence of interrupting device operations. However, for the purposes of calculating the design value of maximum grid current and symmetrical grid current per definitions of symmetrical grid current and maximum grid current, the ratio is assumed constant during the entire duration of a given fault.

3.8 gas-insulated substation: A compact, multicomponent assembly, enclosed in a grounded metallic housing in which the primary insulating medium is a gas, and that normally consists of buses, switchgear, and associated equipment (subassemblies).

3.9 ground: A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth or to some conducting body of relatively large extent that serves in place of the earth.

3.10 grounded: A system, circuit, or apparatus provided with a ground(s) for the purposes of establishing a ground return circuit and for maintaining its potential at approximately the potential of earth.

3.11 ground current: A current flowing into or out of the earth or its equivalent serving as a ground.

3.12 ground electrode: A conductor imbedded in the earth and used for collecting ground current from or dissipating ground current into the earth.

3.13 ground mat: A solid metallic plate or a system of closely spaced bare conductors that are connected to and often placed in shallow depths above a ground grid or elsewhere at the earth's surface, in order to obtain an extra protective measure minimizing the danger of the exposure to high step or touch voltages in a critical operating area or places that are frequently used by people. Grounded metal gratings, placed on or above the soil surface, or wire mesh placed directly under the surface material, are common forms of a ground mat.

3.14 ground potential rise (GPR): The maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum grid current times the grid resistance.

NOTE—Under normal conditions, the grounded electrical equipment operates at near zero ground potential. That is, the potential of a grounded neutral conductor is nearly identical to the potential of remote earth. During a ground fault the portion of fault current that is conducted by a substation grounding grid into the earth causes the rise of the grid potential with respect to remote earth.

3.15 ground return circuit: A circuit in which the earth or an equivalent conducting body is utilized to complete the circuit and allow current circulation from or to its current source.

3.16 grounding grid: A system of horizontal ground electrodes that consists of a number of interconnected, bare conductors buried in the earth, providing a common ground for electrical devices or metallic structures, usually in one specific location.

NOTE—Grids buried horizontally near the earth's surface are also effective in controlling the surface potential gradients. A typical grid usually is supplemented by a number of ground rods and may be further connected to auxiliary ground electrodes to lower its resistance with respect to remote earth.

3.17 grounding system: Comprises all interconnected grounding facilities in a specific area.

3.18 main ground bus: A conductor or system of conductors provided for connecting all designated metallic components of the gas-insulation substation (GIS) to a substation grounding system.

3.19 maximum grid current: A design value of the maximum grid current, defined as follows:

$$I_G = D_f \times I_g \tag{3}$$

where

I_G is the maximum grid current in A
D_f is the decrement factor for the entire duration of fault t_f, given in s
I_g is the rms symmetrical grid current in A

3.20 mesh voltage: The maximum touch voltage within a mesh of a ground grid.

3.21 metal-to-metal touch voltage: The difference in potential between metallic objects or structures within the substation site that may be bridged by direct hand-to-hand or hand-to-feet contact.

NOTE—The metal-to-metal touch voltage between metallic objects or structures bonded to the ground grid is assumed to be negligible in conventional substations. However, the metal-to-metal touch voltage between metallic objects or structures bonded to the ground grid and metallic objects internal to the substation site, such as an isolated fence, but not bonded to the ground grid may be substantial. In the case of a gas-insulated substation (GIS), the metal-to-metal touch voltage between metallic objects or structures bonded to the ground grid may be substantial because of internal faults or induced currents in the enclosures.

In a conventional substation, the worst touch voltage is usually found to be the potential difference between a hand and the feet at a point of maximum reach distance. However, in the case of a metal-to-metal contact from hand-to-hand or from hand-to-feet, both situations should be investigated for the possible worst reach conditions. Figure 12 and Figure 13 illustrate these situations for air-insulated substations, and Figure 14 illustrates these situations in GIS.

3.22 noncontinuous enclosure: A bus enclosure with the consecutive sections of the housing of the same phase conductor electrically isolated (or insulated from each other), so that no current can flow beyond each enclosure section.

3.23 primary ground electrode: A ground electrode specifically designed or adapted for discharging the ground fault current into the ground, often in a specific discharge pattern, as required (or implicitly called for) by the grounding system design.

3.24 step voltage: The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without contacting any grounded object.

3.25 subtransient reactance: Reactance of a generator at the initiation of a fault. This reactance is used in calculations of the initial symmetrical fault current. The current continuously decreases, but it is assumed to be steady at this value as a first step, lasting approximately 0.05 s after an applied fault.

3.26 surface material: A material installed over the soil consisting of, but not limited to, rock or crushed stone, asphalt, or man-made materials. The surfacing material, depending on the resistivity of the material, may significantly impact the body current for touch and step voltages involving the person's feet.

3.27 symmetrical grid current: That portion of the symmetrical ground fault current that flows between the grounding grid and surrounding earth. It may be expressed as

$$I_g = S_f \times I_f \tag{4}$$

where

I_g	is the rms symmetrical grid current in A
I_f	is the rms symmetrical ground fault current in A
S_f	is the fault current division factor

3.28 symmetrical ground fault current: The maximum rms value of symmetrical fault current after the instant of a ground fault initiation. As such, it represents the rms value of the symmetrical component in the first half-cycle of a current wave that develops after the instant of fault at time zero. For phase-to-ground faults

$$I_{f(0+)} = 3I_0'' \tag{5}$$

where

$I_{f(0+)}$	is the initial rms symmetrical ground fault current
I_0''	is the rms value of zero-sequence symmetrical current that develops immediately after the instant of fault initiation, reflecting the subtransient reactances of rotating machines contributing to the fault

This rms symmetrical fault current is shown in an abbreviated notation as I_f, or is referred to only as $3I_0$. The underlying reason for the latter notation is that, for purposes of this guide, the initial symmetrical fault current is assumed to remain constant for the entire duration of the fault.

3.29 touch voltage: The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure.

3.30 transferred voltage: A special case of the touch voltage where a voltage is transferred into or out of the substation from or to a remote point external to the substation site.

3.31 transient enclosure voltage (TEV): Very fast transient phenomena, which are found on the grounded enclosure of GIS systems. Typically, ground leads are too long (inductive) at the frequencies of interest to effectively prevent the occurrence of TEV. The phenomenon is also known as transient ground rise (TGR) or transient ground potential rise (TGPR).

3.32 very fast transient (VFT): A class of transients generated internally within a gas-insulated substation (GIS) characterized by short duration and very high frequency. VFT is generated by the rapid collapse of voltage during breakdown of the insulating gas, either across the contacts of a switching device or line-to-ground during a fault. These transients can have rise times in the order of nanoseconds implying a frequency content extending to about 100 MHz. However, dominant oscillation frequencies, which are related to physical lengths of GIS bus, are usually in the 20–40 MHz range.

3.33 very fast transients overvoltage (VFTO): System overvoltages that result from generation of VFT. While VFT is one of the main constituents of VFTO, some lower frequency (≅ 1 MHz) component may be present as a result of the discharge of lumped capacitance (voltage transformers). Typically, VFTO will not exceed 2.0 per unit, though higher magnitudes are possible in specific instances.

3.34 *X/R* ratio: Ratio of the system reactance to resistance. It is indicative of the rate of decay of any dc offset. A large *X/R* ratio corresponds to a large time constant and a slow rate of decay.

4. Safety in grounding

4.1 Basic problem

In principle, a safe grounding design has the following two objectives:

— To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
— To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

A practical approach to safe grounding thus concerns and strives for controlling the interaction of two grounding systems, as follows:

— The intentional ground, consisting of ground electrodes buried at some depth below the earth's surface.
— The accidental ground, temporarily established by a person exposed to a potential gradient in the vicinity of a grounded facility.

People often assume that any grounded object can be safely touched. A low substation ground resistance is not, in itself, a guarantee of safety. There is no simple relation between the resistance of the ground system as a whole and the maximum shock current to which a person might be exposed. Therefore, a substation of relatively low ground resistance may be dangerous, while another substation with very high resistance may be safe or can be made safe by careful design. For instance, if a substation is supplied from an overhead line with no shield or neutral wire, a low grid resistance is important. Most or all of the total ground fault current enters the earth causing an often steep rise of the local ground potential [see Figure 2(a)]. If a shield wire, neutral wire, gas-insulated bus, or underground cable feeder, etc., is used, a part of the fault current returns through this metallic path directly to the source. Since this metallic link provides a low impedance parallel path to the return circuit, the rise of local ground potential is ultimately of lesser magnitude [see Figure 2(b)]. In either case, the effect of that portion of fault current that enters the earth within the substation area should be further analyzed. If the geometry, location of ground electrodes, local soil characteristics, and other factors contribute to an excessive potential gradient at the earth's surface, the grounding system may be inadequate despite its capacity to carry the fault current in magnitudes and durations permitted by protective relays.

Clause 5 through Clause 8 detail those principal assumptions and criteria that enable the evaluation of all necessary factors in protecting human life, the most precious element of the accidental circuit.

4.2 Conditions of danger

During typical ground fault conditions, the flow of current to earth will produce potential gradients within and around a substation. Figure 3 shows this effect for a substation with a simple rectangular grounding grid in homogeneous soil.

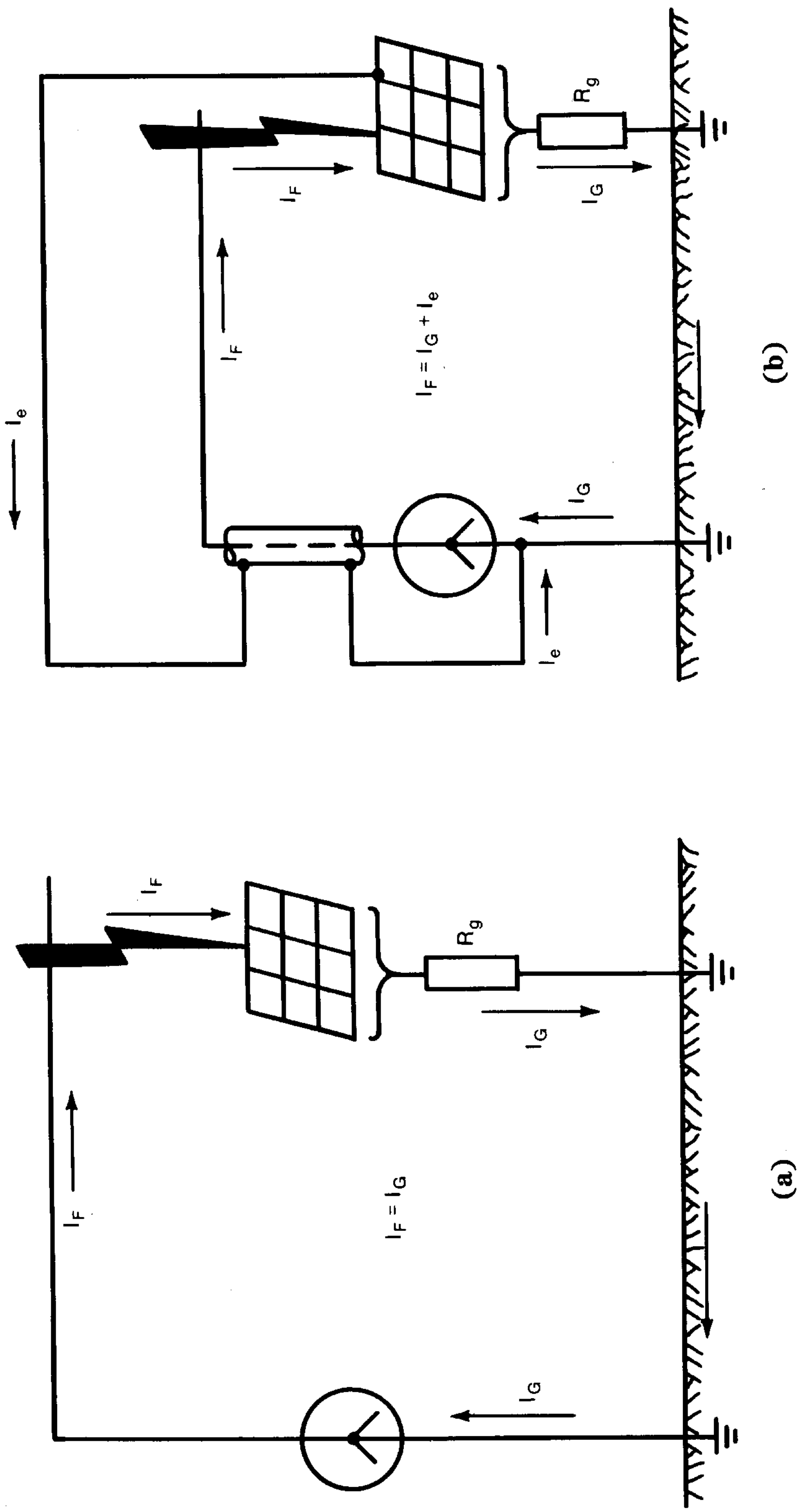


Figure 2—Equipotential contours of a typical grounding grid with and without ground rods

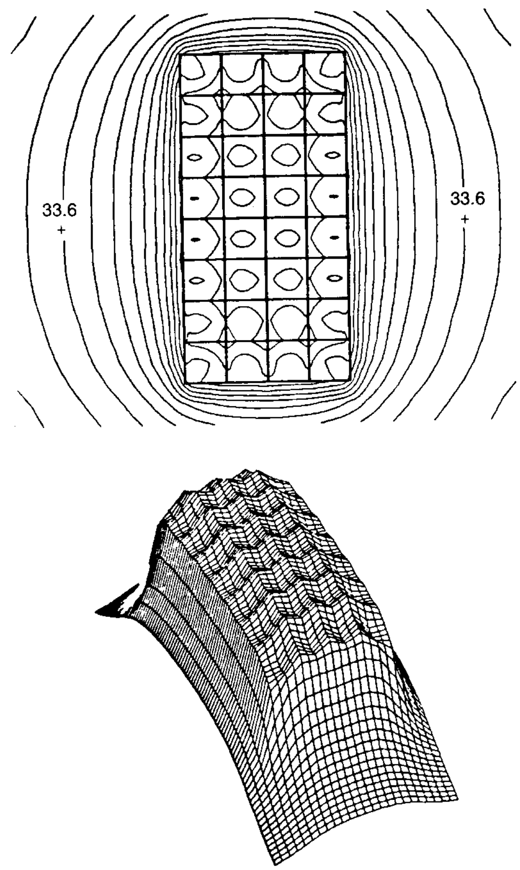


Figure 3—Equipotential contours if a typical grounding grid with and without ground rods

Unless proper precautions are taken in design, the maximum potential gradients along the earth's surface may be of sufficient magnitude during ground fault conditions to endanger a person in the area. Moreover, dangerous voltages may develop between grounded structures or equipment frames and the nearby earth.

The circumstances that make electric shock accidents possible are as follows:

a) Relatively high fault current to ground in relation to the area of ground system and its resistance to remote earth.
b) Soil resistivity and distribution of ground currents such that high potential gradients may occur at points at the earth's surface.
c) Presence of an individual at such a point, time, and position that the body is bridging two points of high potential difference.
d) Absence of sufficient contact resistance or other series resistance to limit current through the body to a safe value under circumstances a) through c).
e) Duration of the fault and body contact, and hence, of the flow of current through a human body for a sufficient time to cause harm at the given current intensity.

The relative infrequency of accidents is due largely to the low probability of coincidence of all the unfavorable conditions listed above.

5. Range of tolerable current

Effects of an electric current passing through the vital parts of a human body depend on the duration, magnitude, and frequency of this current. The most dangerous consequence of such an exposure is a heart condition known as ventricular fibrillation, resulting in immediate arrest of blood circulation.

5.1 Effect of frequency

Humans are very vulnerable to the effects of electric current at frequencies of 50 Hz or 60 Hz. Currents of approximately 0.1 A can be lethal. Research indicates that the human body can tolerate a slightly higher 25 Hz current and approximately five times higher direct current. At frequencies of 3000–10 000 Hz, even higher currents can be tolerated (Dalziel and Mansfield [B33]; Dalziel, Ogden, and Abbott [B36]). In some cases the human body is able to tolerate very high currents due to lightning surges. The International Electrotechnical Commission provides curves for the tolerable body current as a function of frequency and for capacitive discharge currents [IEC 60479-2 (1987-03) [B83])]. Other studies of the effects of both direct and oscillatory impulse currents are reported in Dalziel [B25][B27].

Information regarding special problems of dc grounding is contained in the 1957 report of the AIEE Substations Committee [B21]. The hazards of an electric shock produced by the electrostatic effects of overhead transmission lines are reviewed in Part 1 of the 1972 report of the General Systems Subcommittee [B88]. Additional information on the electrostatic effects of overhead transmission lines can be found in Chapter 8 of the *EPRI Transmission Line Reference Book 345 kV and Above* [B57].

5.2 Effect of magnitude and duration

The most common physiological effects of electric current on the body, stated in order of increasing current magnitude, are threshold perception, muscular contraction, unconsciousness, fibrillation of the heart, respiratory nerve blockage, and burning (Geddes and Baker [B74]; IEC 60479-1 (1994-09) [B82]).

Current of 1 mA is generally recognized as the threshold of perception; that is, the current magnitude at which a person is just able to detect a slight tingling sensation in his hands or fingertips caused by the passing current (Dalziel [B27]).

Currents of 1–6 mA, often termed let-go currents, though unpleasant to sustain, generally do not impair the ability of a person holding an energized object to control his muscles and release it. Dalziel's classic experiment with 28 women and 134 men provides data indicating an average let-go current of 10.5 mA for women and 16 mA for men, and 6 mA and 9 mA as the respective threshold values (Dalziel and Massogilia [B34]).

In the 9–25 mA range, currents may be painful and can make it difficult or impossible to release energized objects grasped by the hand. For still higher currents muscular contractions could make breathing difficult. These effects are not permanent and disappear when the current is interrupted, unless the contraction is very severe and breathing is stopped for minutes rather than seconds. Yet even such cases often respond to resuscitation (Dalziel [B29]).

It is not until current magnitudes in the range of 60–100 mA are reached that ventricular fibrillation, stoppage of the heart, or inhibition of respiration might occur and cause injury or death. A person trained in cardiopulmonary resuscitation (CPR) should administer CPR until the victim can be treated at a medical facility (Dalziel [B30]; Dalziel and Lee [B31]).

Hence, this guide emphasizes the importance of the fibrillation threshold. If shock currents can be kept below this value by a carefully designed grounding system, injury or death may be avoided.

As shown by Dalziel and others (Dalziel, Lagen, and Thurston [B35]; Dalziel and Massogilia [B34]), the nonfibrillating current of magnitude I_B at durations ranging from 0.03–3.0 s is related to the energy absorbed by the body as described by the following equation:

$$S_B = (I_B)^2 \times t_s \tag{6}$$

where

I_B is the rms magnitude of the current through the body in A
t_s is the duration of the current exposure in s
S_B is the empirical constant related to the electric shock energy tolerated by a certain percent of a given population

A more detailed discussion of Equation (6) is provided in Clause 6.

5.3 Importance of high-speed fault clearing

Considering the significance of fault duration both in terms of Equation (6) and implicitly as an accident-exposure factor, high-speed clearing of ground faults is advantageous for two reasons

a) The probability of exposure to electric shock is greatly reduced by fast fault clearing time, in contrast to situations in which fault currents could persist for several minutes or possibly hours.
b) Tests and experience show that the chance of severe injury or death is greatly reduced if the duration of a current flow through the body is very brief.

The allowed current value may, therefore, be based on the clearing time of primary protective devices, or that of the backup protection. A good case could be made for using the primary clearing time because of the low combined probability that relay malfunctions will coincide with all other adverse factors necessary for an accident, as described in Clause 4. It is more conservative to choose the backup relay clearing times in Equation (6), because they assure greater safety margin.

An additional incentive to use switching times less than 0.5 s results from the research done by Biegelmeier and Lee [B9]. Their research provides evidence that a human heart becomes increasingly susceptible to ventricular fibrillation when the time of exposure to current is approaching the heartbeat period, but that the danger is much smaller if the time of exposure to current is in the region of 0.06–0.3 s.

In reality, high ground gradients from faults are usually infrequent, and shocks from high ground gradients are even more infrequent. Further, both events are often of very short duration. Thus, it would not be practical to design against shocks that are merely painful and do not cause serious injury; that is, for currents below the fibrillation threshold.

6. Tolerable body current limit

The magnitude and duration of the current conducted through a human body at 50 Hz or 60 Hz should be less than the value that can cause ventricular fibrillation of the heart.

6.1 Duration formula

The duration for which a 50 Hz or 60 Hz current can be tolerated by most people is related to its magnitude in accordance with Equation (6). Based on the results of Dalziel's studies (Dalziel [B26]; Dalziel and Lee [B32]), it is assumed that 99.5% of all persons can safely withstand, without ventricular fibrillation, the passage of a current with magnitude and duration determined by the following formula:

$$I_B = \frac{k}{\sqrt{t_s}} \tag{7}$$

where, in addition to the terms previously defined for Equation (6)

$$k = \sqrt{S_B}$$

Dalziel found that the shock energy that can be survived by 99.5% of persons weighing approximately 50 kg (110 lb) results in a value of S_B of 0.0135. Thus, k_{50} = 0.116 and the formula for the allowable body current becomes

$$I_B = \frac{0.116}{\sqrt{t_s}} \text{ for 50 kg body weight} \tag{8}$$

Equation (8) results in values of 116 mA for t_s = 1 s and 367 mA for t_s = 0.1 s.

Because Equation (7) is based on tests limited to a range of between 0.03 s and 3.0 s, it obviously is not valid for very short or long durations.

Over the years, other researchers have suggested other values for I_B. In 1936 Ferris et al. [B66] suggested 100 mA as the fibrillation threshold. The value of 100 mA was derived from extensive experiments at Columbia University. In the experiments, animals having body and heart weights comparable to humans were subjected to maximum shock durations of 3 s. Some of the more recent experiments suggest the existence of two distinct thresholds: one where the shock duration is shorter than one heartbeat period and another one for the current duration longer than one heartbeat. For a 50 kg (110 lb) adult, Biegelmeier [B7][B8] proposed the threshold values at 500 mA and 50 mA, respectively. Other studies on this subject were carried out by Lee and Kouwenhoven [B31][B95][B99]. The equation for tolerable body current developed by Dalziel is the basis for the derivation of tolerable voltages used in this guide.

6.2 Alternative assumptions

Fibrillation current is assumed to be a function of individual body weight, as illustrated in Figure 4. The figure shows the relationship between the critical current and body weight for several species of animals (calves, dogs, sheep, and pigs), and a 0.5% common threshold region for mammals.

In the 1961 edition of this guide, constants S_B and k in Equation (6) and Equation (7), were given as 0.0272 and 0.165, respectively, and had been assumed valid for 99.5% of all people weighing approximately 70 kg (155 lb). Further studies by Dalziel [B28][B32], on which Equation (7) is based, lead to the alternate value of k = 0.157 and S_B = 0.0246 as being applicable to persons weighing 70 kg (155 lb). Thus

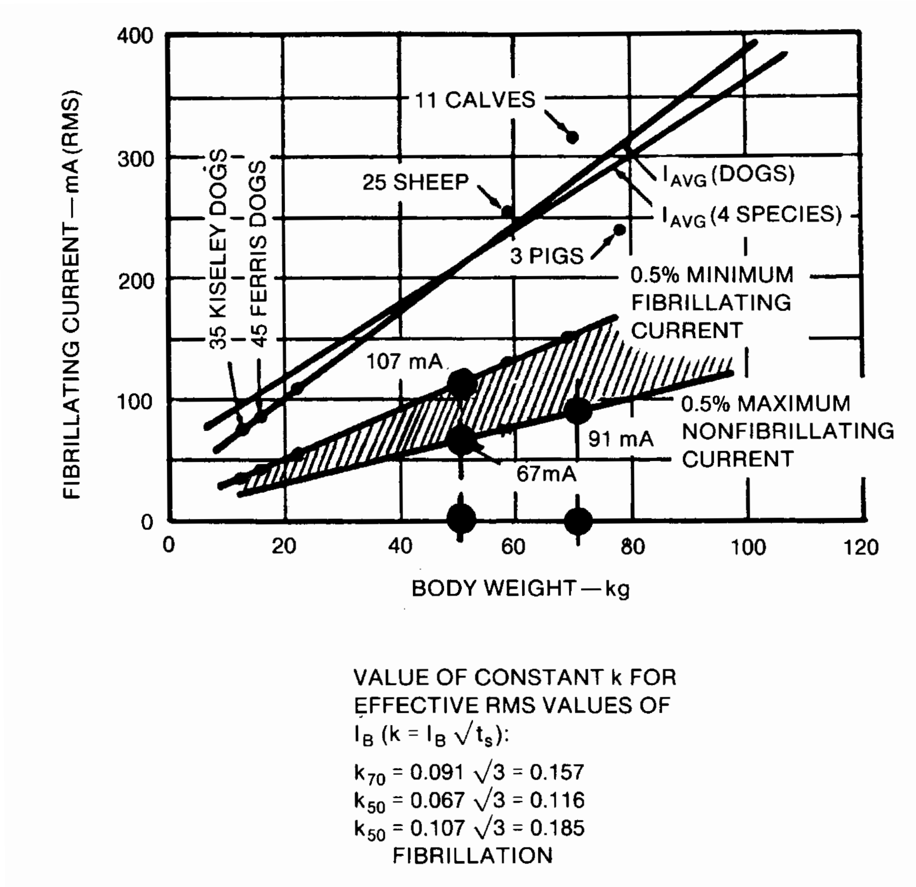


Figure 4—Fibrillating current versus body weight for various animals based on a three-second duration of the electrical shock

$$I_B = \frac{0.157}{\sqrt{t_s}} \text{ for 70 kg body weight} \qquad (9)$$

Users of this guide may select $k = 0.157$ provided that the average population weight can be expected to be at least 70 kg.[7]

Equation (7) indicates that much higher body currents can be allowed where fast-operating protective devices can be relied upon to limit the fault duration. A judgment decision is needed as to whether to use the clearing time of primary high-speed relays, or that of the back-up protection, as the basis for calculation.

6.3 Comparison of Dalziel's equations and Biegelmeier's curve

The comparison of Equation (8), Equation (9), and the Z-shaped curve of body current versus time developed by Biegelmeier that was published by Biegelmeier and Lee [B9] is shown in Figure 5. The Z curve has a 500 mA limit for short times up to 0.2 s, then decreases to 50 mA at 2.0 s and beyond.

[7]Typically, these conditions can be met in places that are not accessible to the public, such as in switchyards protected by fences or walls, etc. Depending on specific circumstances, an assessment should be made if a 50 kg criterion Equation (8) ought to be used for areas outside the fence.

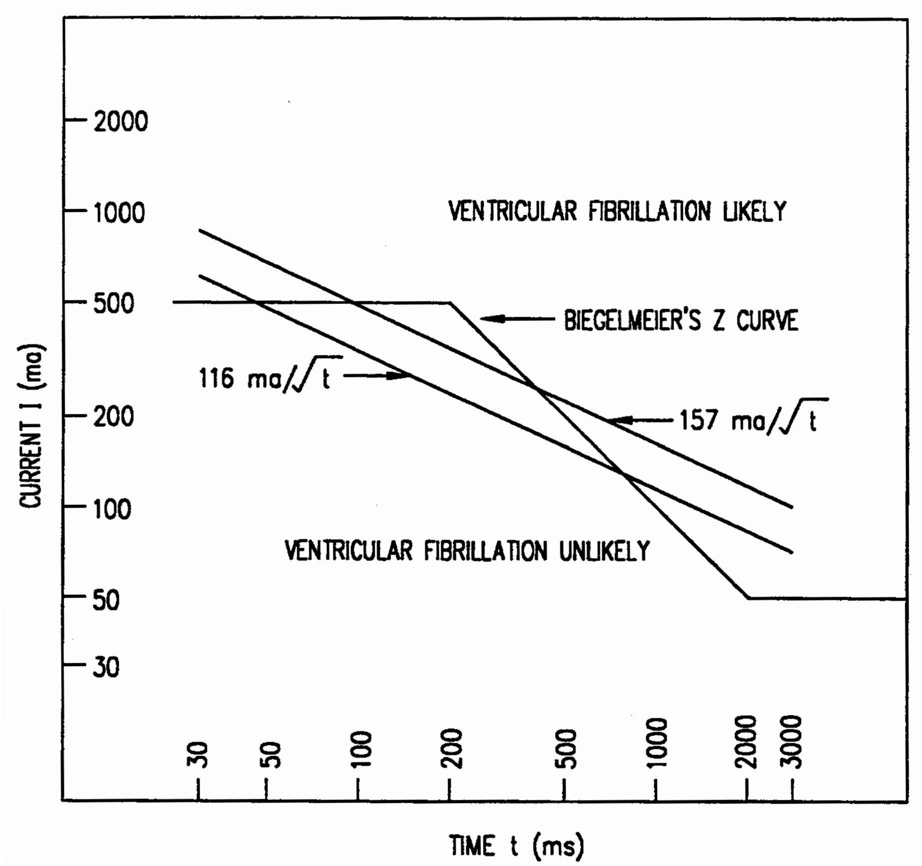


Figure 5—Body current versus time

Using Equation (8), the tolerable body current will be less than Biegelmeier's Z curve for times from 0.06 s to 0.7 s.

6.4 Note on reclosing

Reclosure after a ground fault is common in modern operating practice. In such circumstances, a person might be subjected to the first shock without permanent injury. Next, a single instantaneous automatic reclosure could result in a second shock, initiated within less than 0.33 s from the start of the first. It is this second shock, occurring after a relatively short interval of time before the person has recovered, that might cause a serious accident. With manual reclosure, the possibility of exposure to a second shock is reduced because the reclosing time interval may be substantially greater.

The cumulative effect of two or more closely spaced shocks has not been thoroughly evaluated, but a reasonable allowance can be made by using the sum of individual shock durations as the time of a single exposure.

7. Accidental ground circuit

7.1 Resistance of the human body

For dc and 50 Hz or 60 Hz ac currents, the human body can be approximated by a resistance. The current path typically considered is from one hand to both feet, or from one foot to the other one. The internal resistance of the body is approximately 300 Ω, whereas values of body resistance including skin range from 500 Ω to 3000 Ω, as suggested in Daziel [B26], Geddes and Baker [B74], Gieiges [B75], Kiselev [B94], and Osypka [B118]. The human body resistance is decreased by damage or puncture of the skin at the point of contact.

As mentioned in 5.2, Dalziel [B34] conducted extensive tests using saltwater to wet hands and feet to determine safe let-go currents, with hands and feet wet. Values obtained using 60 Hz for men were as follows: the current was 9.0 mA; corresponding voltages were 21.0 V for hand-to-hand and 10.2 V for hand-to-feet. Hence, the ac resistance for a hand-to-hand contact is equal to 21.0/0.009 or 2330 Ω, and the hand-to-feet resistance equals 10.2/0.009 or 1130 Ω, based on this experiment.

Thus, for the purposes of this guide, the following resistances, in series with the body resistance, are assumed as follows:

a) Hand and foot contact resistances are equal to zero.
b) Glove and shoe resistances are equal to zero.

A value of 1000 Ω in Equation (10), which represents the resistance of a human body from hand-to-feet and also from hand-to-hand, or from one foot to the other foot, will be used throughout this guide.

$$R_B = 1000\ \Omega \qquad (10)$$

7.2 Current paths through the body

It should be remembered that the choice of a 1000 Ω resistance value relates to paths such as those between the hand and one foot or both feet, where a major part of the current passes through parts of the body containing vital organs, including the heart. It is generally agreed that current flowing from one foot to the other is far less dangerous. Referring to tests done in Germany, Loucks [B100] mentioned that much higher foot-to-foot than hand-to-foot currents had to be used to produce the same current in the heart region. He stated that the ratio is as high as 25:1.

Based on these conclusions, resistance values greater than 1000 Ω could possibly be allowed, where a path from one foot to the other foot is concerned. However, the following factors should be considered:

a) A voltage between the two feet, painful but not fatal, might result in a fall that could cause a larger current flow through the chest area. The degree of this hazard would further depend on the fault duration and the possibility of another successive shock, perhaps on reclosure.
b) A person might be working or resting in a prone position when a fault occurs.

It is apparent that the dangers from foot-to-foot contact are far less than from the other type. However, since deaths have occurred from case a) above, it is a danger that should not be ignored (Bodier [B14]; Langer [B96]).

7.3 Accidental circuit equivalents

Using the value of tolerable body current established by either Equation (8) or Equation (9) and the appropriate circuit constants, it is possible to determine the tolerable voltage between any two points of contact.

The following notations are used for the accidental circuit equivalent shown in Figure 6:

I_b is the body current (body is part of the accidental circuit) in A
R_A is the total effective resistance of the accidental circuit in Ω
V_A is the total effective voltage of the accidental circuit (touch or step voltage) in V

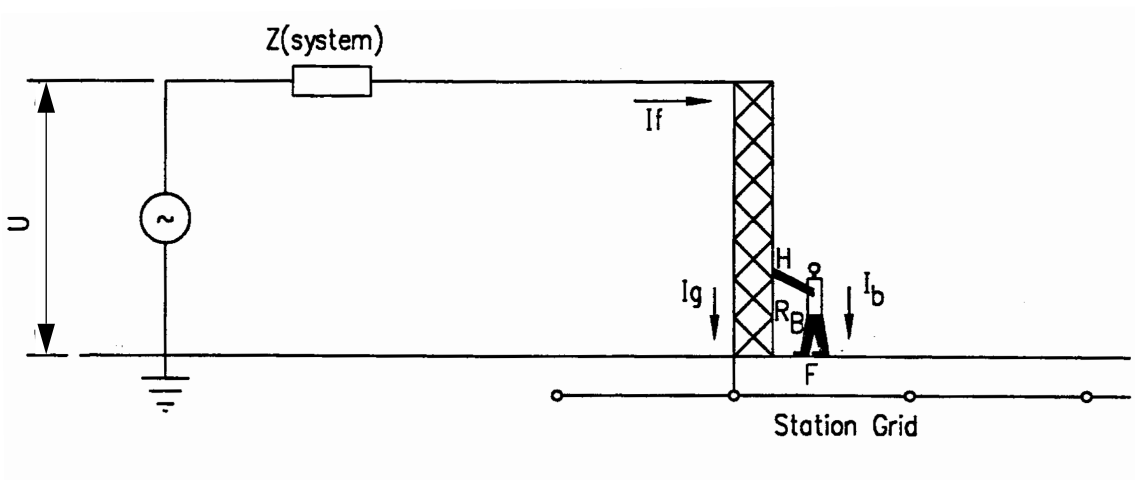


Figure 6—Exposure to touch voltage

The tolerable body current, I_B, defined by Equation (8) or Equation (9), is used to define the tolerable total effective voltage of the accidental circuit (touch or step voltage): the tolerable total effective voltage of the accidental circuit is that voltage that will cause the flow of a body current, I_b, equal to the tolerable body current, I_B.

Figure 6 shows the fault current I_f being discharged to the ground by the grounding system of the substation and a person touching a grounded metallic structure at H. Various impedances in the circuit are shown in Figure 7. Terminal H is a point in the system at the same potential as the grid into which the fault current flows and terminal F is the small area on the surface of the earth that is in contact with the person's two feet. The current, I_b, flows from H through the body of the person to the ground at F. The Thevenin theorem allows us to represent this two terminal (H, F) network of Figure 7 by the circuit shown in Figure 8 (Dawalibi, Southey, and Baishiki [B49]; Dawalibi, Xiong, and Ma [B50]).

The Thevenin voltage V_{Th} is the voltage between terminals H and F when the person is not present. The Thevenin impedance Z_{Th} is the impedance of the system as seen from points H and F with voltage sources of the system short circuited. The current I_b through the body of a person coming in contact with H and F is given by

$$I_b = \frac{V_{Th}}{Z_{Th} + R_B} \tag{11}$$

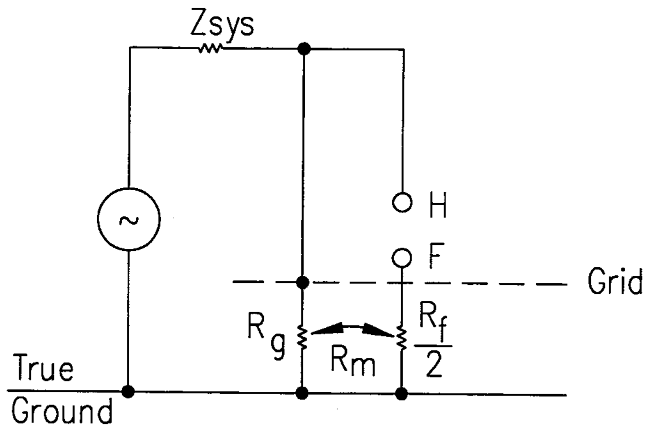


Figure 7—Impedances to touch voltage circuit

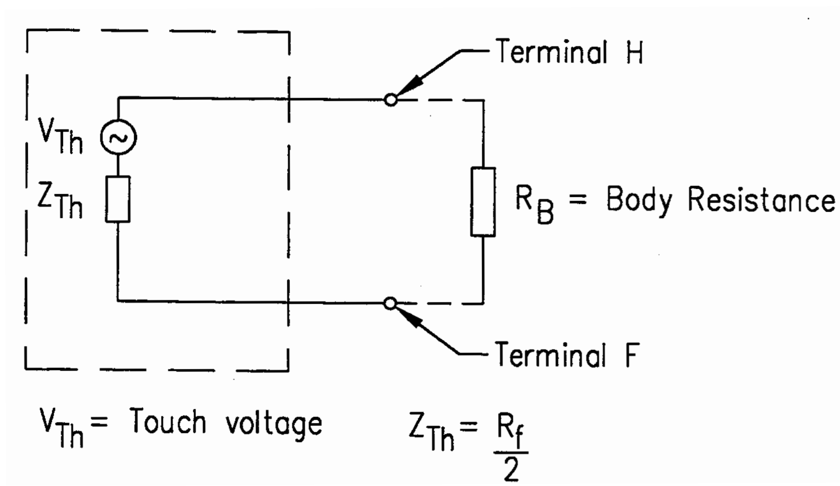


Figure 8—Touch voltage circuit

where

R_B is the resistance of the human body in Ω

Figure 9 shows the fault current I_f being discharged to the ground by the grounding system of the substation. The current, I_b, flows from one foot F_1 through the body of the person to the other foot, F_2. Terminals F_1 and F_2 are the areas on the surface of the earth that are in contact with the two feet, respectively. The Thevenin theorem allows us to represent this two-terminal (F_1, F_2) network in Figure 10. The Thevenin voltage V_{Th} is the voltage between terminals F_1 and F_2 when the person is not present. The Thevenin impedance Z_{Th} is the impedance of the system as seen from the terminals F_1 and F_2 with the voltage sources of the system short circuited. The current I_b through the body of a person is given by Equation (11).

The Thevenin equivalent impedance, Z_{Th}, is computable with a number of methods (Dawalibi, Southey, and Baishiki [B49]; Dawalibi, Xiong, and Ma [B50]; ERPI EL-2699 [B60]; Thapar, Gerez, and Kejriwal [B143];

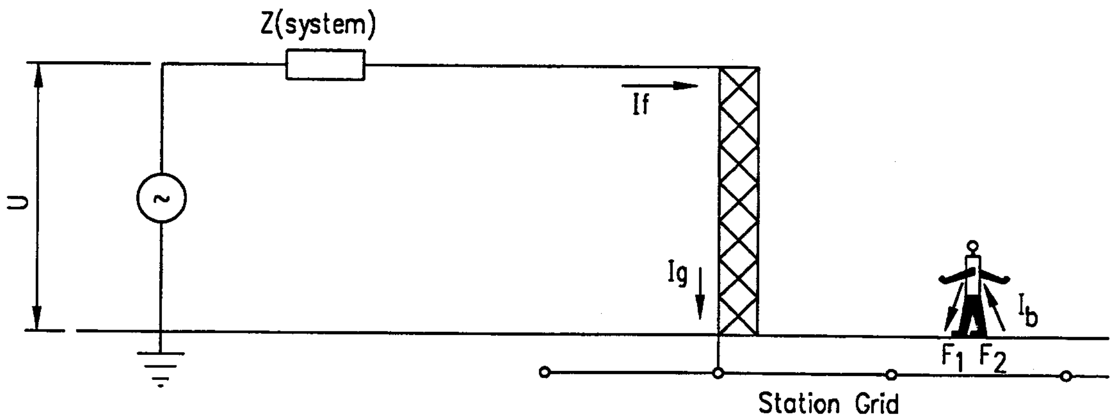


Figure 9—Exposure to step voltage

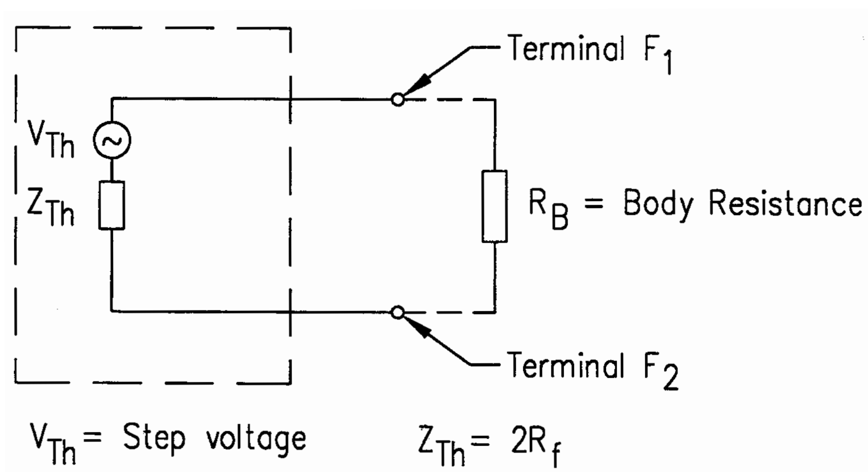


Figure 10—Step voltage circuit

Laurent [B97]). In this guide, the following conservative formulas for the Thevenin equivalent impedance are used.

For touch voltage accidental circuit

$$Z_{Th} = \frac{R_f}{2} \tag{12}$$

And for the step voltage accidental circuit

$$Z_{Th} = 2R_f \tag{13}$$

where

R_f is the ground resistance of one foot (with presence of the substation grounding system ignored) in Ω

For the purpose of circuit analysis, the human foot is usually represented as a conducting metallic disc and the contact resistance of shoes, socks, etc., is neglected. The ground resistance in ohms of a metallic disc of radius *b* (m) on the surface of a homogeneous earth of resistivity ρ (Ω·m) is given by Laurent [B97]

$$R_f = \frac{\rho}{4b} \tag{14}$$

Traditionally, the metallic disc representing the foot is taken as a circular plate with a radius of 0.08 m. With only slight approximation, equations for Z_{Th} can be obtained in numerical form and expressed in terms of ρ as follows.

For touch voltage accidental circuit

$$Z_{Th} = 1.5\rho \tag{15}$$

And for step voltage accidental circuit

$$Z_{Th} = 6.0\rho \tag{16}$$

Based on investigation reported in Dawalibi, Xiong, and Ma [B50]; Meliopoulos, Xia, Joy, and Cokkonides [B107]; and Thapar, Gerez, and Kejriwal [B143], Equation (15) and Equation (16) are conservative in the sense that they underestimate the Thevenin equivalent impedance and, therefore, will result in higher body currents.

The permissible total equivalent voltage (i.e., tolerable touch and step voltage), using Equation (15) and Equation (16), is

$$E_{touch} = I_B(R_B + 1.5\rho) \tag{17}$$

and

$$E_{step} = I_B(R_B + 6.0\rho) \tag{18}$$

7.4 Effect of a thin layer of surface material

Equation (14) is based on the assumption of uniform soil resistivity. However, a 0.08–0.15 m (3–6 in) layer of high resistivity material, such as gravel, is often spread on the earth's surface above the ground grid to increase the contact resistance between the soil and the feet of persons in the substation. The relatively shallow depth of the surface material, as compared to the equivalent radius of the foot, precludes the assumption of uniform resistivity in the vertical direction when computing the ground resistance of the feet. However, for a person in the substation area, the surface material can be assumed to be of infinite extent in the lateral direction.

If the underlying soil has a lower resistivity than the surface material, only some grid current will go upward into the thin layer of the surface material, and the surface voltage will be very nearly the same as that without the surface material. The current through the body will be lowered considerably with the addition of the surface material because of the greater contact resistance between the earth and the feet. However, this resistance may be considerably less than that of a surface layer thick enough to assume uniform resistivity in all directions. The reduction depends on the relative values of the soil and the surface material resistivities, and on the thickness of the surface material.

The converse of the derating principle is also true. If the underlying soil has a higher resistivity than the surface material, a substantial portion of the grid current will go upward into the thin layer of surface material. However, unlike the case described in the preceding paragraph, the surface potentials will be altered substantially due to the concentration of current near the surface. Thus, the effective resistivity of the surface material should not be upgraded without taking into account this change in surface potential. This problem can best be solved by using multilayer soil analysis (see Clause 13).

An analytical expression for the ground resistance of the foot on a thin layer of surface material can be obtained with the use of the method of images (Sunde [B130]; Thapar, Gerez, and Emmanuel [B142]; Thapar, Gerez, and Kejriwal [B143]).[8]

Equation (19) through Equation (21) give the ground resistance of the foot on the surface material (Thapar, Gerez, and Kejriwal [B143]).

$$R_f = \left[\frac{\rho_s}{4b}\right] C_s \tag{19}$$

$$C_s = 1 + \frac{16b}{\rho_s}\sum_{n=1}^{\infty} K^n R_{m(2nh_s)} \tag{20}$$

$$K = \frac{\rho - \rho_s}{\rho + \rho_s} \tag{21}$$

where

C_s	is the surface layer derating factor
K	is the reflection factor between different material resistivities
ρ_s	is the surface material resistivity in Ω·m
ρ	is the resistivity of the earth beneath the surface material in Ω·m
h_s	is the thickness of the surface material in m
b	is the radius of the circular metallic disc representing the foot in m
$R_{m(2nh_s)}$	is the mutual ground resistance between the two similar, parallel, coaxial plates, separated by a distance ($2nh_s$), in an infinite medium of resistivity, ρ_s, in Ω·m

For the determination of $R_{m(2nh_s)}$, consider a thin circular plate, D1, in the x-y plane with the z axis passing through its center. The radius of the plate is b and it discharges a current I in an infinite uniform medium of resistivity, ρ_s. Using cylindrical coordinates, the potential at any point (r,z) is given by the following equations (Jackson [B89]):

$$r = \sqrt{x^2 + y^2} \tag{22}$$

$$z = 2nh_s \tag{23}$$

$$V_{r,z} = \frac{I \cdot \rho_s}{4\pi b}\sin^{-1}\left[\frac{2b}{\sqrt{(r-b)^2 + (z^q)} + \sqrt{(r+b)^2 + z^2}}\right] \tag{24}$$

[8]Expressions for the ground resistance of the foot given in Equation (16) through Equation (19) of the 1986 version of this guide were based on the simple procedure for hemispheric electrodes. This simplification gave lower value of the ground resistance of the foot. The error was significant for low values of the depth of the surface layer. The new revised expressions for the ground resistance of the foot given in this standard are based on the circular plate representation of the foot.

Consider another similar plate, D2, placed parallel and coaxial to the circular plate, D1, and at a distance (2*nh*) from it. The potential produced on D2 can be determined by evaluating the average potential over the surface of the plate. It is given by

$$V_{D2} = \frac{1}{\pi b^2}\int_0^b (2\pi x \cdot V_{r,z})dx \tag{25}$$

The mutual ground resistance, $R_{m(2nh_s)}$, between the two plates is given by

$$R_{m(2nh_s)} = \frac{V_{D2}}{I} \tag{26}$$

Comparing Equation (14) and Equation (19), C_s can be considered as a corrective factor to compute the effective foot resistance in the presence of a finite thickness of surface material. Because the quantity C_s is rather tedious to evaluate without the use of a computer, these values have been precalculated for b = 0.08 m and are given in the form of graphs in Figure 11.

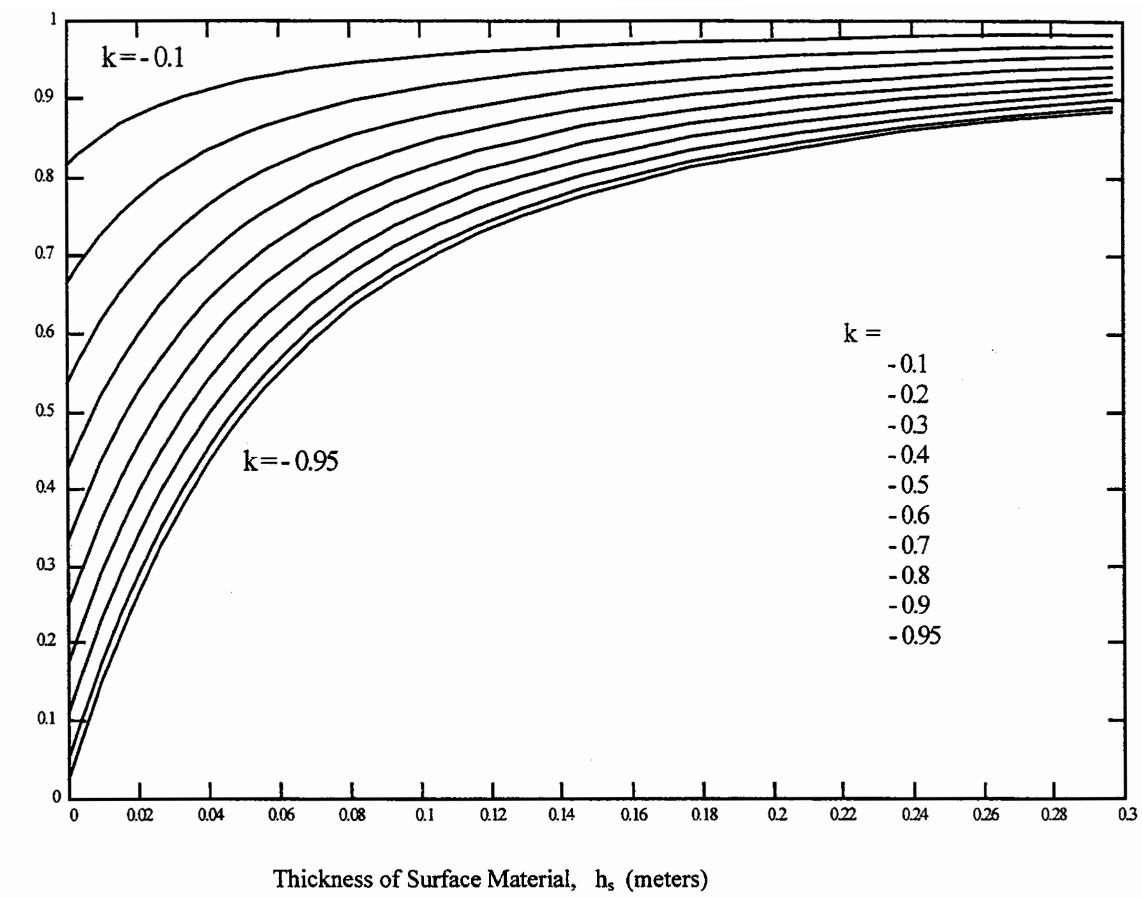


Figure 11—C_S versus h_S

Computer models have also been used to determine the value of C_s (Dawalibi, Xiong, and Ma [B50]; Meliopoulos, Xia, Joy, and Cokkonides [B107]). There is a close match in the values obtained from these computer models with the values given in Figure 11.

The following empirical equation gives the value of C_s. The values of C_s obtained using Equation (27) are within 5% of the values obtained with the analytical method (Thapar, Gerez, and Kejriwal [B143]).

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0.09} \qquad (27)$$

8. Criteria of tolerable voltage

8.1 Definitions

NOTE—The following definitions are also listed in Clause 3, but repeated here for the convenience of the reader.

8.1.1 ground potential rise (GPR): The maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum grid current times the grid resistance.

NOTE—Under normal conditions, the grounded electrical equipment operates at near zero ground potential. That is, the potential of a grounded neutral conductor is nearly identical to the potential of remote earth. During a ground fault the portion of fault current that is conducted by a substation grounding grid into the earth causes the rise of the grid potential with respect to remote earth.

8.1.2 mesh voltage: The maximum touch voltage within a mesh of a ground grid.

8.1.3 metal-to-metal touch voltage: The difference in potential between metallic objects or structures within the substation site that may be bridged by direct hand-to-hand or hand-to-feet contact.

NOTE—The metal-to-metal touch voltage between metallic objects or structures bonded to the ground grid is assumed to be negligible in conventional substations. However, the metal-to-metal touch voltage between metallic objects or structures bonded to the ground grid and metallic objects internal to the substation site, such as an isolated fence, but not bonded to the ground grid may be substantial. In the case of a gas-insulated substation (GIS), the metal-to-metal touch voltage between metallic objects or structures bonded to the ground grid may be substantial because of internal faults or induced currents in the enclosures.

In a conventional substation, the worst touch voltage is usually found to be the potential difference between a hand and the feet at a point of maximum reach distance. However, in the case of a metal-to-metal contact from hand-to-hand or from hand-to-feet, both situations should be investigated for the possible worst reach conditions. Figure 12 and Figure 13 illustrate these situations for air-insulated substations, and Figure 14 illustrates these situations in GIS.

8.1.4 step voltage: The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without contacting any other grounded object.

8.1.5 touch voltage: The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure.

8.1.6 transferred voltage: A special case of the touch voltage where a voltage is transferred into or out of the substation from or to a remote point external to the substation site.

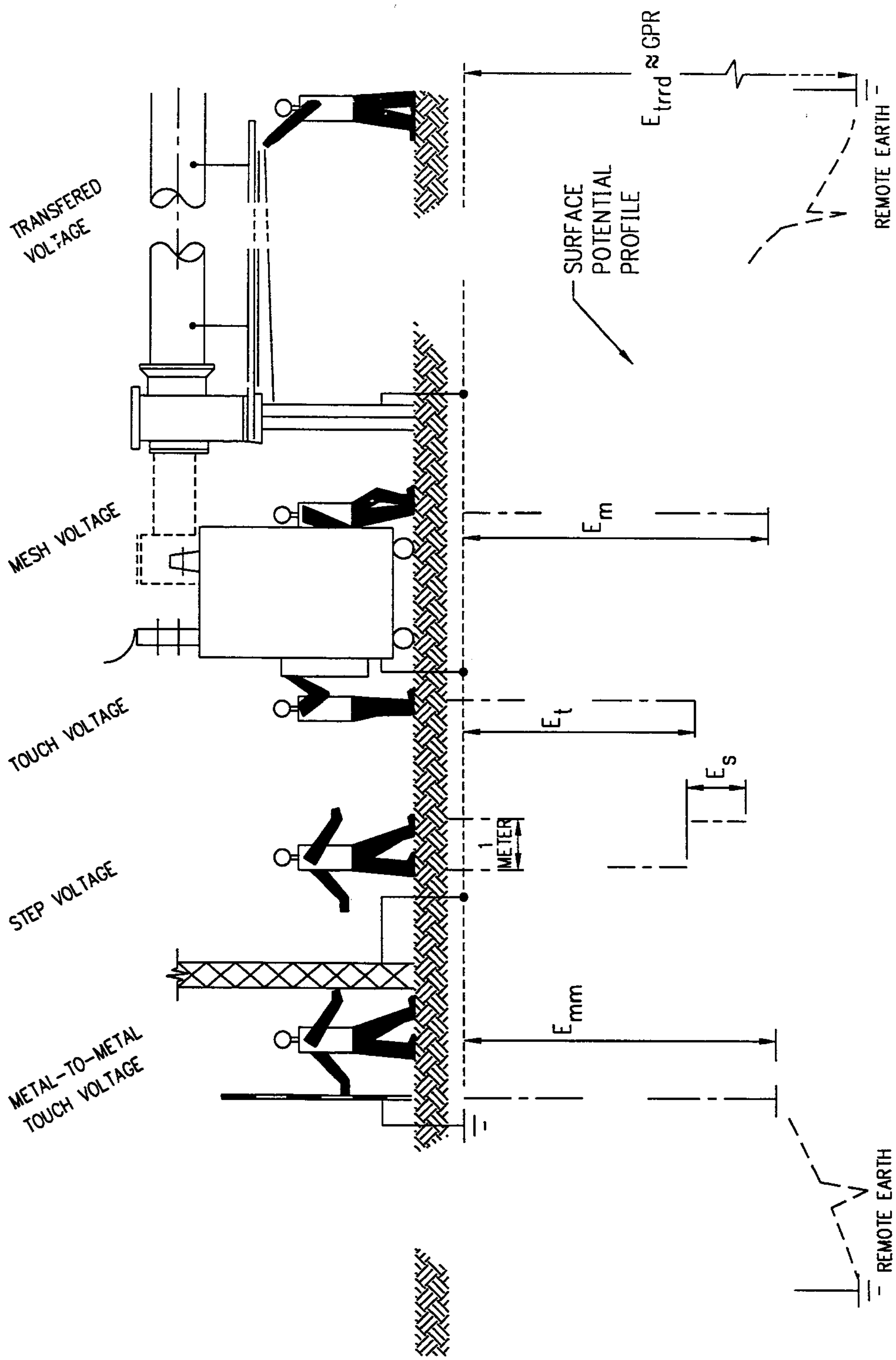


Figure 12—Basic shock situations

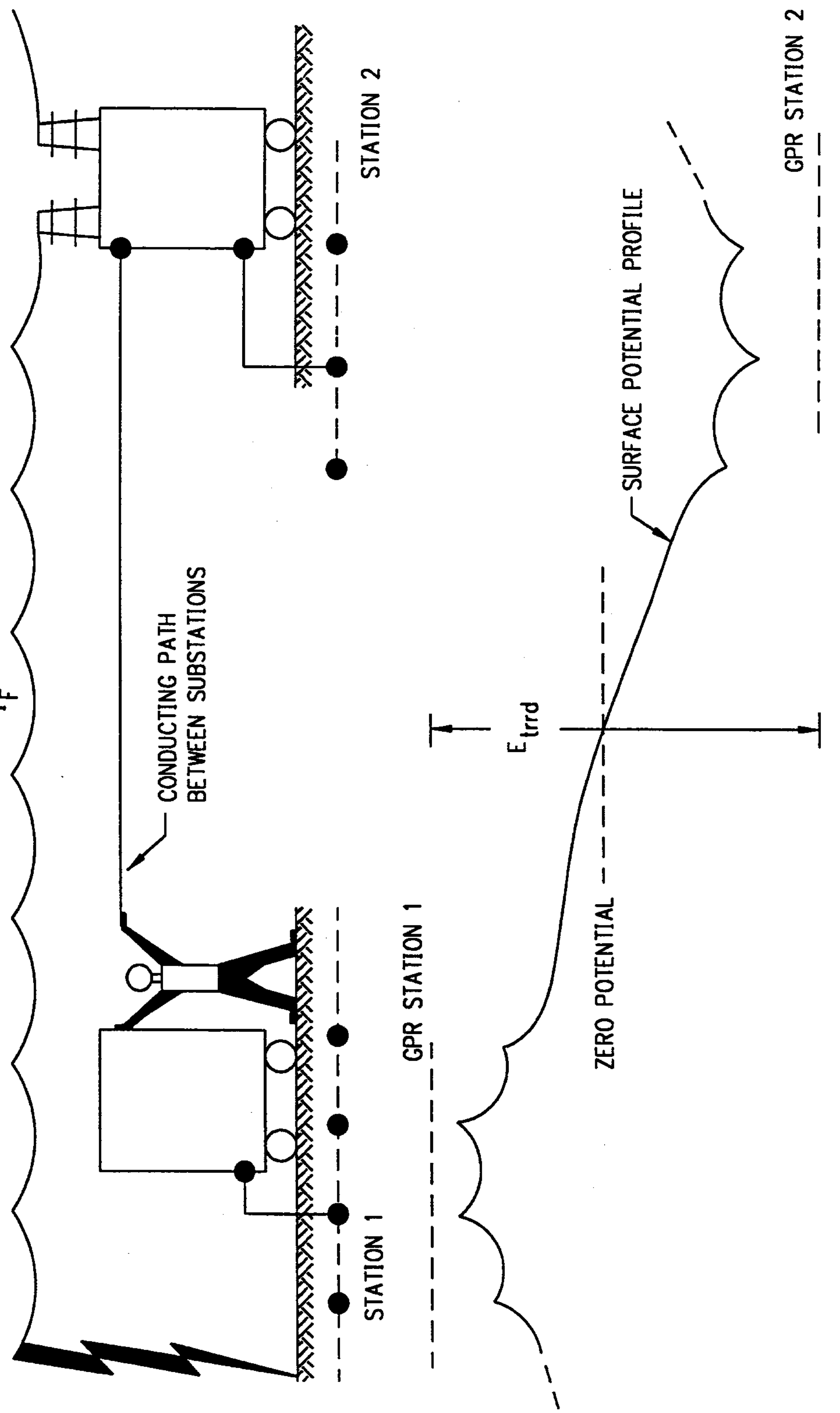


Figure 13—Typical situation of extended transferred potential

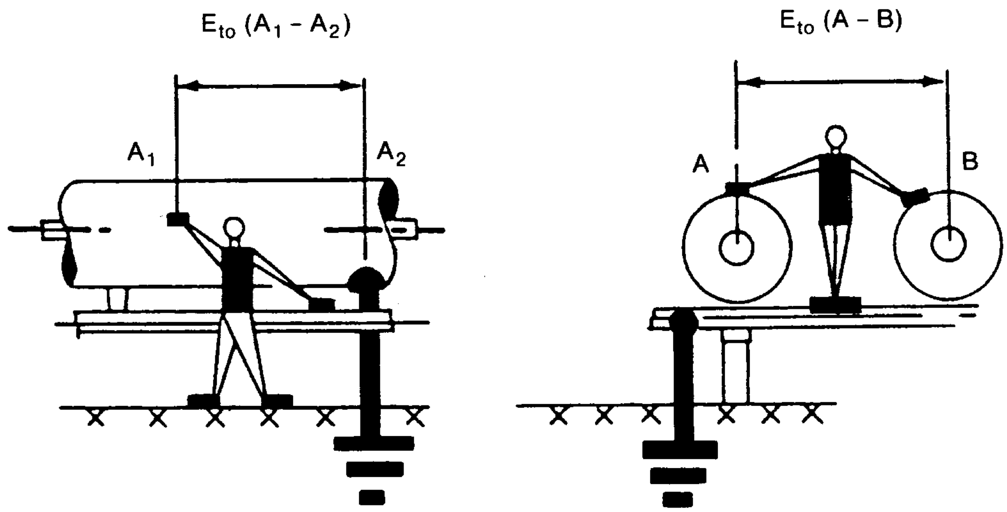


Figure 14—Typical metal-to-metal touch situation in GIS

8.2 Typical shock situations

Figure 12 and Figure 13 show five basic situations involving a person and grounded facilities during a fault. For a foot-to-foot contact, the accidental circuit equivalent is that of Figure 9, and its driving voltage *U* is equal to E_s (step voltage). For the three examples of hand-to-feet contact Figure 12 applies, and *U* is equal to E_t (touch voltage), E_m (mesh voltage), or E_{trrd} (transferred voltage), respectively. The accidental circuit involving metal-to-metal contact, either hand-to-hand or hand-to-feet, is shown in Figure 14 where *U* is equal to the metal-to-metal touch voltage, E_{mm}.

During a fault, the earth conducts currents that emanate from the grid and other permanent ground electrodes buried below the earth's surface. The resulting potential gradients have a primary effect on the value of *U*.

In the case of conventional substations, the typical case of metal-to-metal touch voltage occurs when metallic objects or structures within the substation site are not bonded to the ground grid. Objects such as pipes, rails, or fences that are located within or near the substation ground grid area, and not bonded to the ground grid, meet this criteria. Substantial metal-to-metal touch voltages may be present when a person standing on or touching a grounded object or structure comes into contact with a metallic object or structure within the substation site that is not bonded to the ground grid. Calculation of the actual metal-to-metal touch voltage is complex. In practice, hazards resulting from metal-to-metal contact may best be avoided by bonding potential danger points to the substation grid.

Typically, the case of transferred voltage occurs when a person standing within the substation area touches a conductor grounded at a remote point, or a person standing at a remote point touches a conductor connected to the substation grounding grid. During fault conditions, the resulting potential to ground may equal or exceed the full GPR of a grounding grid discharging the fault current, rather than the fraction of this total voltage encountered in the ordinary touch contact situations (see Figure 13). In fact, as discussed in Clause 17, the transferred voltage may exceed the sum of the GPRs of both substations, due to induced voltages on communication circuits, static or neutral wires, pipes, etc. It is impractical, and often impossible, to design a ground grid based on the touch voltage caused by the external transferred voltages. Hazards from these external transferred voltages are best avoided by using isolating or neutralizing devices and by treating and clearly labeling these circuits, pipes, etc., as being equivalent to energized lines.

8.3 Step and touch voltage criteria

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and the system de-energized. The maximum driving voltage of any accidental circuit should not exceed the limits defined as follows. For step voltage the limit is

$$E_{step} = (R_B + 2R_f) \cdot I_B \tag{28}$$

for body weight of 50 kg

$$E_{step50} = (1000 + 6C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}} \tag{29}$$

for body weight of 70 kg

$$E_{step70} = (1000 + 6C_s \cdot \rho_s)\frac{0.157}{\sqrt{t_s}} \tag{30}$$

Similarly, the touch voltage limit is

$$E_{touch} = \left(R_B + \frac{R_f}{2}\right) \cdot I_B \tag{31}$$

for body weight of 50 kg

$$E_{step50} = (1000 + 1.5C_s \cdot \rho_s)\frac{0.116}{\sqrt{t_s}} \tag{32}$$

for body weight of 70 kg

$$E_{step70} = (1000 + 1.5C_s \cdot \rho_s)\frac{0.157}{\sqrt{t_s}} \tag{33}$$

where

E_{step}	is the step voltage in V
E_{touch}	is the touch voltage in V
C_s	is determined from Figure 11 or Equation (27)
r_s	is the resistivity of the surface material in Ω·m
t_s	is the duration of shock current in seconds

If no protective surface layer is used, then C_s =1 and $\rho_s = \rho$.

The metal-to-metal touch voltage limits are derived from the touch voltage equations, Equation (32) and Equation (33). Metal-to-metal contact, both hand-to-hand and hand-to-feet, will result in $\rho_s = 0$. Therefore, the total resistance of the accidental circuit is equal to the body resistance, R_B.

With the substitution of $\rho_s = 0$ in the foot resistance terms of Equation (32) and Equation (33), the metal-to-metal touch voltage limit is for body weight of 50 kg

$$E_{mm-touch50} = \frac{116}{\sqrt{t_s}} \quad (34)$$

for body weight of 70 kg

$$E_{mm-touch70} = \frac{157}{\sqrt{t_s}} \quad (35)$$

where

E_{mm} is the metal-to-metal touch voltage in V

The actual step voltage, touch voltage, or metal-to-metal touch voltage should be less than the respective maximum allowable voltage limits to ensure safety. Hazards from external transferred voltages are best avoided by isolation or neutralizing devices and labeling these danger points as being equivalent to live lines.

8.4 Typical shock situations for gas-insulated substations

In the grounding analysis of GIS, the touch voltage considerations present several unique problems. Unlike conventional facilities, the GIS equipment features a metal sheath enclosing gas-insulated switchgear and inner high-voltage buses. Each bus is completely contained within its enclosure and the enclosures are grounded. Because a voltage is induced in the outer sheath whenever a current flows in the coaxial busbar, certain parts of the enclosure might be at different potentials with respect to the substation ground. To evaluate the maximum voltage occurring on the bus enclosure during a fault, it is necessary to determine the inductance of the outer sheath to ground, the inductance of the inner conductor, and the mutual inductances for a given phase configuration of individual buses.

A person touching the outer sheath of a GIS might be exposed to voltages resulting from two basic fault conditions

a) An internal fault within the gas-insulated bus system, such as a flashover between the bus conductor and the inner wall of the enclosure.
b) A fault external to the GIS in which a fault current flows through the GIS bus and induces currents in the enclosures.

Because the person may stand on a grounded metal grating and the accidental circuit may involve a hand-to-hand and hand-to-feet current path, the analysis of GIS grounding necessitates consideration of metal-to-metal touch voltage (see Figure 14).

Most GIS manufacturers consider the enclosure properly designed and adequately grounded if the potential difference between individual enclosures, and the potential difference between an enclosure and other grounded structures, does not exceed 65–130 V during a fault. The metal-to-metal touch voltage equations, Equation (34) and Equation (35), reveal that this voltage range corresponds to fault times ranging from 0.8 s to 3.2 s if a 50 kg criterion is used, and ranging from 1.46 s to 5.8 s for the assumption of a 70 kg body. This relationship is, however, better perceived in the graphical form of Figure 15, which also helps to grasp the related problem of sufficient safety margins.

The fault conditions and the corresponding circuit equivalents for determining or verifying the critical safety design parameters of GIS grounding is detailed in Clause 10.

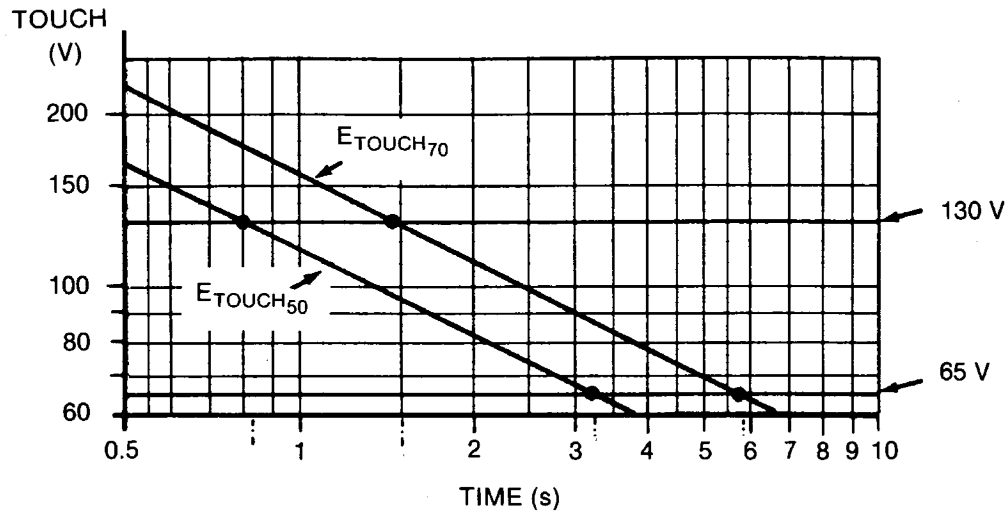


Figure 15—Touch voltage limits for metal-to-metal contact and a typical range of enclosure voltages to ground

8.5 Effect of sustained ground currents

After the safe step and touch voltage limits are established, the grounding system can then be designed based on the available fault current and overall clearing time. The designer should also consider sustained low-level (below setting of protective relays) fault magnitudes that may be above the let-go current threshold. Some sustained faults above the let-go current, but below the fibrillation threshold, may cause asphyxiation from prolonged contraction of the chest muscles. However, it would not be practical to design against lesser shocks that are painful, but cause no permanent injury.

9. Principal design considerations

9.1 Definitions

NOTE—The following definitions are also listed in Clause 3, but repeated here for the convenience of the reader.

9.1.1 auxiliary ground electrode: A ground electrode with certain design or operating constraints. Its primary function may be other than conducting the ground fault current into the earth.

9.1.2 ground electrode: A conductor imbedded in the earth and used for collecting ground current from or dissipating ground current into the earth.

9.1.3 ground mat: A solid metallic plate or a system of closely spaced bare conductors that are connected to and often placed in shallow depths above a ground grid or elsewhere at the earth surface, in order to obtain an extra protective measure minimizing the danger of the exposure to high step or touch voltages in a critical operating area or places that are frequently used by people. Grounded metal gratings, placed on or above the soil surface, or wire mesh placed directly under the surface material, are common forms of a ground mat.

9.1.4 grounding grid: A system of horizontal ground electrodes that consists of a number of interconnected, bare conductors buried in the earth, providing a common ground for electrical devices or metallic structures, usually in one specific location.

NOTE—Grids buried horizontally near the earth's surface are also effective in controlling the surface potential gradients. A typical grid usually is supplemented by a number of ground rods and may be further connected to auxiliary ground electrodes, to lower its resistance with respect to remote earth.

9.1.5 grounding system: Comprises all interconnected grounding facilities in a specific area.

9.1.6 primary ground electrode: A ground electrode specifically designed or adapted for discharging the ground fault current into the ground, often in a specific discharge pattern, as required (or implicitly called for) by the grounding system design.

9.2 General concept

A grounding system should be installed in a manner that will limit the effect of ground potential gradients to such voltage and current levels that will not endanger the safety of people or equipment under normal and fault conditions. The system should also ensure continuity of service.

In the discussion that follows, it is assumed that the system of ground electrodes has the form of a grid of horizontally buried conductors, supplemented by a number of vertical ground rods connected to the grid. Based on two surveys, the first reported in an AIEE application guide in 1954 [B3], and the second published in 1980 (Dawalibi, Bauchard, and Mukhedkar [B45]), this concept represents the prevailing practice of most utilities both in the United States and in other countries.

Some of the reasons for using the combined system of vertical rods and horizontal conductors are as follows:

a) In substations a single electrode is, by itself, inadequate in providing a safe grounding system. In turn, when several electrodes, such as ground rods, are connected to each other and to all equipment neutrals, frames, and structures that are to be grounded, the result is essentially a grid arrangement of ground electrodes, regardless of the original objective. If the connecting links happen to be buried in a soil having good conductivity, this network alone may represent an excellent grounding system. Partly for this reason, some utilities depend on the use of a grid alone. However, ground rods are of a particular value, as explained in item b).
b) If the magnitude of current dissipated into the earth is high, it seldom is possible to install a grid with resistance so low as to assure that the rise of a ground potential will not generate surface gradients unsafe for human contact. Then, the hazard can be eliminated only by control of local potentials through the entire area. A system that combines a horizontal grid and a number of vertical ground rods penetrating lower soils has the following advantages:
    1) While horizontal (grid) conductors are most effective in reducing the danger of high step and touch voltages on the earth's surface, provided that the grid is installed in a shallow depth [usually 0.3–0.5 m (12–18 in) below grade], sufficiently long ground rods will stabilize the performance of such a combined system. For many installations this is important because freezing or drying of upper soil layers could vary the soil resistivity with seasons, while the resistivity of lower soil layers remains nearly constant.
    2) Rods penetrating the lower resistivity soil are far more effective in dissipating fault currents whenever a two-layer or multilayer soil is encountered and the upper soil layer has higher resistivity than the lower layers. For many GIS and other space-limited installations, this condition becomes in fact the most desirable one to occur, or to be achieved by the appropriate design means (extra-long ground rods, grounding wells, etc.).

3) If the rods are installed predominately along the grid perimeter in high-to-low or uniform soil conditions, the rods will considerably moderate the steep increase of the surface gradient near the peripheral meshes. See Clause 16 for details of this arrangement. These details are pertinent to the use of simplified methods in determining the voltage gradient at the earth's surface.

9.3 Primary and auxiliary ground electrodes

In general, most grounding systems utilize two groups of ground electrodes. Primary ground electrodes are specifically designed for grounding purposes. Auxiliary ground electrodes are electrodes that comprise various underground metal structures installed for purposes other than grounding. Typical primary electrodes include such things as grounding grids, counterpoise conductors, ground rods, and ground wells. Typical auxiliary electrodes include underground metal structures and reinforcing bars encased in concrete, if connected to the grounding grid. Auxiliary ground electrodes may have a limited current carrying capability.

9.4 Basic aspects of grid design

Conceptual analysis of a grid system usually starts with inspection of the substation layout plan, showing all major equipment and structures. To establish the basic ideas and concepts, the following points may serve as guidelines for starting a typical grounding grid design:

a) A continuous conductor loop should surround the perimeter to enclose as much area as practical. This measure helps to avoid high current concentration and, hence, high gradients both in the grid area and near the projecting cable ends. Enclosing more area also reduces the resistance of the grounding grid.

b) Within the loop, conductors are typically laid in parallel lines and, where practical, along the structures or rows of equipment to provide for short ground connections.

c) A typical grid system for a substation may include 4/0 bare copper conductors buried 0.3–0.5 m (12–18 in) below grade, spaced 3–7 m (10–20 ft) apart, in a grid pattern. At cross-connections, the conductors would be securely bonded together. Ground rods may be at the grid corners and at junction points along the perimeter. Ground rods may also be installed at major equipment, especially near surge arresters. In multilayer or high resistivity soils, it might be useful to use longer rods or rods installed at additional junction points.

d) This grid system would be extended over the entire substation switchyard and often beyond the fence line. Multiple ground leads or larger sized conductors would be used where high concentrations of current may occur, such as at a neutral-to-ground connection of generators, capacitor banks, or transformers.

e) The ratio of the sides of the grid meshes usually is from 1:1 to 1:3, unless a precise (computer-aided) analysis warrants more extreme values. Frequent cross-connections have a relatively small effect on lowering the resistance of a grid. Their primary role is to assure adequate control of the surface potentials. The cross-connections are also useful in securing multiple paths for the fault current, minimizing the voltage drop in the grid itself, and providing a certain measure of redundancy in the case of a conductor failure.

9.5 Design in difficult conditions

In areas where the soil resistivity is rather high or the substation space is at a premium, it may not be possible to obtain a low impedance grounding system by spreading the grid electrodes over a large area, as is done in more favorable conditions. Such a situation is typical of many GIS installations and industrial substations, occupying only a fraction of the land area normally used for conventional equipment. This often makes the control of surface gradients difficult. Some of the solutions include

a) Connection(s) of remote ground grid(s) and adjacent grounding facilities, a combined system utilizing separate installations in buildings, underground vaults, etc. A predominant use of remote ground electrodes requires careful consideration of transferred potentials, surge arrester locations, and other critical points. A significant voltage drop may develop between the local and remote grounding facilities, especially for high-frequency surges (lightning).
b) Use of deep-driven ground rods and drilled ground wells.
c) Various additives and soil treatments used in conjunction with ground rods and interconnecting conductors are more fully described in 14.5.
d) Use of wire mats. It is feasible to combine both a surface material and fabricated mats made of wire mesh to equalize the gradient field near the surface. A typical wire mat might consist of copper-clad steel wires of No. 6 AWG, arranged in a 0.6 m × 0.6 m (24 in × 24 in) grid pattern, installed on the earth's surface and below the surface material, and bonded to the main grounding grid at multiple locations.
e) Where feasible, controlled use of other available means to lower the overall resistance of a ground system, such as connecting static wires and neutrals to the ground (see 15.3). Typical is the use of metallic objects on the site that qualify for and can serve as auxiliary ground electrodes, or as ground ties to other systems. Consequences of such applications, of course, have to be carefully evaluated.
f) Wherever practical, a nearby deposit of low resistivity material of sufficient volume can be used to install an extra (satellite) grid. This satellite grid, when sufficiently connected to the main grid, will lower the overall resistance and, thus, the ground potential rise of the grounding grid. The nearby low resistivity material may be a clay deposit or it may be a part of some large structure, such as the concrete mass of a hydroelectric dam (Verma, Merand, and Barbeau [B148]).

9.6 Connections to grid

Conductors of adequate ampacity and mechanical strength (see Clause 11) should be used for the connections between

a) All ground electrodes, such as grounding grids, rodbeds, ground wells, and, where applicable, metal, water, or gas pipes, water well casings, etc.
b) All above-ground conductive metal parts that might accidentally become energized, such as metal structures, machine frames, metal housings of conventional or gas-insulated switchgear, transformer tanks, guards, etc. Also, conductive metal parts that might be at a different potential relative to other metal parts that have become energized should be bonded together, usually via the ground grid.
c) All fault current sources such as surge arresters, capacitor banks or coupling capacitors, transformers, and, where appropriate, machine neutrals and lighting and power circuits.

Copper cables or straps are usually employed for these ground connections. However, transformer tanks are sometimes used as part of a ground path for surge arresters. Similarly, most steel or aluminum structures may be used for the ground path if it can be established that their conductance, including that of any connections, is and can be maintained as equivalent to that of the conductor that would normally be installed. Where this practice is followed, any paint films that might otherwise introduce a highly resistive connection should be removed, and a suitable joint compound should be applied, or other effective means, such as jumpers across the connections, should be taken to prevent subsequent deterioration of the connection. In the case of GIS installations, extra attention should be paid to the possibility of unwanted circulation of induced currents. Clause 10 covers the subject in more detail.

Equal division of currents between multiple ground leads at cross-connections or similar junction points should not be assumed.

All accessible ground leads should be inspected on a periodic basis. Exothermic weld, brazed, or pressure-type connectors can be used for underground connections (see 11.4). Soldered connections should be avoided because of the possibility of failure under high fault currents.

Open circuits, even in exposed locations, can escape detection, and it obviously is impractical to inspect buried portions of the grounding network once it is installed. More detailed discussion of test methods used to determine the continuity of buried grounding systems is included in 19.4. Those facilities that are most likely to supply or carry a high current, such as transformer and circuit breaker tanks, switch frames, and arrester pads, should be connected to the grid with more than one ground lead. The leads should preferably be run in opposite directions to eliminate common mode failure.[9]

10. Special considerations for GIS

10.1 Definitions

NOTE—The following definitions are also listed in Clause 3, but repeated here for the convenience of the reader.

10.1.1 continuous enclosure: A bus enclosure in which the consecutive sections of the housing along the same phase conductor are bonded together to provide an electrically continuous current path throughout the entire enclosure length. Cross-bondings, connecting the other phase enclosures, are made only at the extremities of the installation and at a few selected intermediate points.

10.1.2 enclosure currents: Currents that result from the voltages induced in the metallic enclosure by the current(s) flowing in the enclosed conductor(s).

10.1.3 gas-insulated substation: A compact, multicomponent assembly, enclosed in a grounded metallic housing in which the primary insulating medium is a compressed gas, and that normally consists of buses, switchgear, and associated equipment (subassemblies).

10.1.4 main ground bus: A conductor or system of conductors provided for connecting all designated metallic components of the GIS to a substation grounding system.

10.1.5 noncontinuous enclosure: A bus enclosure with the consecutive sections of the housing of the same phase conductor electrically isolated (or insulated from each other), so that no current can flow beyond each enclosure section.

10.1.6 transient enclosure voltage (TEV): Very fast transient phenomena, which are found on the grounded enclosure of GIS systems. Typically, ground leads are too long (inductive) at the frequencies of interest to effectively prevent the occurrence of TEV. The phenomenon is also known as transient ground rise (TGR) or transient ground potential rise (TGPR).

10.1.7 very fast transient (VFT): A class of transients generated internally within GIS characterized by short duration and very high frequency. VFT is generated by the rapid collapse of voltage during breakdown of the insulating gas, either across the contacts of a switching device or line-to-ground during a fault. These transients can have rise times in the order of nanoseconds implying a frequency content extending to about 100 MHz. However, dominant oscillation frequencies, which are related to physical lengths of GIS bus, are usually in the 20–40 MHz range.

[9]One possible exception is grounding of the secondaries of potential and current transformers. The grounding of such devices usually must be restricted to a single point to avoid any parallel path that could cause undesirable circulation of currents affecting the performance of relays and metering devices.

10.1.8 very fast transients overvoltage (VFTO): System overvoltages that result from generation of VFT. While VFT is one of the main constituents of VFTO, some lower frequency (≅ 1 MHz) component may be present as a result of the discharge of lumped capacitance (voltage transformers). Typically, VFTO will not exceed 2.0 per unit, though higher magnitudes are possible in specific instances.

10.2 GIS characteristics

GIS are subjected to the same magnitude of ground fault current and require the same low-impedance grounding as conventional substations.

Typically, the GIS installation necessitates 10–25% of the land area required for conventional equipment. Because of this smaller area, it may be difficult to obtain adequate grounding solely by conventional methods. Particular attention should be given to the bonding of the metallic enclosures of the GIS assembly, as these enclosures carry induced currents of significant magnitude, which must be confined to specific paths. In this respect, grounding recommendations by the manufacturer of a given GIS usually need to be strictly followed.

As a result of the compact nature of GIS and its short distances, electrical breakdown in the insulating gas, either across the contacts of a switching device during operation or in a fault that generates very high frequency transients that can couple onto the grounding system. In some cases, these transients may have to be considered in the overall grounding design. These transients may cause high magnitude, short duration ground rises and are also the source of electromagnetic interference (EMI) in the GIS. While EMI is beyond the scope of this document, the EMI mitigation techniques often involve special considerations in the grounding design (Harvey [B79]).

10.3 Enclosures and circulating currents

The shielding effectiveness of the bus enclosure is determined by its impedance, which governs the circulation of induced currents.

With separate enclosures for each phase, the magnitude and direction of the enclosure current is influenced by the size of the enclosure and the phase spacing between the buses, as well as by the method of interconnecting the enclosures.

In a *continuous* enclosure design, a voltage is induced in an enclosure by the current in the conductor that it surrounds, producing a longitudinal current flow in the enclosure. When a continuity of all phase enclosures is maintained through short connections at both ends, the enclosure current is only slightly less than that flowing in the inner bus in the opposite direction. This current returns through the housing (enclosures) of adjacent phases when the load is equalized between phases. The magnetizing current lags the enclosure current by approximately 90°. The flux is mainly contained within the enclosure.

In a *noncontinuous* enclosure design, there are no external return paths for enclosure currents. Thus the voltage induced in a noncontinuous enclosure by the current of an inner bus(es) that it surrounds cannot produce any longitudinal current flow. Also, voltages might be induced in each enclosure by the currents in the conductors not enclosed by it. Nonuniform voltages result, causing local current flows in each isolated enclosure section, with the currents flowing in nonuniform patterns. Because of these properties, the noncontinuous design is generally considered less advantageous than that of the continuous type. As such, it is not currently used by the industry.

10.4 Grounding of enclosures

Normally, the continuous-type enclosures provide a return path for induced currents so that the conductor and enclosure form a concentric pair with effective external shielding of the field internal to the enclosure. However, under asymmetrical faults, the dc component is not shielded and causes an external voltage drop due to enclosure resistance.

Frequent bonding and grounding of GIS enclosures is the best solution to minimize hazardous touch and step voltages within the GIS area. Additional measures[10] include the use of conductive platforms (ground mats) that are connected to GIS structures and grounded.

To limit the undesirable effects caused by circulating currents, the following requirements should be met:

a) All metallic enclosures should normally operate at ground voltage level.

b) When grounded at the designated points, the bus enclosure design should ensure that no significant voltage differences exist between individual enclosure sections and that neither the supporting structures nor any part of the grounding systems is adversely influenced by the flow of induced currents.

c) To avoid the circulation of enclosure currents beyond regular return path within the GIS assembly, power cable sheath grounds should be tied to the grounding system via connections that are separated from the GIS enclosures. To facilitate this isolation, the design of cable terminations should be such that an isolating air gap or proper insulation elements are provided. Very fast transients generated by switching or by faults in the GIS may cause these insulation elements to flashover. In such cases, the consequences of such flashovers on current distribution within the grounding system should be considered (Fujimoto, Croall, and Foty [B68]).

d) Enclosure return currents also cannot be permitted to flow through any mounted current transformers.

10.5 Cooperation between GIS manufacturer and user

Usually it is the GIS manufacturer who defines clearly what constitutes the main ground bus of the GIS and specifies what is required of the user for connecting the GIS assembly to the substation ground. Ample documentation is necessary to assure that none of the proposed connections from the main ground bus to the grounding grid will interfere with the required enclosure current path or any other operational feature of the GIS design. That may be especially pertinent if the main ground bus consists of a system of interconnections between the GIS components and structures, and no separate busbar (continuous common ground bus loop) is furnished.

Usually the GIS manufacturer also provides, or is responsible for

a) Providing the subassembly-to-subassembly bonding to assure safe voltage gradients between all intentionally grounded parts of the GIS assembly and between those parts and the main ground bus of the GIS.

b) Furnishing readily accessible connectors of sufficient mechanical strength to withstand electromagnetic forces and normal abuse, and that are capable of carrying the anticipated maximum fault current in that portion of the circuit without overheating.

c) Providing ground pads or connectors, or both, allowing, at least, for two paths to ground from the main ground bus, or from each metallic enclosure and auxiliary piece of GIS equipment designated

[10]Despite all measures described, the presence of circulating currents can cause different parts of the GIS metal housing to have a slightly different potential to ground. Although the resulting voltage differences are small and generally of no concern to a shock hazard, accidental metallic bridging of adjacent enclosures can cause annoying sparks.

for a connection to the substation ground if the main ground bus of the GIS assembly does not actually exist.

d) Recommending proper procedures for connections between dissimilar metals, typically between a copper cable or a similar ground conductor and aluminum enclosures.

The user usually provides information on the sources of fault current and the expected magnitudes and durations that should be considered. Moreover, the user should assist the GIS manufacturer in reviewing all proposed grounding provisions to assure proper interfacing of

a) Connections for the neutral current of grounded equipment or apparatus and for dissipating surges caused by lightning and switching within the GIS.
b) Devices for dissipating lightning and switching surge currents external to the GIS assembly.
c) Requirements of protective relaying, and satisfying the provisions necessary for telephone and communication facilities.
d) Ground connections to all GIS supporting frames and structures, metallic sheaths, and installation of shielding for cable terminations where applicable.
e) Connections to all pads or connectors furnished by the GIS manufacturer.
f) Safe voltage for step and touch, under both normal and abnormal operating conditions external to the GIS assembly.
g) Compliance with the grounding specifications, related to correct grounding practices, as mutually agreed to by the GIS manufacturer and the user.

10.6 Other special aspects of GIS grounding

Precautions should be taken to prevent excessive currents from being induced into adjacent frames, structures, or reinforcing steel, and to avoid establishment of current loops via other substation equipment, such as transformers or separate switchgear. If there is the possibility of undesirable current loops via ground connections, or if any sustained current path might partially close or pass through grounded structures, the substation grounding scheme and the physical layout should be carefully reviewed with the GIS manufacturer.

Equal care is needed in the proximity of discontinuities in enclosure grounding paths at the transformer connections to GIS and at the interface points to conventional switchgear to prevent circulating currents in the circuit breaker and transformer tank steel.

Where applicable, all isolating elements should be able to withstand the full potential difference that may occur between the locally grounded system and that external to the GIS. In many cases, the very fast transients generated by switching or by faults in the GIS may cause very high transient voltages to appear at these points. For instance, the isolation of high-pressure oil pipe cables from the GIS grounding system often involves difficulties. Although the individual HV or EHV terminators may provide adequate separation from the external grounds (by the virtue of a design that usually includes the use of base plate insulators made of high-voltage rated porcelain or fiberglass), problems sometimes arise if the same level of insulation is also expected at other interface points. One typical problem area is the auxiliary piping between the oil chamber of individual GIS terminators and the oil diffusion chamber at the end of a pipe cable that frequently branches to a variety of oil pressure monitoring instruments and alarm devices (Graybill, Koehler, and Nadkarni, and Nicholas [B77]). There the isolation of metal parts is often achieved by the means of ceramic or plastic inserts. Adequate creepage distance should be ensured where possible. To protect against transient voltages, other precautions might be necessary (Dick, Fujimoto, Ford, and Harvey [B52]; Ford and Geddes [B67]; Fujimoto, Croall, and Foty [B68]).

In these and similar circumstances,[11] a close cooperation with the GIS manufacturer in the early stages of the design is very important.

10.7 Notes on grounding of GIS foundations

Since the earth path of ground currents is strongly affected by the relative position of conductive objects that are in the ground, more attention should be paid to those portions of the GIS grounding system that include discontinuities, or where the design requires an abrupt change in the pattern of ground electrodes. The following circumstances are of concern.

In the limited space of GIS substations, a substantial part of the substation area is often occupied by concrete foundations, which may cause irregularities in a current discharge path. In this respect, a simple monolithic concrete steel reinforced slab is advantageous both as an auxiliary grounding device and for seismic reasons.

If a continuous floor slab is used, a good adjunct measure is to tie its reinforcing steel mesh to the common ground bus (main ground bus) so that both the GIS enclosures and the structural steel in and above the foundation will be approximately the same potential level. The assumption is that this measure should produce a better ground and the reinforcing bars, being considerably closer together than the wires of a typical ground grid, should produce more even potentials within the floor and at the surface.[12]

GIS foundations, which include reinforcing bars and other metals, can act as auxiliary ground electrodes and may be so used provided that under no circumstances the discharge of current would result in a damage of concrete because of local overheating or a gradual erosion of the concrete-steel bonds. For further details, refer to 14.6.

10.8 Touch voltage criteria for GIS

Although the GIS manufacturer generally designs the equipment to meet the already mentioned requirements for safe operation and usually performs most, if not all, calculations that are necessary for determining the sheath voltages and currents during faults, there still are circumstances when the user has to ascertain that the entire installation is safe. Having this possibility in mind, some of the critical aspects of interconnecting the GIS with a grounding system are briefly discussed next.

A certain paradox, inherent to the GIS design, may occur when one tries to determine the best concept of GIS grounding. In contrast to the general wisdom that a large ground connection necessarily equals a good grounding practice, the circulating currents generated in the GIS enclosures during a fault should also be taken into account. To be considered are: 1) where these currents will circulate, and 2) where and to what degree the design engineer or GIS manufacturer, or both, prefer these currents to circulate.

Typically in a continuous enclosure design, the path of enclosure currents includes some structural members of the GIS frame and the enclosures themselves. With each phase enclosure tied to the enclosures of adjacent phases at both ends, several loops are formed. Because a cross section of the mentioned structural members is usually much smaller than that of the enclosure and comparable to that of the grounding straps that connect the GIS assembly to a ground grid (and for that matter, also to the reinforcing bars of the concrete foundation), several questions need to be asked

[11]The direct effect of transmitted enclosure voltage (TEV) on humans may not be fatal, but its secondary effect on personnel should be of concern to the design engineer and the manufacturer. In addition, TEV might necessitate that more stringent electromagnetic compatibility requirements be considered for auxiliary equipment.

[12]It might be argued that the concrete slab, being a fairly good conductor itself, could produce a more uniform voltage at the floor level if no current would flow into the reinforcing bars from the ground system. If the bars are connected, the electrical field in the earth between the bars of the slab and the underlying grid would be zero. (As both mats are at the same potential, hardly any current would flow out of the bars into the concrete and toward the ground grid.) Therefore, the concrete with reinforcing bars will produce a substantially uniform potential field across the floor surface.

a) If the currents divide and flow via all available metallic paths, what ratio is to be expected between the currents circulating within the GIS assembly and those circulating via a ground connection?
b) How much current circulating via a ground connection loop is too much?
c) Should the GIS be designed to be safe if no circulating current would (at least for an external fault) circulate via ground connections?
d) And finally, how much grounding is needed for the best balance between operational and safety-related requirements?

Presently, there are no clear-cut answers and solutions to the questions listed above. Some manufacturers prefer to supply a special ground bus (main ground bus) as a part of the GIS package, with clearly designated ground connection points. Others do not use any main ground bus at all, but simply designate certain points on the enclosure as grounding pads and let the utility complete the grounding.

In either case, it becomes necessary to limit the body current to some value in a milliampere range, while the fault currents that are of concern range from hundreds to thousands of amperes. Thus, one can safely assume that the full potential difference existing prior to a contact would not change while forcing the current through an alternate path including the body. Then the case of a person touching the GIS sheath metal can be reduced to the problem of finding the voltage drop between two points of contact along one or between two enclosures and a common ground. For the hand-to-feet contact made by a person standing on a nonmetallic surface (for instance, a concrete slab or the soil layer above the grounding grid), only a minor modification of the application criterion of Equation (32) and Equation (33) is required in order to take into account the maximum inductive voltage drop occurring within the GIS assembly.

The touch voltage criterion for GIS is

$$\sqrt{E_t^2 + (E'_{to\ max})^2} < E_{touch} \tag{36}$$

where

E_t	is the maximum touch voltage, as determined for the point underneath a person's feet
$E'_{to\ max}$	is the (predominantly inductive) maximum value of metal-to-metal voltage difference on and between GIS enclosures, or between these enclosures and the supporting structures, including any horizontal or vertical members for which the GIS assembly is designed

In practical situations, as shown in Figure 16, a multiplicity of return paths and considerable cross-coupling occurs. This makes the calculation of longitudinally induced currents difficult and for some remote external faults often outright unpractical, as too many parameters remain undefined. As a rule, because of a great variety in possible physical arrangements of the GIS assembly, the GIS manufacturers perform detailed calculations for determining the basic design parameters, such as spacing and location of bonds.

10.9 Recommendations

The following recommendations should be considered for GIS installations:

a) When applying the touch voltage criterion Equation (36), the following facts should be considered. The case of an internal fault with ground return requires the addition of the resistive and inductive voltage drop to the resistive drop representing the difference of potentials between the substation ground and the point beneath a person's feet. This generally is not necessary for faults external to the GIS. For an external line-to-ground fault, the voltages induced on the sheath should be checked for a hand-to-hand metal-to-metal contact, but the calculation of step and touch voltages at the earth's surface is the same as that for conventional installations [i.e., the inductive term $E'_{to\ max}$ in Equation (36) is zero].

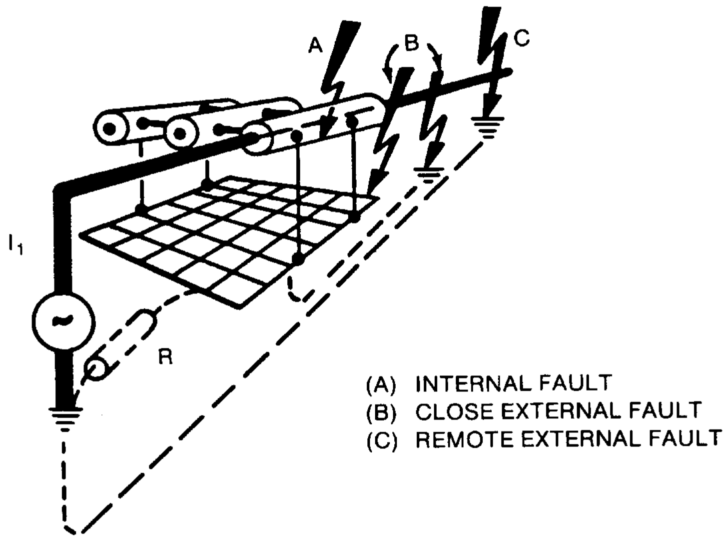


Figure 16—Typical faults in GIS

b) In evaluating the magnitude of induced voltages caused by faults external to the GIS, only the case of a close-in fault [case (B) in Figure 16] needs to be analyzed because remote external faults will cause less of a problem.

11. Selection of conductors and connections

In assessing which conductor material and what conductor size or what maximum allowable temperature limit needs to be applied in individual design situations, the final choice should always reflect the considerations outlined in 11.1–11.4.

11.1 Basic requirements

Each element of the grounding system, including grid conductors, connections, connecting leads, and all primary electrodes, should be so designed that for the expected design life of the installation, the element will

a) Have sufficient conductivity, so that it will not contribute substantially to local voltage differences.
b) Resist fusing and mechanical deterioration under the most adverse combination of a fault magnitude and duration.
c) Be mechanically reliable and rugged to a high degree.
d) Be able to maintain its function even when exposed to corrosion or physical abuse.

11.2 Choice of material for conductors and related corrosion problems

11.2.1 Copper

Copper is a common material used for grounding. Copper conductors, in addition to their high conductivity, have the advantage of being resistant to most underground corrosion because copper is cathodic with respect to most other metals that are likely to be buried in the vicinity.

11.2.2 Copper-clad steel

Copper-clad steel is usually used for underground rods and occasionally for grounding grids, especially where theft is a problem. Use of copper, or to a lesser degree copper-clad steel, therefore assures that the integrity of an underground network will be maintained for years, so long as the conductors are of an adequate size and not damaged and the soil conditions are not corrosive to the material used.

11.2.3 Aluminum

Aluminum is used for ground grids less frequently. Although at first glance the use of aluminum would be a natural choice for GIS equipment with enclosures made of aluminum or aluminum alloys, there are the following disadvantages to consider:

a) Aluminum itself may corrode in certain soils. The layer of corroded aluminum material is nonconductive for all practical grounding purposes.
b) Gradual corrosion caused by alternating currents may also be a problem under certain conditions.

Thus, aluminum should be used only after full investigation of all circumstances, despite the fact that, like steel, it would alleviate the problem of contributing to the corrosion of other buried objects. However, aluminum is anodic to many other metals, including steel and, if interconnected to one of these metals in the presence of an electrolyte, the aluminum will sacrifice itself to protect the other metal. If aluminum is used, the high purity electric conductor grades are recommended as being more suitable than most alloys.

11.2.4 Steel

Steel may be used for ground grid conductors and rods. Of course, such a design requires that attention is paid to the corrosion of the steel. Use of a galvanized or corrosion resistant steel, in combination with cathodic protection, is typical for steel grounding systems (Mahonar and Nagar [B101]).

11.2.5 Other considerations

A grid of copper or copper-clad steel forms a galvanic cell with buried steel structures, pipes, and any of the lead-based alloys that might be present in cable sheaths. This galvanic cell may hasten corrosion of the latter. Tinning the copper has been tried by some of the utilities. That reduces the cell potential with respect to steel and zinc by about 50% and practically eliminates this potential with respect to lead (tin being slightly sacrificial to lead). The disadvantage of using a tinned copper conductor is that it accelerates and concentrates the natural corrosion, caused by the chemicals in the soil, of the copper in any small bare area. Other often-used methods are

a) Insulation of the sacrificial metal surfaces with a coating such as plastic tape, asphalt compound, or both.
b) Routing of buried metal elements so that any copper-based conductor will cross water pipe lines or similar objects made of other uncoated metals as nearly as possible at right angles, and then applying an insulated coating to one metal or the other where they are in proximity. The insulated coating is usually applied to the pipe.

c) Cathodic protection using sacrificial anodes or impressed current systems.

d) Use of nonmetallic pipes and conduits.

In GIS, the use of cathodic protection may also be required for other reasons. Cathodic protection is commonly used to protect facilities that are external to the GIS, such as pressurized pipe-type cables, lead shielded cables, etc. Because of the complexity of GIS installations, it is essential to consider all aspects of corrosion prevention before designing the grounding system. Specific guidelines are difficult to establish because substation conditions may be different due to location and application in the electric power system.

The subject of underground corrosion and cathodic protection is complex. Many studies have been made and much has been published on this subject. A detailed discussion of these phenomena is beyond the scope of this guide.

11.3 Conductor sizing factors

11.3.1 Symmetrical currents

The short time temperature rise in a ground conductor, or the required conductor size as a function of conductor current, can be obtained from Equation (37) through Equation (42), which are taken from the derivation by Sverak [B133]. These equations are also included as Appendix B in IEEE Std 837-1989. These equations evaluate the ampacity of any conductor for which the material constants are known, or can be determined by calculation. Material constants of the commonly used grounding materials are listed in Table 1. Equation (37) through Equation (42) are derived for symmetrical currents (with no dc offset).

$$I = A_{mm^2}\sqrt{\left(\frac{TCAP \cdot 10^{-4}}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)} \tag{37}$$

where

I	is the rms current in kA
A_{mm^2}	is the conductor cross section in mm^2
T_m	is the maximum allowable temperature in °C
T_a	is the ambient temperature in °C
T_r	is the reference temperature for material constants in °C
α_o	is the thermal coefficient of resistivity at 0 °C in 1/°C
α_r	is the thermal coefficient of resistivity at reference temperature T_r in 1/°C
ρ_r	is the resistivity of the ground conductor at reference temperature T_r in μΩ-cm
K_o	$1/\alpha_o$ or $(1/\alpha_r) - T_r$ in °C
t_c	is the duration of current in s
$TCAP$	is the thermal capacity per unit volume from Table 1, in J/(cm^3·°C) (further defined in 11.3.1.1)

It should be noted that α_r and ρ_r are both to be found at the same reference temperature of T_r °C. Table 1 provides data for α_r and ρ_r at 20 °C.

If the conductor size is given in kcmils (mm^2 × 1.974 = kcmils), Equation (37) becomes

$$I = 5.07 \cdot 10^{-3} A_{kcmil}\sqrt{\left(\frac{TCAP}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)} \tag{38}$$

Table 1—Material constants

Description	Material conductivity (%)	α_r factor at 20 °C (1/°C)	K_o at 0 °C (0 °C)	Fusing[a] temperature T_m (°C)	ρ_r 20 °C (μΩ·cm)	TCAP thermal capacity [J/(cm^3·°C)]
Copper, annealed soft-drawn	100.0	0.003 93	234	1083	1.72	3.42
Copper, commercial hard-drawn	97.0	0.003 81	242	1084	1.78	3.42
Copper-clad steel wire	40.0	0.003 78	245	1084	4.40	3.85
Copper-clad steel wire	30.0	0.003 78	245	1084	5.86	3.85
Copper-clad steel rod[b]	20.0	0.003 78	245	1084	8.62	3.85
Aluminum, EC grade	61.0	0.004 03	228	657	2.86	2.56
Aluminum, 5005 alloy	53.5	0.003 53	263	652	3.22	2.60
Aluminum, 6201 alloy	52.5	0.003 47	268	654	3.28	2.60
Aluminum-clad steel wire	20.3	0.003 60	258	657	8.48	3.58
Steel, 1020	10.8	0.001 60	605	1510	15.90	3.28
Stainless-clad steel rod[c]	9.8	0.001 60	605	1400	17.50	4.44
Zinc-coated steel rod	8.6	0.003 20	293	419	20.10	3.93
Stainless steel, 304	2.4	0.001 30	749	1400	72.00	4.03

[a]From ASTM standards.
[b]Copper-clad steel rods based on 0.254 mm (0.010 in) copper thickness.
[c]Stainless-clad steel rod based on 0.508 mm (0.020 in) No. 304 stainless steel thickness over No. 1020 steel core.

Equation (37) and Equation (38), in conjunction with Equation (39) (which defines *TCAP*), reflect two basic assumptions

a) That all heat will be retained in the conductor (adiabatic process).

b) That the product of specific heat (*SH*) and specific weight (*SW*), *TCAP*, is approximately constant because *SH* increases and *SW* decreases at about the same rate. For most metals, these premises are applicable over a reasonably wide temperature range, as long as the fault duration is within a few seconds.

11.3.1.1 Alternate formulations

TCAP can be calculated for materials not listed in Table 1 from the specific heat and specific weight. Specific heat, *SH*, in cal/(grams × °C) and specific weight, *SW*, in gram/cm^3 are related to the thermal capacity per unit volume in J/(cm^3 × °C) as follows:

4.184 J = 1 calorie

Therefore, *TCAP* is defined by;

$$TCAP\ [\text{cal}/(\text{cm}^3 \cdot {}^\circ\text{C})] = SH\ [\text{cal}/(\text{gram} \cdot {}^\circ\text{C})] \cdot SW\ (\text{gram}/\text{cm}^3)$$

or

$$TCAP\ [\text{J}/(\text{cm}^3 \cdot {}^\circ\text{C})] = 4.184\ (\text{J}/\text{cal}) \cdot SH\ [(\text{cal}/(\text{gram} \cdot {}^\circ\text{C})] \cdot SW\ (\text{gram}/\text{cm}^3) \tag{39}$$

Once *TCAP* is determined, Equation (37) and Equation (38) can be used to determine the ampacity of the conductor.

Equation (37) and Equation (38) can be arranged to give the required conductor size as a function of conductor current.

$$A_{mm^2} = I \frac{1}{\sqrt{\left(\frac{TCAP \cdot 10^{-4}}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}} \tag{40}$$

$$A_{kcmil} = I \frac{197.4}{\sqrt{\left(\frac{TCAP}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}} \tag{41}$$

Example: A tabulation can be made, using Equation (41) and Table 1, to get data for 30% and 40% copper-clad steel, and for 100% and 97% copper conductors. For instance, to calculate the 1 s size of a 30% copper-clad steel conductor, one gets

t_c = 1.0, α_{20} = 0.003 78, ρ_{20} = 5.86, *TCAP* = 3.85, T_m = 1084, T_a = 40, K_0 = 245

Thus, for *I* = 1 kA and using Equation (41)

$$A_{kcmil} = \frac{197.4}{\sqrt{267.61}} = 12.06 \text{ kcmil or } 12.06 \text{ kcmil/kA}$$

11.3.1.2 Formula simplification

The formula in English units can be simplified to the following:

$$A_{kcmil} = I \cdot K_f \sqrt{t_c} \tag{42}$$

where

A_{kcmil} is the area of conductor in kcmil
I is the rms fault current in kA

t_c is the current duration in s

K_f is the constant from Table 2 for the material at various values of T_m (fusing temperature or limited conductor temperature based on 11.3.3) and using ambient temperature (T_a) of 40 °C

Table 2—Material constants

Material	Conductivity (%)	T_m [a] (°C)	K_f
Copper, annealed soft-drawn	100.0	1083	7.00
Copper, commercial hard-drawn	97.0	1084	7.06
Copper, commercial hard-drawn	97.0	250	11.78
Copper-clad steel wire	40.0	1084	10.45
Copper-clad steel wire	30.0	1084	12.06
Copper-clad steel rod	20.0	1084	14.64
Aluminum EC Grade	61.0	657	12.12
Aluminum 5005 Alloy	53.5	652	12.41
Aluminum 6201 Alloy	52.5	654	12.47
Aluminum-clad steel wire	20.3	657	17.20
Steel 1020	10.8	1510	15.95
Stainless clad steel rod	9.8	1400	14.72
Zinc-coated steel rod	8.6	419	28.96
Stainless steel 304	2.4	1400	30.05

[a]See 11.3.3 for comments concerning material selection.

Examples: Using Equation (42) for a 20 kA, 3 s fault

a) For soft drawn copper

$$A_{kcmil} = 20 \times 7.00 \sqrt{3}$$

$$= 242.5 \text{ kcmil}$$

use 250 kcmil

b) For 40% conductivity copper-clad steel conductor

$$A_{kcmil} = 20 \times 10.45 \sqrt{3}$$

$$= 362.0 \text{ kcmil}$$

use 19/#7 conductor

c) For steel conductor

$$A_{kcmil} = 20 \times 15.95 \sqrt{3}$$

$$= 552.5 \text{ kcmil}$$

use 7/8 inch diameter conductor

One can also compare the fusing currents of a stated conductor size for various durations of time. Using 4/0 AWG (211.6 kcmil) soft drawn copper as an example

If $t_c = 0.5$ s; $I = 211.6 / (7.00 \sqrt{0.5}) = 42.7$ kA

If $t_c = 1.0$ s; $I = 211.6 / (7.00 \sqrt{1.0}) = 30.2$ kA

If $t_c = 3.0$ s; $I = 211.6 / (7.00 \sqrt{3.0}) = 17.5$ kA

The conductor size actually selected is usually larger than that based on fusing because of factors such as

a) The conductor should have the strength to withstand any expected mechanical and corrosive abuse during the design life of the grounding installation.
b) The conductor should have a high enough conductance to prevent any possible dangerous voltage drop during a fault, for the life of the grounding installation.
c) The need to limit the conductor temperature (see 11.3.3).
d) A factor of safety should be applied to the grounding system as with other electrical components.

11.3.2 Asymmetrical currents

11.3.2.1 Using decrement factor

In cases where accounting for a possible dc offset component in the fault current is desired, an equivalent value of the symmetrical current, I_F, representing the effective value of an asymmetrical current integrated over the entire fault duration, t_c, can be determined as a function of *X/R* by using the decrement factor D_f, Equation (79) in 15.10, prior to the application of Equation (37) through Equation (42).

$$I_F = I_f \times D_f \tag{43}$$

The resulting value of I_F is always larger than I_f because the decrement factor is based on a very conservative assumption that the ac component does not decay with time but remains constant at its initial subtransient value.

11.3.2.2 Using asymmetrical current tables

Because the dc offset in the fault current will cause the conductor to reach a higher temperature for the same fault conditions (fault current duration and magnitude), Equation (43) determines an equivalent value of the symmetrical current in the presence of dc offset. In addition, if present, dc offset will result in mechanical forces and absorbed energy being almost four times the value than for an equivalent symmetric current case. However, the effect of dc offsets can be neglected if the duration of the current is greater than or equal to 1 s or the *X/R* ratio at the fault location is less than 5.

Fusing characteristics for various sizes of copper conductor with various degree of dc offset are presented in Table 3 through Table 6. These fusing characteristics have been derived theoretically, and then extensively verified experimentally (Reichman, Vainberg, and Kuffel [B122]).

Table 3—Ultimate current carrying capabilities of copper grounding cables; currents are RMS values, for frequency of 60 Hz, X/R = 40; current in kiloamperes

Cable size, AWG	Nominal cross section, mm^2	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	22	16	12	10	9	5
#1	42.41	28	21	16	13	11	7
1/0	53.48	36	26	20	17	14	8
2/0	67.42	45	33	25	21	18	11
3/0	85.03	57	42	32	27	23	14
4/0	107.20	72	53	40	34	30	17
250 kcmil	126.65	85	62	47	40	35	21
350 kcmil	177.36	119	87	67	56	49	29

Table 4—Ultimate current carrying capabilities of copper grounding cables; currents are RMS values, for frequency of 60 Hz, X/R = 20; current in kiloamperes

Cable size, AWG	Nominal cross section, mm^2	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	25	18	13	11	9	5
#1	42.41	32	22	16	13	12	7
1/0	53.48	40	28	21	17	15	9
2/0	67.42	51	36	26	22	19	11
3/0	85.03	64	45	33	27	24	14
4/0	107.20	81	57	42	35	30	18
250 kcmil	126.65	95	67	50	41	36	21
350 kcmil	177.36	134	94	70	58	50	29

Table 5—Ultimate current carrying capabilities of copper grounding cables; currents are RMS values, for frequency of 60 Hz, X/R = 10; current in kiloamperes

Cable size, AWG	Nominal cross section, mm^2	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	27	19	13	11	9	5
#1	42.41	35	23	17	14	12	7
1/0	53.48	44	30	21	17	15	9
2/0	67.42	56	38	27	22	19	11
3/0	85.03	70	48	34	28	24	14
4/0	107.20	89	60	43	36	31	18
250 kcmil	126.65	105	71	51	42	36	21
350 kcmil	177.36	147	99	72	59	51	30

Table 6—Ultimate current carrying capabilities of copper grounding cables; currents are RMS values, for frequency of 60 Hz, X/R = 0; current in kiloamperes

Cable size, AWG	Nominal cross section, mm^2	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	31	19	14	11	9	5
#1	42.41	39	24	17	14	12	7
1/0	53.48	49	31	22	18	15	9
2/0	67.42	62	39	28	22	19	11
3/0	85.03	79	50	35	28	25	14
4/0	107.20	99	63	44	36	31	18
250 kcmil	126.65	117	74	52	43	37	21
350 kcmil	177.36	165	104	73	60	52	30

NOTES

1—The current values in Table 3 through Table 6 were computed from the computer program RTGC (Reichman, Vainberg, and Kuffel [B122]). This computer program can be used directly to determine the grounding cable size requirements for known *X/R* ratio and fault clearing time.

2—Current is computed for maximum dc offset (see 15.10).

3—Initial conductor temperature = 40 °C; final conductor temperature = 1083 °C.

4—Metric values are soft conversions. Soft conversion is a direct area calculation, in metric units, from the AWG size.

11.3.3 Additional conductor sizing factors

The designer should take precautions to ensure that the temperature of any conductor and connection in the grounding installation does not pose a danger to the safe operation of the substation. For instance

a) Typically, conductors and connections near flammable materials should be subject to more stringent temperature limitations.
b) If the strength of hard drawn copper is required for mechanical reasons, then it may be prudent not to exceed 250 °C to prevent annealing of the conductors.

The possible exposure to a corrosive environment should be carefully examined. Even when the correct conductor size and the selected joining (connecting) method have satisfied all the IEEE Std 837-1989 test requirements, it may be prudent to choose a larger conductor size to compensate for some gradual reduction in the conductor cross-section during the design life of the installation where the soil environment tends to promote corrosion.

The down leads from the equipment to the grid may be subjected to the total fault current into the grid, while the grid divides this current so that each conductor segment in the grid is only subjected to some fraction of the total fault current. Thus, the down leads may have to be larger than the grid conductors or may have to be multiples from the equipment to the grid to have sufficient ampacity for the total fault current.

Ground lead conductors conducting lightning current seldom require further consideration. The size of the conductor, which is selected according to its fault current requirements, usually is also adequate for carrying short time surges caused by lightning (Bellaschi [B6]).

In practice, the requirements on mechanical reliability will set the minimum conductor size. While it might seem proper for the designer to establish minimum sizes in light of local conditions, the need for conservatism deserves consideration. Some of the specific reasons are

a) Relay malfunctions can result in fault duration in excess of primary clearing times. The backup clearing time is usually adequate for sizing the conductor. For smaller substations, this may approach 3 s or longer. However, because large substations usually have complex or redundant protection schemes, the fault will generally be cleared in 1 s or less.
b) The ultimate value of current used to determine the conductor size should take into account the possibility of future growth. It is less costly to include an adequate margin in conductor size during the initial design than to try to reinforce a number of ground leads at a later date.

11.4 Selection of connections

All connections made in a grounding network above and below ground should be evaluated to meet the same general requirements of the conductor used; namely, electrical conductivity, corrosion resistance, current carrying capacity, and mechanical strength. These connections should be massive enough to maintain a temperature rise below that of the conductor and to withstand the effect of heating. The connections should also be strong enough to withstand the mechanical forces caused by the electromagnetic forces of maximum expected fault currents and be able to resist corrosion for the intended life of the installation.

IEEE Std 837-1989 provides detailed information on the application and testing of permanent connections for use in substation grounding. Grounding connections that pass IEEE Std 837-1989 for a particular conductor size range and material should satisfy all the criteria—electrical conductivity, corrosion resistance, current carrying capacity, and mechanical strength—for that same conductor size range and material.

12. Soil characteristics

12.1 Soil as a grounding medium

The behavior of a ground electrode buried in soil can be analyzed by means of the circuit in Figure 17. As shown, most soils behave both as a conductor of resistance, *r*, and as a dielectric. Except for high-frequency and steep-front waves penetrating a very resistive soil material, the charging current is negligible in comparison to the leakage current, and the earth can be represented by a pure resistance.

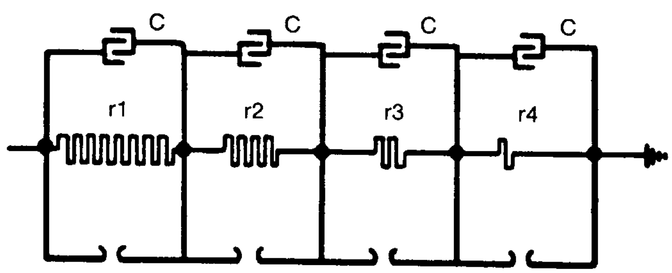


Figure 17—Soil model

12.2 Effect of voltage gradient

The soil resistivity is not affected by a voltage gradient unless the latter exceeds a certain critical value. The value somewhat varies with the soil material, but it usually has the magnitude of several kilovolts per centimeter. Once exceeded, arcs would develop at the electrode surface and progress into the earth so as to increase the effective size of the electrode, until gradients are reduced to values that the soil material can withstand. This condition is illustrated by the presence of gaps in Figure 17. Because the substation grounding system normally is designed to comply with far more stringent criteria of step and touch voltage limits, the gradient can always be assumed to be below the critical range.

12.3 Effect of current magnitude

Soil resistivity in the vicinity of ground electrodes may be affected by current flowing from the electrodes into the surrounding soil. The thermal characteristics and the moisture content of the soil will determine if a current of a given magnitude and duration will cause significant drying and thus increase the effective soil resistivity. A conservative value of cur-rent density, as given by Armstrong [B4], is not to exceed 200 A/m^2 for 1 s.

12.4 Effect of moisture, temperature, and chemical content

Electrical conduction in soils is essentially electrolytic. For this reason the resistivity of most soils rises abruptly whenever the moisture content accounts for less than 15% of the soil weight. The amount of moisture further depends upon the grain size, compactness, and variability of the grain sizes. However, as shown in curve 2 of Figure 18, the resistivity is little affected once the moisture content exceeds approximately 22%, as shown in IEEE Std 142-1991.

The effect of temperature on soil resistivity is nearly negligible for temperatures above the freezing point. At 0 °C, the water in the soil starts to freeze and the resistivity increases rapidly. Curve 3 shows this typical variation for a sandy loam soil containing 15.2% of moisture by weight.

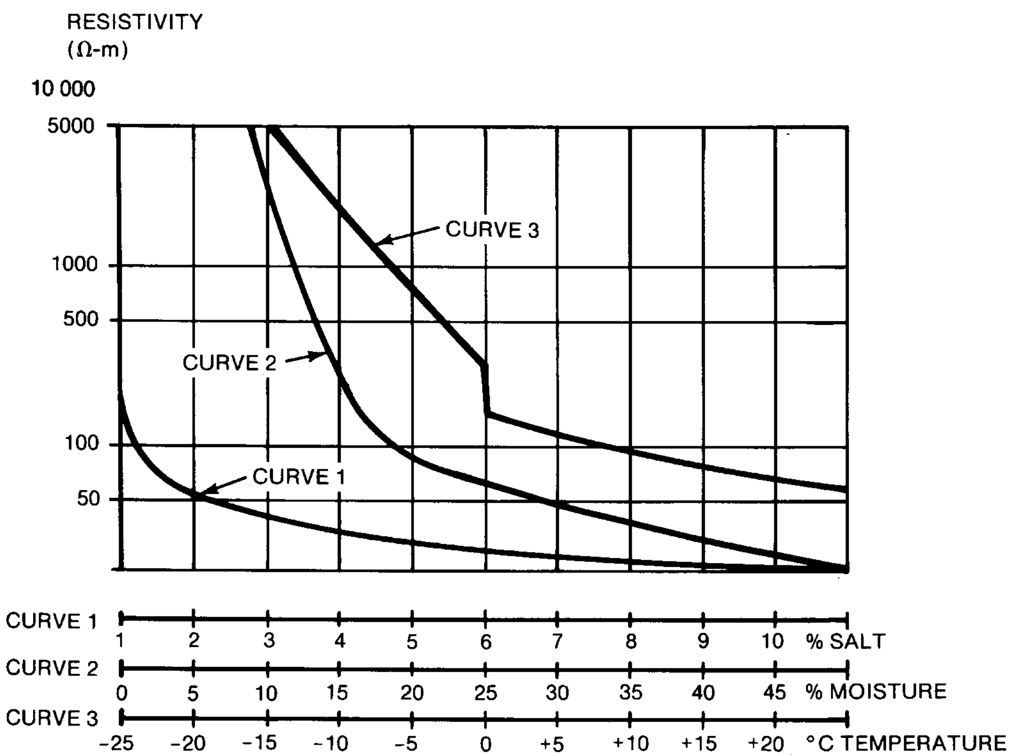


Figure 18—Effects of moisture, temperature, and salt upon soil resistivity

The composition and the amount of soluble salts, acids, or alkali present in the soil may considerably affect its resistivity. Curve 1 of Figure 18 illustrates a typical effect of salt (sodium chloride) on the resistivity of a soil containing 30% moisture by weight (Towne [B147]).

Figure 18 should not be used for calculation purposes. To determine the actual soil resistivity, tests such as those described in IEEE Std 81-1983 should be performed at the site.

12.5 Use of surface material layer

Gravel or surface material coverings, usually about 0.08–0.15 m (3–6 in) in depth, are very useful in retarding the evaporation of moisture and, thus, in limiting the drying of topsoil layers during prolonged dry weather periods. Also, as discussed in 7.4, covering the surface with a material of high resistivity is very valuable in reducing shock currents. The value of this layer in reducing shock currents is not always fully realized. Tests by Bodier [B14] at a substation in France showed that the river gravel used as yard surfacing when moistened had a resistivity of 5000 Ω·m. A layer 0.1–0.15 m (4–6 in) thick decreased the *danger factor* (ratio of body to short-circuit current) by a ratio of 10:1, as compared to the natural moist ground. Tests by Langer [B96] in Germany compared body currents when touching a hydrant while standing on wet coarse gravel of 6000 Ω·m resistivity with body currents while standing on dry sod. The current in the case of dry sod was of the order of 20 times the value for wet coarse gravel. Tests reported by others provide further confirmation of these benefits (Elek [B54]; EPRI TR-100863 [B64]).

In basing calculations on the use of a layer of clean surface material or gravel, consideration should be given to the possibility that insulation may become impaired in part through filling of voids by compression of the lowest ballast layers into the soil beneath by material from subsequent excavations, if not carefully removed, and in some areas by settlement of airborne dust.

The range of resistivity values for the surface material layer depends on many factors, some of which are kinds of stone, size, condition of stone (that is, clean or with fines), amount and type of moisture content, atmospheric contamination, etc. Table 7 indicates that the resistivity of the water with which the rock is wet has considerable influence on the measured resistivity of the surface material layer. Thus, surface material subjected to sea spray may have substantially lower resistivity than surface material utilized in arid environments. As indicated by Table 7, local conditions, size, and type of stone, etc., may affect the value of resistivity. Thus, it is important that the resistivity of rock samples typical of the type being used in a given area be measured.

Table 7 gives typical resistivity values for different types of surface material measured by several different parties in different regions of the United States (Abledu and Laird [B2]; EPRI TR-100863 [B64]; Hammond and Robson [B78]; Thompson [B145][B146]). These values are not valid for all types and sizes of stone in any given region. Tests should be performed to determine the resistivity of the stone typically purchased by the utility.

13. Soil structure and selection of soil model

13.1 Investigation of soil structure

Resistivity investigations of a substation site are essential for determining both the general soil composition and degree of homogeneity. Boring test samples and other geological investigations often provide useful information on the presence of various layers and the nature of soil material, leading at least to some ideas as to the range of resistivity at the site.

Table 7—Typical surface material resistivities

Number	Description of surface material (U.S. state where found)	Resistivity of sample Ω·m	
		Dry	Wet
1	Crusher run granite with fines (N.C.)	140×10^6	1300 (ground water, 45 Ω·m)
2	1.5 in (0.04 m) crusher run granite (Ga.) with fines	4000	1200 (rain water, 100 W)
3	0.75–1 in (0.02–0.025 m) granite (Calif.) with fines	—	6513 (10 min after 45 Ω·m water drained)
4	#4 (1 -2 in) (0.025-0.05 m) washed granite (Ga.)	1.5×10^6 to 4.5×10^6	5000 (rain water, 100 Ω·m)
5	#3 (2–4 in) (0.05-0.1 m) washed granite (Ga.)	2.6×10^6 to 3×10^6	10 000 (Rain water, 100 Ω·m)
6	Size unknown, washed limestone (Mich.)	7×10^6	2000–3000 (ground water, 45 Ω·m)
7	Washed granite, similar to 0.75 in (0.02 m) gravel	2×10^6	10 000
8	Washed granite, similar to pea gravel	40×10^6	5000
9	#57 (0.75 in) (0.02 m) washed granite (N.C.)	190×10^6	8000 (ground water, 45 Ω·m)
10	Asphalt	2×10^6 to 30×10^6	10 000 to 6×10^6
11	Concrete	1×10^6 to 1×10^9 [a]	21 to 100

[a]Oven dried concrete (Hammond and Robson [B78]). Values for air-cured concrete can be much lower due to moisture content.

13.2 Classification of soils and range of resistivity

A number of tables exist in the literature showing the ranges of resistivity for various soils and rocks. The tabulation from Rüdenberg [B125] has the advantage of extreme simplicity. More detailed data are available in engineering handbooks and publications (for instance, Sunde [B130] and Wenner [B150]). See Table 8.

13.3 Resistivity measurements

Estimates based on soil classification yield only a rough approximation of the resistivity. Actual resistivity tests therefore are imperative. These should be made at a number of places within the site. Substation sites where the soil may possess uniform resistivity throughout the entire area and to a considerable depth are seldom found. Typically, there are several layers, each having a different resistivity. Often, lateral changes also occur, but in comparison to the vertical ones, these changes usually are more gradual. Soil resistivity tests should be made to determine if there are any important variations of resistivity with depth. The number of such readings taken should be greater where the variations are large, especially if some readings are so high as to suggest a possible safety problem.

Table 8—Range of earth resistivity

Type of earth	Average resistivity (Ω·m)
Wet organic soil	10
Moist soil	10^2
Dry soil	10^3
Bedrock	10^4

If the resistivity varies appreciably with depth, it is often desirable to use an increased range of probe spacing in order to obtain an estimate of the resistivity of deeper layers. This is possible because, as the probe spacing is increased, the test source current penetrates more and more distant areas, in both vertical and horizontal directions, regardless of how much the current path is distorted due to the varying soil conditions (*Manual on Ground Resistance Testing* [B102]).

A number of measuring techniques are described in detail in IEEE Std 81-1983. The Wenner four-pin method, as shown in Figure 19, is the most commonly used technique. In brief, four probes are driven into the earth along a straight line, at equal distances *a* apart, driven to a depth *b*. The voltage between the two inner (potential) electrodes is then measured and divided by the current between the two outer (current) electrodes to give a value of resistance *R*.

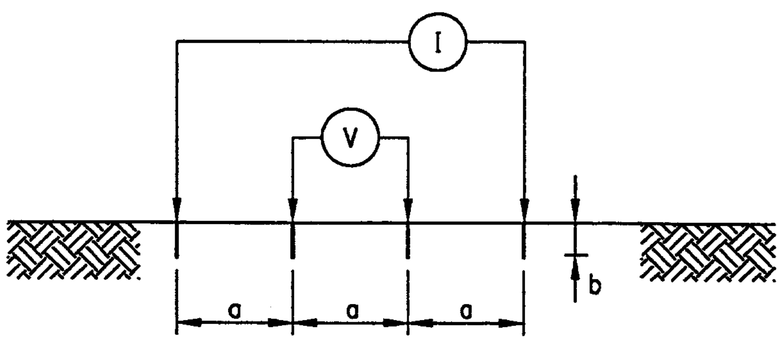


Figure 19—Wenner four-pin method

Then,

$$\rho_a = \frac{4\pi a R}{1 + \frac{2a}{\sqrt{a^2 + 4b^2}} - \frac{a}{\sqrt{a^2 + b^2}}} \tag{44}$$

where

ρ_a is the apparent resistivity of the soil in Ω·m
R is the measured resistance in Ω
a is the distance between adjacent electrodes in m
b is the depth of the electrodes in m

If b is small compared to a, as is the case of probes penetrating the ground only a short distance, Equation (44) can be reduced to

$$\rho_a = 2\pi aR \tag{45}$$

The current tends to flow near the surface for the small probe spacing, whereas more of the current penetrates deeper soils for large spacing. Thus, it is usually a reasonable approximation to assume that the resistivity measured for a given probe spacing a represents the apparent resistivity of the soil to a depth of a when soil layer resistivity contrasts are not excessive. Equation (44) and Equation (45) thus can be used to determine the apparent resistivity ρ_a at a depth a.

Schlumburger-Palmer [B119] is a modified version of the Wenner method. This method gives greater sensitivity for large probe spacing, as described in IEEE Std 81-1983.

Another method of measuring soil resistivity, as shown in Figure 20 and described in IEEE Std 81-1983, is the driven-rod method based on the three-pin or fall-of-potential method (Blattner [B11][B12]; Purdy [B121]). In this method, the depth L_r of the driven-rod located in the soil to be tested is varied. The other two rods, known as reference rods, are driven to a shallow depth in a straight line. The location of the voltage rod is varied between the test rod and the current rod. Alternately, the voltage rod may be placed on the side opposite the current rod. The apparent resistivity is given by

$$\rho_a = \frac{2\pi L_r R}{\ln\left(\frac{8L_r}{d}\right) - 1} \tag{46}$$

where

L_r is the length of the rod in m
d is the diameter of the rod in m

A plot of the measured apparent resistivity value ρ_a versus the rod length L_r provides a visual aid for determining earth resistivity variations with depth.

Tests conducted by Ohio State University [B62] demonstrated that either the Wenner four-pin method or the driven-rod three-pin method can provide the information needed to develop a soil model.

The Wenner four-pin method is the most popular method in use. There are a number of reasons for this popularity. The four-pin method obtains the soil resistivity data for deeper layers without driving the test pins to those layers. No heavy equipment is needed to perform the four-pin test. The results are not greatly affected by the resistance of the test pins or the holes created in driving the test pins into the soil.

An advantage of the driven-rod method, although not related necessarily to the measurements, is the ability to determine to what depth the ground rods can be driven. Knowing if and how deep rods can be driven into the earth can save the need to redesign the ground grid. Often, because of hard layers in the soil such as rock, hard clay, etc., it becomes practically impossible to drive the test rod any further resulting in insufficient data. A technique for the prediction of the soil resistivity to a depth 10 times the depth of known resistivity value has been developed by Blattner [B11]. This technique can be effectively used in cases where the test rod cannot be driven deep. However, the user is advised to review practical limitations of this technique before using it. A disadvantage of the driven-rod method is that when the test rod is driven deep in the ground, it usually loses contact with the soil due to the vibration and the larger diameter couplers resulting in higher measured resistance values. A ground grid designed with these higher soil resistivity values may be unnecessarily conservative. The driven-rod method presents an uncertainty in the resistance value. The 62% rule is valid only for large electrode separation and uniform soil. In nonuniform soils, this assumption may

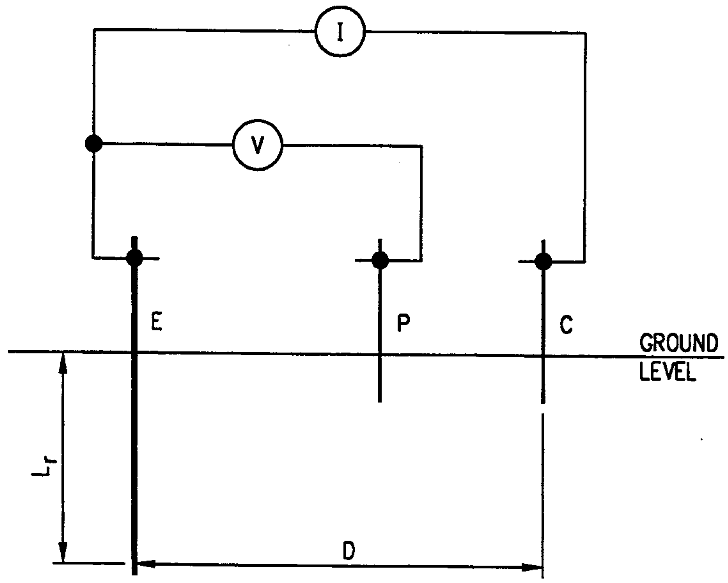


Figure 20—Circuit diagram for three-pin or driven-ground rod method

affect the outcome of the readings. If the flat portion of the curve is used to determine the test rod resistance, this flat portion may not give the correct resistance in nonuniform soil, and the flat portion may not even be obtained unless the test and current rod separation is very large (Dawalibi and Mukhedkar [B39][B44]).

Resistivity measurement records should include temperature data and information on the moisture content of the soil at the time of measurement. All data available on known buried conductive objects in the area studied should also be recorded.

Buried conductive objects in contact with the soil can invalidate readings made by the methods described if they are close enough to alter the test current flow pattern. This is particularly true for large or long objects. For this reason, the soil resistivity measurements are likely to be significantly distorted in an area where grid conductors have already been installed, except for shallow-depth measurements in or near the center of a very large mesh rectangle. In such cases, a few approximate readings might be taken in a short distance outside the grid, with the probes so placed as to minimize the effect of the grid on the current flow pattern. Though not conclusive as to conditions inside the grid, such readings may be used for approximation, especially if there is reason to believe that the soil in the entire area is reasonably homogeneous.

13.4 Interpretation of soil resistivity measurements

Interpretation of apparent resistivity obtained in the field is perhaps the most difficult part of the measurement program. The basic objective is to derive a soil model that is a good approximation of the actual soil. Soil resistivity varies laterally and with respect to depth, depending on the soil stratification. Seasonal variations may occur in soil resistivity due to varying weather conditions as described in EPRI TR-100863 [B64]. It must be recognized that the soil model is only an approximation of the actual soil conditions and that a perfect match is unlikely.

The most commonly used soil resistivity models are the uniform soil model and the two-layer soil model. Two-layer soil models are often a good approximation of many soil structures while multilayer soil models may be used for more complex soil conditions. Interpretation of the soil resistivity measurements may be accomplished either manually or by use of computer analysis techniques described in Blattner and Dawalibi

[B13]; Blattner [B11][B12]; Endrenyi [B56]; EPRI TR-100622 [B63]; EPRI EL-3982 [B62]; EPRI EL-2699 [B60]; Lazzara and Barbeito [B98]; Meliopoulos, Papelexopoulos, Webb, and Blattner [B105]; Meliopoulos and Papelexopoulos [B103]; Moore [B110]; Nahman and Salamon [B112]; Roman [B123]; and Tagg [B135].

A uniform soil model should be used only when there is a moderate variation in apparent resistivity. In homogeneous soil conditions, which rarely occur in practice, the uniform soil model may be reasonably accurate. If there is a large variation in measured apparent resistivity, the uniform soil model is unlikely to yield accurate results.

A more accurate representation of the actual soil conditions can be obtained by use of a two-layer model. The two-layer model consists of an upper layer of finite depth and with different resistivity than a lower layer of infinite thickness. There are several techniques to determine an equivalent two-layer model from apparent resistivity obtained from field tests. In some instances a two-layer model can be approximated by visual inspection of a plot of the apparent resistivity versus depth from driven rod measurements or apparent resistivity versus probe spacing from Wenner four-pin measurements (Blattner [B10][B12]; IEEE Tutorial Course 86 [B87]).

Computer programs available to the industry may also be used to derive a two-layer soil model and multilayer soil models (Dawalibi and Barbeito [B38]; EPRI TR-100622 [B63]; EPRI EL-2699 [B60]; Orellara and Mooney [B117]).

In some instances the variation in soil resistivity may exhibit minimums and maximums such that an equivalent two-layer model may not yield an accurate model. In such instances a different soil model, such as a multilayer model, may be required as described in Dawalibi, Ma, and Southey [B46] and Dawalibi and Barbeito [B38].

13.4.1 Uniform soil assumption

A uniform soil model can be used instead of the multilayer soil model whenever the two-layer or multilayer computation tools are not available. Unfortunately, an upper bound of the error on all relevant grounding parameters is difficult to estimate in general, but when the contrast between the various layer resistivities is moderate, an average soil resistivity value may be used as a first approximation or to establish order of magnitudes. The approximate uniform soil resistivity may be obtained by taking an arithmetic average of the measured apparent resistivity data as shown in Equation (47).

$$\rho_{a(av1)} = \frac{\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + \ldots + \rho_{a(n)}}{n} \qquad (47)$$

where

$\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} + \ldots + \rho_{a(n)}$	are the measured apparent resistivity data obtained at different spacings in the four-pin method or at different depths in the driven ground rod method in Ω·m
n	is total number of measurements

A majority of the soils will not meet the criteria of Equation (47). It is difficult to develop a uniform soil model when the resistivity of a soil varies significantly. Because the step and touch voltage equations of this guide are based on uniform soil models, an attempt was made to develop a guideline to approximate a non-uniform soil to a uniform soil. Apparent soil resistivity data were obtained using the four pin method from several different geographical locations. The soil data from each location were approximated with three different equivalent soil models. These approximate models consisted of one computer-generated (EPRI TR-100622 [B63]) two-layer model and two uniform soil models. The uniform soil models were determined from measured apparent resistivity data using Equation (47) and Equation (48). In the next step, the grid resistance and step/touch voltages for a 76.2 m × 76.2 m (250 ft × 250 ft) grid with a total of 64 uniformly distributed ground rods were computed using a computer program (EPRI TR-100622 [B63]). The depth of the ground rods was dependent on the soil model used. For example, in the case of the two layer model, the ground rods penetrated the lower layer. Refer to Annex E for more details of this investigation. Finally, the grounding parameters computed for the two-layer model were compared with that computed using the uniform soil models. The grounding parameters computed using the uniform soil model of Equation (50) compared well with that computed using the two layer model.

$$\rho_{2(av2)} = \frac{\rho_{a(max)} + \rho_{a(min)}}{2} \tag{48}$$

where

$\rho_{a(max)}$ is the maximum apparent resistivity value (from measured data) in Ω·m.
$\rho_{a(min)}$ is the minimum apparent resistivity value (from measured data) in Ω·m.

There are a number of assumptions made in the above study. As a result, the Equation (48) should be used with caution. For example, use of Equation (48) is not recommended for a ground grid without ground rods (Dawalibi, Ma, and Southey [B47]). In addition, if the uniform soil resistivity determined using Equation (48) is employed to design a ground grid, the ground rods should at least reach the depth where the measured resistivity corresponds to the computed value of $\rho_{a(av2)}$.

There are several methods suggested by different authors to approximate a nonuniform soil with a uniform soil model. One of these methods includes using the average of upper layer apparent resistivity for the touch and step voltage calculations and the average of lower layer apparent resistivity for the grounding system resistance calculation. Dawalibi, Ma, and Southey [B46]; Dawalibi and Barbeito [B38]; EPRI TR-100622 [B63]; Fujimoto, Dick, Boggs, and Ford [B69]; and Thapar and Gerez [B140] may provide additional information about interpretation of the measured soil data and the influence of multilayer, two-layer, and uniform soil models on grounding parameters.

13.4.2 Nonuniform soil assumptions

Another approach to situations where resistivity varies markedly with depth is suggested by Sunde [B130], and in some of the books on geophysical prospecting to which he refers. For example, it is often possible from field readings taken with a wide range of probe spacing to deduce a stratification of the earth into two or more layers of appropriate thickness that will account for the actual test variations (Moore [B110]).

13.4.2.1 Two-layer soil model (general)

A two-layer soil model can be represented by an upper layer soil of a finite depth above a lower layer of infinite depth. The abrupt change in resistivity at the boundaries of each soil layer can be described by means of a reflection factor. The reflection factor, *K*, is defined by Equation (49).

$$K = \frac{\rho_2 - \rho_1}{\rho_1 + \rho_2} \tag{49}$$

where

ρ_1 is the upper layer soil resistivity, in Ω·m
ρ_2 is the lower layer soil resistivity, in Ω·m

While the most accurate representation of a grounding system should certainly be based on the actual variations of soil resistivity present at the substation site, it will rarely be economically justifiable or technically feasible to model all these variations. However, in most cases, the representation of a ground electrode based on an equivalent two-layer earth model is sufficient for designing a safe grounding system.

IEEE Std 81-1983 provides methods for determining the equivalent resistivities of the upper and lower layer of soil and the height of the upper layer for such a model.

There are other methods suggested by authors that include determining a two-layer model and using the upper layer resistivity for touch and step calculations and the lower resistivity for resistance and methods that modify the equations presented in the guide to be used in two-layer soil models. These papers may provide the designer with more information about the interpretation of soils and the impact of multilayer, two-layer, and uniform models (Dawalibi, Ma, and Southey [B46]; Dawalibi and Barbeito [B38]; Thapar and Gerez [B140]).

13.4.2.2 Two-layer soil model by graphical method

A two-layer soil model can be approximated by using graphical methods described in Blattner and Dawalibi [B13]; Endrenyi [B56]; Tagg [B136]; Roman [B123]; and Sunde [B130]. Sunde's graphical method is described in the following paragraphs.

In Sunde's method, the graph shown in Figure 21 is used to approximate a two-layer soil model. The graph in Figure 21, which is based on the Wenner four-pin test data, is reproduced from figure 2.6 of Sunde [B130], with notations revised to match the symbols used in this guide.

Parameters ρ_1 and ρ_2 are obtained by inspection of resistivity measurements (see the example in Figure 22). Only *h* is obtained by Sunde's graphical method, as follows:

a) Plot a graph of apparent resistivity ρ_a on y-axis vs. pin spacing on x-axis.
b) Estimate ρ_1 and ρ_2 from the graph plotted in a). ρ_a corresponding to a smaller spacing is ρ_1 and for a larger spacing is ρ_2. Extend the apparent resistivity graph at both ends to obtain these extreme resistivity values if the field data are insufficient.
c) Determine ρ_2/ρ_1 and select a curve on the Sunde graph in Figure 21, which matches closely, or interpolate and draw a new curve on the graph.
d) Select the value on the y-axis of ρ_a/ρ_1 within the sloped region of the appropriate ρ_2/ρ_1 curve of Figure 21.
e) Read the corresponding value of *a/h* on the x-axis.
f) Compute ρ_a by multiplying the selected value, ρ_a/ρ_1, in (d) by ρ_1.
g) Read the corresponding probe spacing from the apparent resistivity graph plotted in a).
h) Compute *h*, the depth of the upper level, using the appropriate probe separation, *a*.

Using the soil data from soil type 1 in Table E.2 in Annex E, a plot of resistivity vs. spacing can be drawn. See figure Figure 22. Both ρ_1 and ρ_2 can be determined by visual inspection. Assuming ρ_1 =100 Ω·m and ρ_2 = 300 Ω·m, the following example illustrates Sunde's graphical method:

a) Plot Figure 22.
b) Choose ρ_1 =100 Ω·m, ρ_2 = 300 Ω·m
c) ρ_2/ρ_1 = 300/100 = 3. Draw curve on Figure 21. See Figure 23 for an example.
d) Select ρ_a/ρ_1 = 2.
e) Read *a/h* = 2.7 from figure Figure 23 for ρ_a/ρ_1 = 2.
f) Compute ρ_a: $\rho_a = 2\rho_1 = 2(100) = 200$.

g) Read a = 19 on the apparent resistivity curve of Figure 24 for ρ_a = 200.

h) Compute h; $h = \frac{a}{a/h}$ 19/2.7 = 7.0 m or 23 ft.

This compares favorably with the 6.1 m (20 ft) using EPRI TR-100622 [B63].

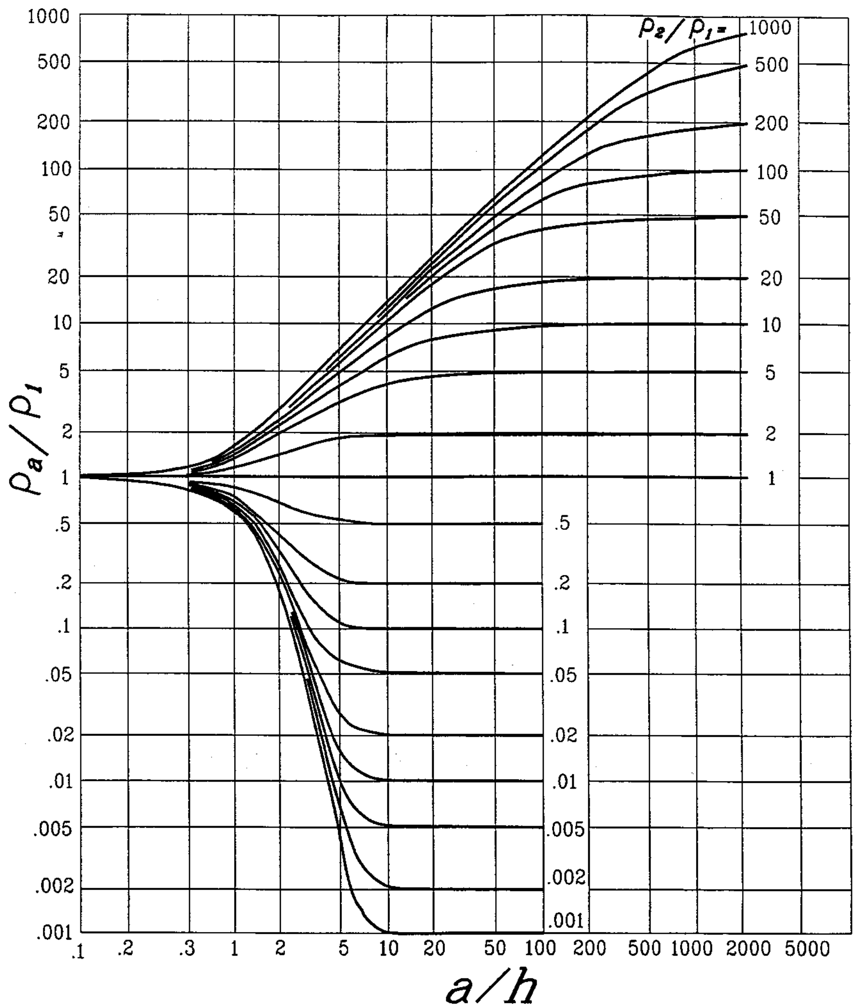


Figure 21—Sunde's graphical method

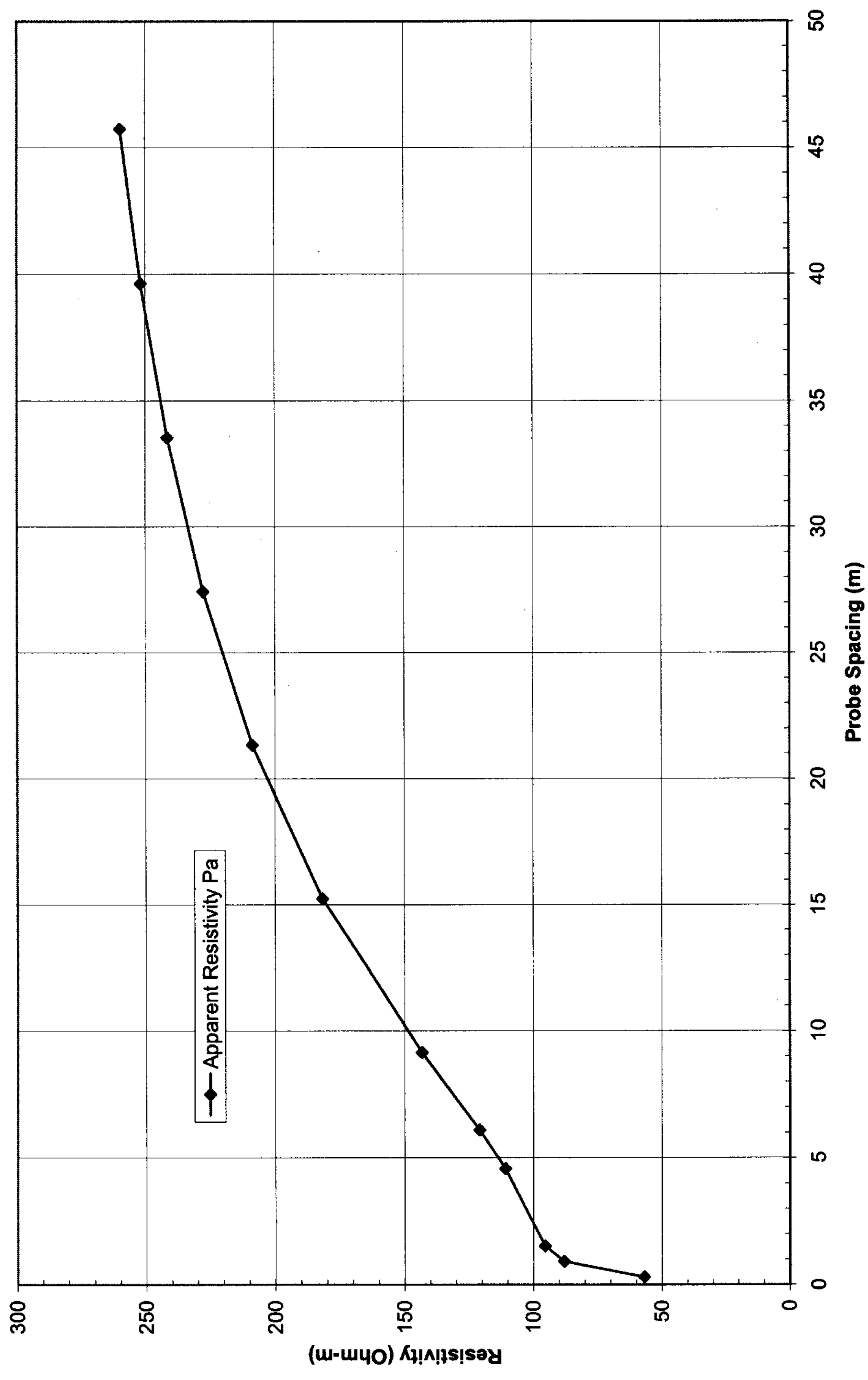


Figure 22—Resistivity plot of data from soil type 1, table E2

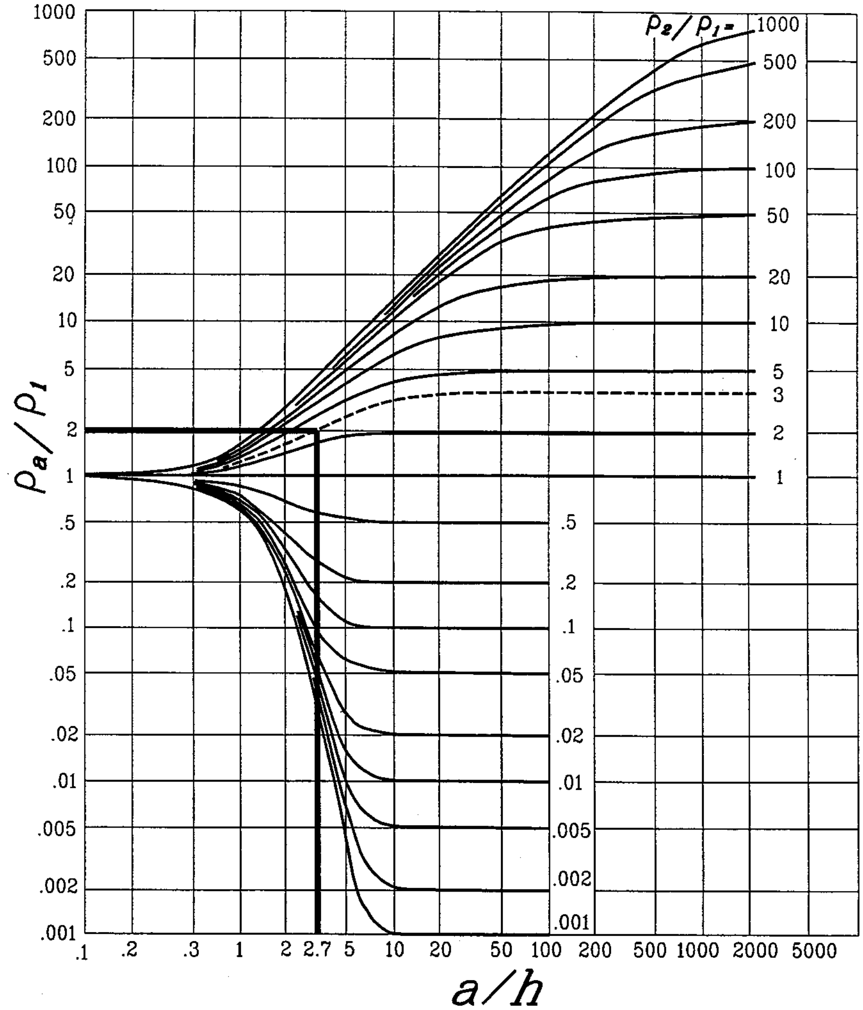


Figure 23—Example of Sunde's graphical method

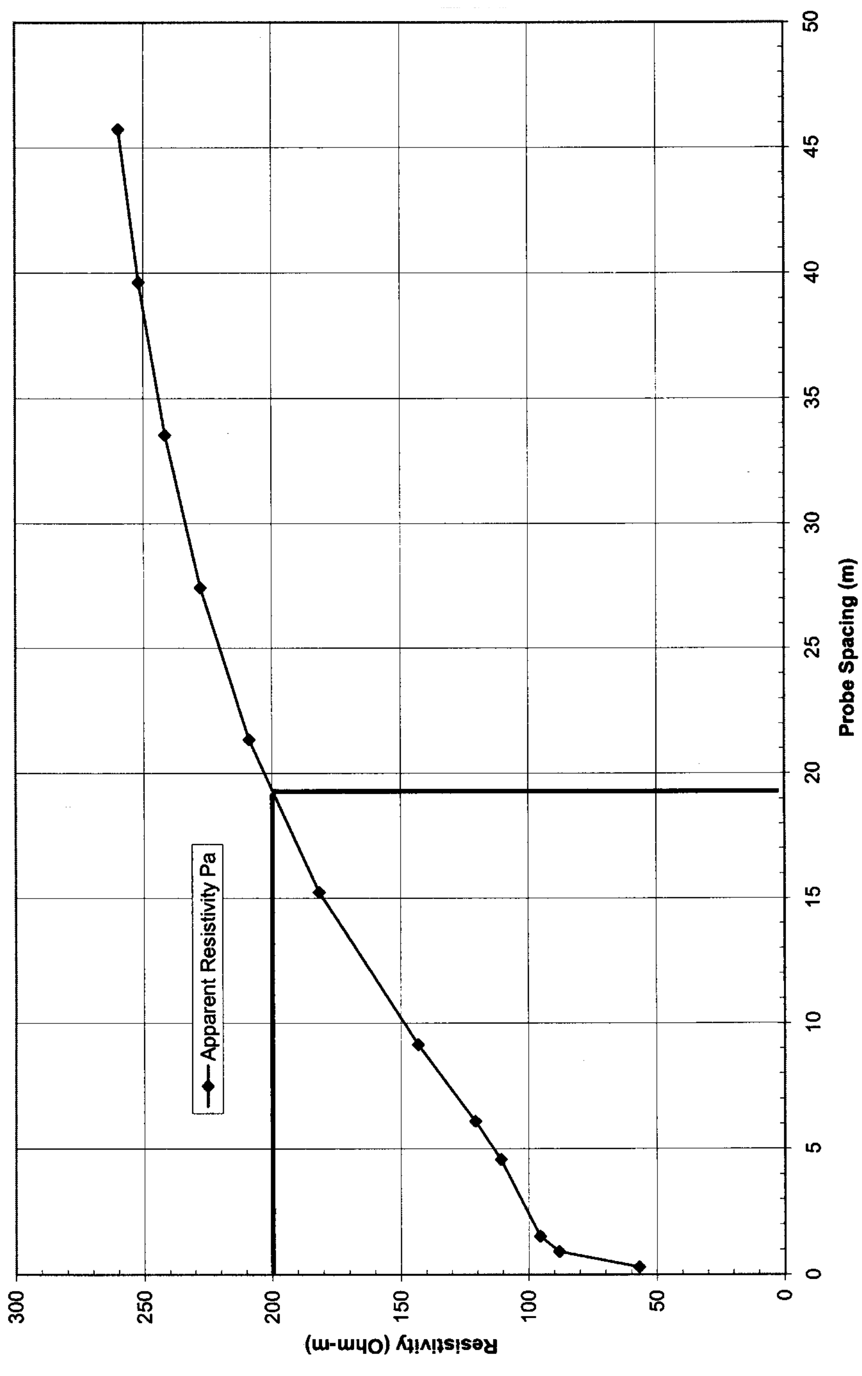


Figure 24—Example to determine “a” from apparent resistivity curve

13.4.2.3 Comparison of uniform and two-layer soil model on grounding systems

The two-layer model approach has been found to be much more accurate than the uniform soil model. A grounding system in a two-layer soil environment behaves differently in comparison with the same system in uniform soil.

Generally, for a grounding system in uniform soil or in two-layer soil with ρ_1 less than ρ_2 (upper layer soil resistivity less than lower layer soil resistivity, a positive reflection factor), the current density is higher in the conductors at the outer edges of the grounding grid. In two-layer soil with ρ_1 greater than ρ_2 (the soil in the upper layer is more resistive than the lower layer soil, a negative reflection factor), the current density is more uniform over all the conductors of the grounding system. This is caused by the tendency of the grid current to go downward into the layer of lower resistivity, rather than up and outward to the more resistive upper layer. Studies by Thapar and Gross [B141] and Dawalibi et al. [B41][B43][B48] provide a wealth of information on this subject.

a) Variations in soil resistivity have considerable influence on the performance of most grounding systems, affecting both the value of ground resistance and ground potential rise, and the step and touch surface voltages. In general, for negative values of K (upper layer more resistive than lower layer), the resistance is less than that of the same grounding system in uniform soil with resistivity ρ_1. In contrast, for positive values of K, the resistance is generally higher than that in uniform soil and resistivity ρ_1. A similar relationship exists for the step and touch voltages produced on the surface of a two-layer earth versus that on the surface of uniform soil. For negative values of K, the step and touch voltages are generally lower than the voltages for the same grounding system in uniform soil of resistivity ρ_1. Also, for positive values of K, the step and touch voltages are generally higher than in uniform soil.[13]

b) Other parameters, such as the upper layer height h, also affect the differences in the performance of ground electrodes in a two-layer environment and in uniform soil conditions. The general rule is that when the upper layer height h becomes significantly larger than the electrode's own dimensions, the performance of the electrode approaches the performance of the same electrode in uniform soil of resistivity ρ_1.

c) Also, it must be recognized that the above characteristics are based on the premise of a constant fault current source. The actual currents in the grounding system will change from case to case as a function of ρ_1 and ρ_2, reflecting the local changes relative to all other ground fault current paths predetermined by the fault location. This current division is discussed in Clause 15. Therefore, in certain cases some of the assumptions given above may not always hold true.

For design applications involving relatively simple grounding arrangements of electrodes buried in a reasonably uniform soil, the approximate methods provided elsewhere in the guide will be suitable for obtaining a realistic design with adequate safety margins. However, for designs involving a large grounded area, odd-shaped grids, etc., or where the resistivity of soil is clearly very nonuniform, the engineer responsible for the design should decide if more sophisticated methods are needed (Zaborszky [B152]).

Annex F provides a parametric analysis of various grid configurations in uniform and two-layer soil models.

13.4.2.4 Multilayer soil model

Highly nonuniform soil conditions may be encountered. Such soil conditions may require the use of multilayer modeling techniques if an equivalent two-layer soil model is not feasible. A multilayer soil model may

[13]As discussed in 12.5, it is a common practice to have a thin layer of surface material overlaying the grounded area of a substation. It could appear that such a high resistivity layer, having the layer height h, much less than the depth of the grounding system, might worsen both the step and touch voltage. However, this is not the case. The surface material is used to increase the contact resistance between a person's foot and the earth surface. Thus, for a given maximum allowable body current, considerably higher step and touch voltages can be allowed if a high resistivity surface material is present.

include several horizontal layers or vertical layers. Techniques to interpret highly nonuniform soil resistivity require the use of computer programs or graphical methods (Dawalibi, Ma, and Southey [B46]; Dawalibi and Barbeito [B38]; EPRI TR-100622 [B63]; EPRI EL-2699 [B60]; Orellara and Mooney [B117]).

The equations that govern the performance of a grounding system buried in multilayer soil can be obtained by solving Laplace's equations for a point current source, or by the method of images, which gives identical results. The use of either method in determining the earth potential caused by a point current source results in an infinite series of terms representing the contributions of each consequent image of the point current source. Exact formulation of the equations that include these effects is given in Dawalibi and Mukhedkar [B42]; Heppe [B80]; and Sunde [B130].

14. Evaluation of ground resistance

14.1 Usual requirements

A good grounding system provides a low resistance to remote earth in order to minimize the GPR. For most transmission and other large substations, the ground resistance is usually about 1 Ω or less. In smaller distribution substations, the usually acceptable range is from 1 Ω to 5 Ω, depending on the local conditions.

14.2 Simplified calculations

Estimation of the total resistance to remote earth is one of the first steps in determining the size and basic layout of a grounding system. The resistance depends primarily on the area to be occupied by the grounding system, which is usually known in the early design stage. As a first approximation, a minimum value of the substation grounding system resistance in uniform soil can be estimated by means of the formula of a circular metal plate at zero depth

$$R_g = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \tag{50}$$

where

R_g is the substation ground resistance in Ω
ρ is the soil resistivity in Ω·m
A is the area occupied by the ground grid in m^2

Next, an upper limit of the substation ground resistance can be obtained by adding a second term to the above formula, as proposed by Laurent [B97] and Niemann [B115]

$$R_g = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} + \frac{\rho}{L_T} \tag{51}$$

where

L_T is the total buried length of conductors in m

In the case of a grid rod combination in uniform soil, a combined length of horizontal conductors and ground rods will yield a slightly conservative estimate of L_T, because ground rods usually are more effective on a per unit length basis.

The second term recognizes the fact that the resistance of any actual grounding system that consists of a number of conductors is higher than that of a solid metallic plate. The difference will decrease with the increasing length of buried conductors and will approach 0 for infinite L_T, when the condition of a solid plate is reached.

Sverak [B132] expanded Equation (51) to take into account the effect of grid depth

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right] \tag{52}$$

where

h is the depth of the grid in m

For grids without ground rods, this formula has been tested to yield results that are practically identical to those obtained with Equation (56) of Schwarz [B128], described in 14.3.

The following tabulation from Kinyon [B93] offers some idea of how the calculated and actual measured resistance for five different substations compare. Equation (51) was used to compute the grid resistance. See Table 9.

Table 9—Typical grid resistances

Parameter soil texture	**Sub 1 sand and gravel**	**Sub 2 sandy loam**	**Sub 3 sand and clay**	**Sub 4 sand and gravel**	**Sub 5 soil and clay**
Resistivity (Ω·m)	2000	800	200	1300	28.0
Grid area (ft^2)	15 159	60 939	18 849	15 759	61 479
Buried length (ft)	3120	9500	1775	3820	3000
R_g (calculated Ω)	25.7	4.97	2.55	16.15	0.19
R_g (measured Ω)	39.0	4.10	3.65	18.20	0.21

An average value of all measured resistivity values is frequently substituted for the uniform soil resistivity in Equation (51). If this average resistivity is used, Equation (51) usually produces a resistance that is higher than the value that would result from a direct resistance measurement. The calculated and measured resistance values shown in table Table 9 not reflect this trend, because Kinyon [B93] based his calculations on the "... lowest average value of resistivity measured on the site." Readers are referred to Kinyon [B93] for further discussion on his choice of resistivity values used in Table 9.

14.3 Schwarz's equations

Schwarz [B128] developed the following set of equations to determine the total resistance of a grounding system in a homogeneous soil consisting of horizontal (grid) and vertical (rods) electrodes. Schwarz's equations extended accepted equations for a straight horizontal wire to represent the ground resistance, R_1, of a grid consisting of crisscrossing conductors, and a sphere embedded in the earth to represent ground rods, R_2. He also introduced an equation for the mutual ground resistance R_m between the grid and rod bed.

Schwarz used the following equation introduced by Sunde [B130] and Rüdenberg [B127] to combine the resistance of the grid, rods, and mutual ground resistance to calculate the total system resistance, R_g.

$$R_g = \frac{R_1 R_2 - R_m^2}{R_1 + R_2 - 2R_m} \tag{53}$$

where

R_1 ground resistance of grid conductors in Ω
R_2 ground resistance of all ground rods in Ω
R_m mutual ground resistance between the group of grid conductors, R_1, and group of ground rods, R_2 in Ω.

Ground resistance of the grid

$$R_1 = \frac{\rho}{\pi L_c}\left[\ln\left(\frac{2L_c}{a'}\right) + \frac{k_1 \cdot L_c}{\sqrt{A}} - k_2\right] \tag{54}$$

where

ρ is the soil resistivity in Ω·m
L_c is the total length of all connected grid conductors in m
a' is $\sqrt{a \cdot 2h}$ for conductors buried at depth h in m, or
a' is a for conductor on earth surface in m
$2a$ is the diameter of conductor in m
A is the area covered by conductors in m^2
k_1, k_2 are the coefficients [see Figure 25(a) and (b)]

Ground resistance of the rod bed

$$R_2 = \frac{\rho}{2\pi n_R L_R}\left[\ln\left(\frac{4L_R}{b}\right) - 1 + \frac{2k_1 \cdot L_r}{\sqrt{A}}(\sqrt{n_R} - 1)^2\right] \tag{55}$$

where

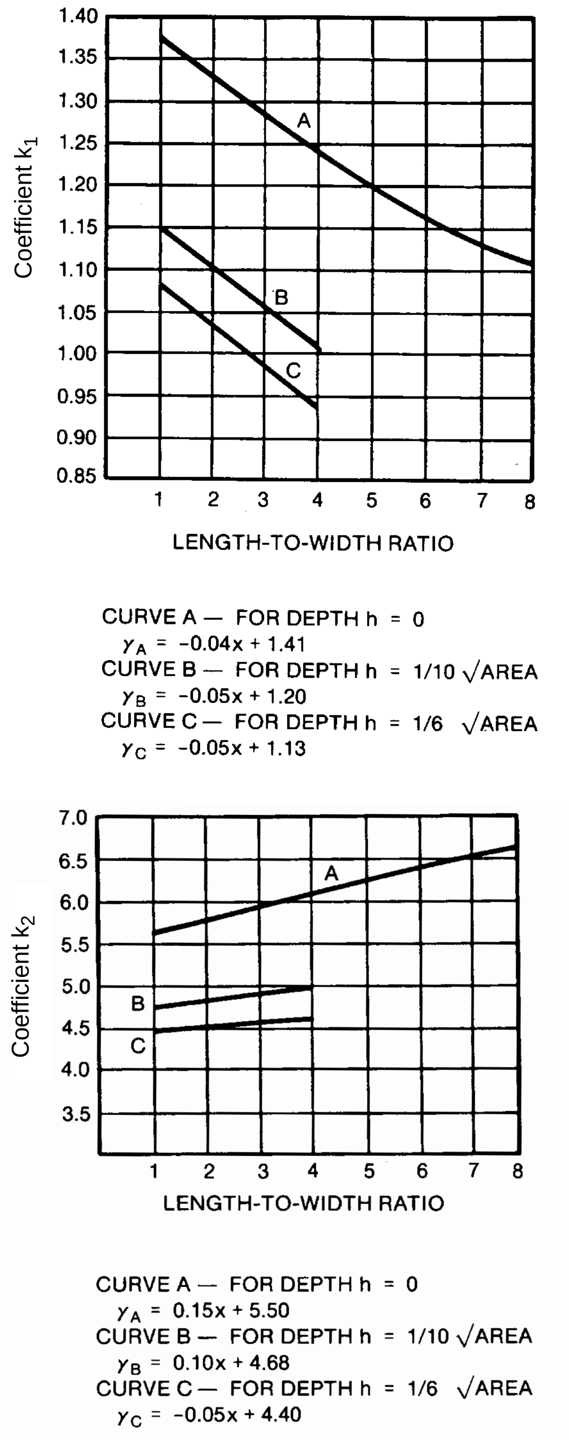
L_r is the length of each rod in m
$2b$ is the diameter of rod in m
n_R number of rods placed in area A

Mutual ground resistance between the grid and the rod bed

$$R_m = \frac{\rho}{\pi L_c}\left[\ln\left(\frac{2L_c}{L_r}\right) + \frac{k_1 \cdot L_c}{\sqrt{A}} - k_2 + 1\right] \tag{56}$$

The combined ground resistance of the grid and the rod bed will be lower than the ground resistance of either component alone, but still higher than that of a parallel combination.

Schwarz compared the results of his equations to previously published theoretical work and to model tests to verify the accuracy of his equations. Since they were published in 1954, Schwarz's equations have been modified by Kercel [B92] to provide equations for constants k_1 and k_2 and further expanded to include the use of equations in two-layer soil (Naham and Salamon [B113][B114]).



(a)

(b)

Figure 25—Coefficients k_1 and k_2 of Schwarz's formula: (a) coefficient k_1, (b) coefficient k_2

14.4 Note on ground resistance of primary electrodes

In general, the ground resistance of any primary electrode depends on the soil resistivity and the size and type of arrangement of all individual conductors comprising the ground electrode. In more complex arrangements involving crisscrossed wires and a large number of rods in the same area, the mutual resistance between individual elements plays an important role.

14.5 Soil treatment to lower resistivity

It is often impossible to achieve the desired reduction in ground resistance by adding more grid conductors or ground rods. An alternate solution is to effectively increase the diameter of the electrode by modifying the soil surrounding the electrode. The inner shell of soil closest to the electrode normally comprises the bulk of the electrode ground resistance to remote earth. This phenomenon is often utilized to an advantage, as follows:

a) Use of sodium chloride, magnesium, and copper sulfates, or calcium chloride, to increase the conductivity of the soil immediately surrounding an electrode. State or federal authorities may not permit using this method because of possible leaching to surrounding areas. Further, the salt treatment must be renewed periodically.

b) Use of bentonite, a natural clay containing the mineral montmorillionite, which was formed by volcanic action years ago. It is noncorrosive, stable, and has a resistivity of 2.5 Ω·m at 300% moisture. The low resistivity results mainly from an electrolytic process between water, Na_2O (soda), K_2O (potash), CaO (lime), MgO (magnesia), and other mineral salts that ionize forming a strong electrolyte with pH ranging from 8 to 10. This electrolyte will not gradually leach out, as it is part of the clay itself. Provided with a sufficient amount of water, it swells up to 13 times its dry volume and will adhere to nearly any surface it touches. Due to its hygroscopic nature, it acts as a drying agent drawing any available moisture from the surrounding environment. Bentonite needs water to obtain and maintain its beneficial characteristics. Its initial moisture content is obtained at installation when the slurry is prepared. Once installed, bentonite relies on the presence of ground moisture to maintain its characteristics. Most soils have sufficient ground moisture so that drying out is not a concern. The hygroscopic nature of bentonite will take advantage of the available water to maintain its as installed condition. If exposed to direct sunlight, it tends to seal itself off, preventing the drying process from penetrating deeper. It may not function well in a very dry environment, because it may shrink away from the electrode, increasing the electrode resistance (Jones [B90]).

c) Chemical-type electrodes consist of a copper tube filled with a salt. Holes in the tube allow moisture to enter, dissolve the salts, and allow the salt solution to leach into the ground. These electrodes are installed in an augured hole and typically back-filled with soil treatment.

d) Ground enhancement materials, some with a resistivity of less than 0.12 Ω·m (about 5% of the resistivity of bentonite), are typically placed around the rod in an augured hole or around grounding conductors in a trench, in either a dry form or premixed in a slurry. Some of these enhancement materials are permanent and will not leach any chemicals into the ground. Other available ground enhancement materials are mixed with local soil in varying amounts and will slowly leach into the surrounding soil, lowering the earth resistivity.

14.6 Concrete-encased electrodes

Concrete, being hygroscopic, attracts moisture. Buried in soil, a concrete block behaves as a semiconducting medium with a resistivity of 30–90 Ω·m. This is of particular interest in medium and highly resistive soils because a wire or metallic rod encased in concrete has lower resistance than a similar electrode buried directly in the earth. This encasement reduces the resistivity of the most critical portion of material surrounding the metal element in much the same manner as a chemical treatment of soils. However, this phenomenon may often be both a design advantage and disadvantage. Some of the reasons are as follows:

a) On the one hand, it is impractical to build foundations for structures where the inner steel (reinforcing bars) is not electrically connected to the metal of the structure. Even if extreme care were taken with the anchor bolt placement in order to prevent any direct metal-to-metal contact, the semiconductive nature of concrete would provide an electrical connection.

b) On the other hand, the presence of a small dc current can cause corrosion of rebar material. Although ac current as such does not produce corrosion, approximately 0.01% of the ac current becomes rectified at the interface of the steel bar and concrete (Rosa, McCollum, and Peters [B124]).

c) Splitting of concrete may occur either due to the above phenomenon because corroded steel occupies approximately 2.2 times its original volume, producing pressures approaching 35 MPa or the passage of a very high current, which would vaporize the moisture in the concrete.

Fortunately, there is a certain threshold potential for dc corrosion, approximately 60 V dc, below which no corrosion will occur. A number of field tests concerning the maximum current loading is reported in Bogajewski, Dawalibi, Gervais, and Mukhedkar [B16]; Dick and Holliday [B53]; and Miller, Hart, and Brown [B107]). The short-time current loading capacity, I_{CE}, of concrete-encased electrodes can be estimated by means of Ollendorff's formula[14] for an indefinitely sustainable current I_∞, adjusted by a 1.4 multiplying factor, or directly from Figure 26.

$$I_{CE} = 1.4(I_\infty) = \frac{1.4}{R_z}\sqrt{2\lambda_g\rho(T_v - T_a)} \tag{57}$$

where

λ_g is the thermal conductivity of the earth in W/(m °C)
R_z is the ground resistance of the concrete-encased electrode in Ω
ρ is the soil resistivity in Ω·m
T_a is the ambient temperature in °C
T_v is the maximum allowable temperature to prevent sudden evaporation of moisture in °C
I_∞ is the indefinitely sustainable current in A

The applicability of this formula has been verified in Bogajewski, Dawalibi, Gervais, and Mukhedkar [B16], which reports on the results of extensive field testing of concrete poles. In general, if damage is to be prevented, the actual current should be less than the value of I_{CE} determined by Equation (57). A 20–25% safety margin is reasonable for most practical applications.

Thus, with proper precautions, the concrete-encased electrodes may be used as auxiliary ground electrodes.

Fagan and Lee [B65] use the following equation for obtaining the ground resistance, R_{CE-rod}, of a vertical rod encased in concrete:

$$R_{CE-rod} = \frac{1}{2\pi L_r}(\rho_c[\ln(D_C/d)] + \rho[\ln(8L_r/D_C) - 1]) \tag{58}$$

where

ρ_c is the resistivity of the concrete in Ω·m

[14]Ollendorff [B116] neglects the cooling effect of evaporated moisture in calculating I_∞.

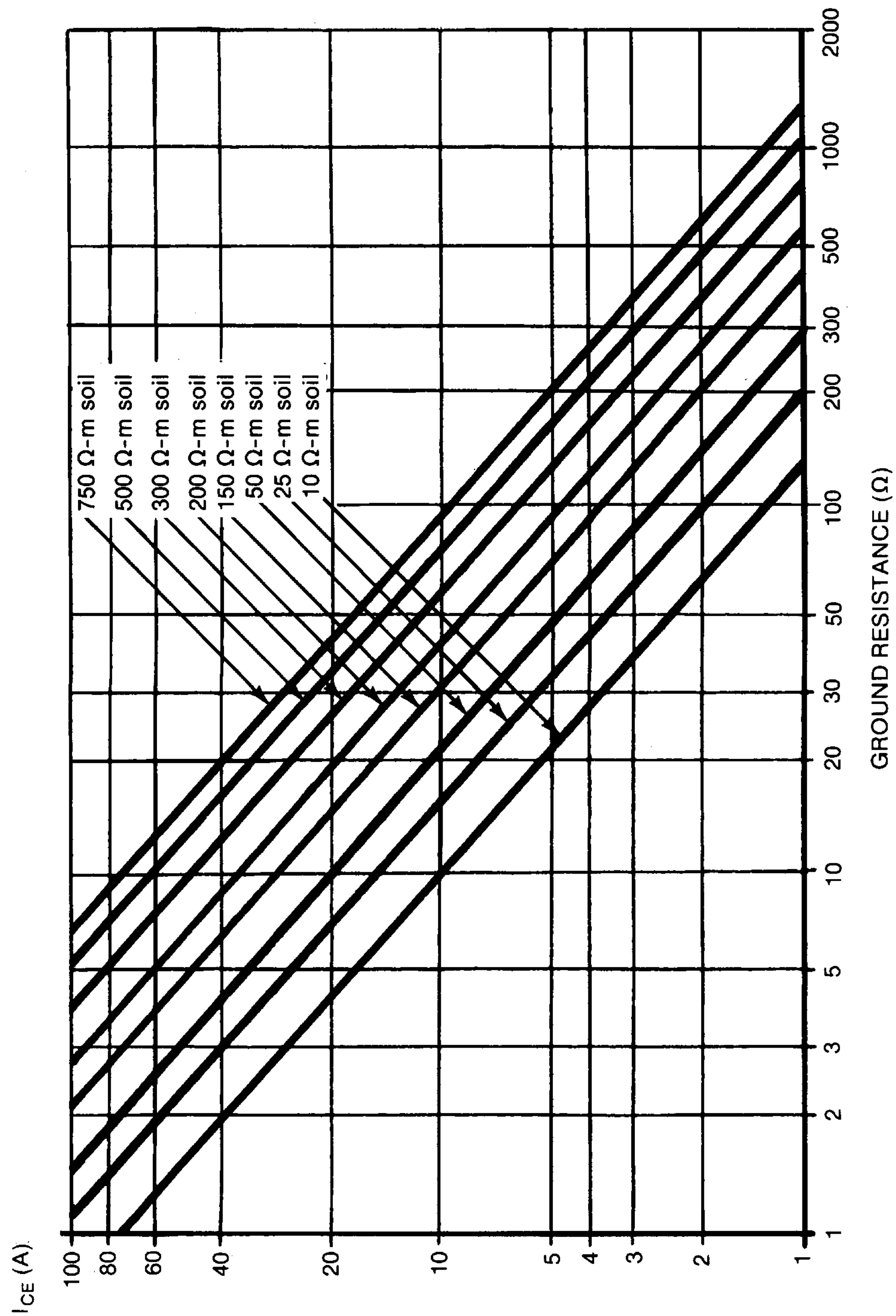


Figure 26—Short-time current loading capability of concrete-encasedground electrodes

ρ is the resistivity of the soil in Ω·m
L_r is the length of the ground rod in m
d is the diameter of the ground rod in m
D_C is the diameter of the concrete shell in m

Equation (58) can be related to the commonly used formula for a ground rod of length L_r and diameter d, as follows:

$$R_{rod} = \frac{\rho}{2\pi L_r}[\ln(8L_r/d) - 1] \tag{59}$$

then Equation (58) can be resolved into

$$R_{CE-rod} = \frac{1}{2\pi L_r}\{\rho[\ln(8L_r/D_C) - 1] + \rho_c[\ln(8L_r/d) - 1] - \rho_c[\ln(8L_r/D_C) - 1]\} \tag{60}$$

representing a combination of two resistances in series:

a) Ground resistance calculated by Equation (59) of a concrete cylinder of diameter D_C, directly buried in soil ρ
b) Ground resistance of the inner segment of diameter D_C, containing a metal rod of diameter d

Obviously, the latter term is obtained as a difference of the hypothetical resistance values for a rod in concrete, if d and D_C are entered into the single-medium formula Equation (59), and ρ is replaced by ρ_c.

Such an approach is generally valid for any other electrode having a different shape. Noting, for convenience

$$R_{SM} = F(\rho, S_O, G) \tag{61}$$

$$R_{DM} = F(\rho_c, S_O, G) + F(\rho, S_i, G) - F(\rho_c, S_i, G) \tag{62}$$

where, in addition to the symbols already mentioned,

R_{SM} is the electrode resistance in single medium in Ω
R_{DM} is the electrode resistance in dual medium in Ω
S_o is the surface area of a given electrode in m^2
S_i is the area of interface in m^2
G is a geometrical factor characterizing the particular shape of a given electrode

This form is adaptable to a variety of electrodes, buried in soil, and assumed to be surrounded by a concentric shell of a material that has different resistivity than the soil. One possible model of this type, for which Schwarz's formula for a rod bed can easily be modified, is shown in Figure 27.

The following recommendations should be considered when using concrete-encased electrodes:

a) Connect anchor bolt and angle stubs to the reinforcing steel for a reliable metal-to-metal contact.
b) Reduce the current duty and dc leakage to allowable levels by making sure that enough primary ground electrodes (grounding grid and ground rods) will conduct most of the fault current.
c) Ground enhancement material may be used in the areas of a high soil resistivity to reduce the resistance of primary grounding. Augering a 100–250 mm (4–10 in) hole and backfilling it with a soil enhancement material around a ground rod is a useful method to prevent the predominance of auxiliary electrodes in dissipating the fault current.

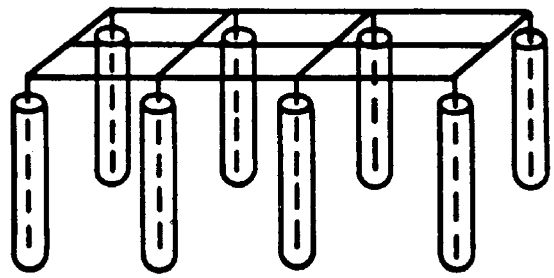


Figure 27—Grid with encased vertical electrodes

15. Determination of maximum grid current

15.1 Definitions

NOTE—The following definitions are also listed in Clause 3, but repeated here for the convenience of the reader.

15.1.1 dc offset: Difference between the symmetrical current wave and the actual current wave during a power system transient condition. Mathematically, the actual fault current can be broken into two parts, a symmetrical alternating component and a unidirectional (dc) component. The unidirectional component can be of either polarity, but will not change polarity, and will decrease at some predetermined rate.

15.1.2 decrement factor: An adjustment factor used in conjunction with the symmetrical ground fault current parameter in safety-oriented grounding calculations. It determines the rms equivalent of the asymmetrical current wave for a given fault duration, t_f, accounting for the effect of initial dc offset and its attenuation during the fault.

15.1.3 fault current division factor: A factor representing the inverse of a ratio of the symmetrical fault current to that portion of the current that flows between the grounding grid and surrounding earth.

$$S_f = \frac{I_g}{3I_0} \tag{63}$$

where

S_f is the fault current division factor
I_g is the rms symmetrical grid current in A
I_0 is the zero-sequence fault current in A

NOTE—In reality, the current division factor would change during the fault duration, based on the varying decay rates of the fault contributions and the sequence of interrupting device operations. However, for the purposes of calculating the design value of maximum grid current and symmetrical grid current per definitions of symmetrical grid current and maximum grid current, the ratio is assumed constant during the entire duration of a given fault.

15.1.4 maximum grid current: A design value of the maximum grid current, defined as follows:

$$I_G = D_f \times I_g \tag{64}$$

where

I_G is the maximum grid current in A
D_f is the decrement factor for the entire duration of fault t_f, given in s
I_g is the rms symmetrical grid current in A

15.1.5 subtransient reactance: Reactance of a generator at the initiation of a fault. This reactance is used in calculations of the initial symmetrical fault current. The current continuously decreases, but it is assumed to be steady at this value as a first step, lasting approximately 0.05 s after a suddenly applied fault.

15.1.6 symmetrical grid current: That portion of the symmetrical ground fault current that flows between the grounding grid and surrounding earth. It may be expressed as

$$I_g = S_f \times I_f \tag{65}$$

where

I_g is the rms symmetrical grid current in A
I_f is the rms value of symmetrical ground fault current in A
S_f is the fault current division factor

15.1.7 synchronous reactance: Steady-state reactance of a generator during fault conditions used to calculate the steady-state fault current. The current so calculated excludes the effect of the automatic voltage regulator or governor.

15.1.8 transient reactance: Reactance of a generator between the subtransient and synchronous states. This reactance is used for the calculation of the symmetrical fault current during the period between the subtransient and steady states. The current decreases continuously during this period, but is assumed to be steady at this value for approximately 0.25 s.

15.1.9 *X/R* ratio: Ratio of the system inductive reactance to resistance. It is indicative of the rate of decay of any dc offset. A large *X/R* ratio corresponds to a large time constant and a slow rate of decay.

15.2 Procedure

In most cases, the largest value of grid current will result in the most hazardous condition. For these cases, the following steps are involved in determining the correct design value of maximum grid current I_G for use in substation grounding calculations:

a) Assess the type and location of those ground faults that are likely to produce the greatest flow of current between the grounding grid and surrounding earth, and hence the greatest GPR and largest local surface potential gradients in the substation area (see 15.8).
b) Determine, by computation, the fault current division factor S_f for the faults selected in a), and establish the corresponding values of symmetrical grid current I_g (see 15.9).
c) For each fault, based on its duration time, t_f, determine the value of decrement factor D_f to allow for the effects of asymmetry of the fault current wave (see 15.10).
d) Select the largest product $D_f \times I_g$, and hence the worst fault condition (see 15.11).

15.3 Types of ground faults

Many different types of faults may occur in the system. Unfortunately, it may be difficult to determine which fault type and location will result in the greatest flow of current between the ground grid and surrounding earth because no simple rule applies. Figure 28 through Figure 31 show maximum grid current I_G for various fault locations and system configurations.

In determining the applicable fault types, consideration should be given to the probability of occurrence of the fault. Multiple simultaneous faults, even though they may result in higher ground current, need not be considered if their probability of occurrence is negligible. It is thus recommended, for practical reasons, that investigation be confined to single-line-to-ground and line-to-line-to-ground faults.

In the case of a line-to-line-to-ground fault, the zero sequence fault current is

$$I_0 = \frac{E \cdot (R_2 + jX_2)}{(R_1 + jX_1) \cdot [R_0 + R_2 + 3R_f + j(X_0 + X_2)] + (R_2 + jX_2) \cdot (R_0 + 3R_f + jX_0)} \quad (66)$$

where

I_0 is the symmetrical rms value of zero sequence fault current in A
E is the phase-to-neutral voltage in V
R_f is the estimated resistance of the fault in Ω (normally it is assumed $R_f = 0$)
R_1 is the positive sequence equivalent system resistance in Ω
R_2 is the negative sequence equivalent system resistance in Ω
R_0 is the zero sequence equivalent system resistance in Ω
X_1 is the positive sequence equivalent system reactance (subtransient) in Ω
X_2 is the negative sequence[15] equivalent system reactance in Ω
X_0 is the zero sequence equivalent system reactance in Ω

The values R_1, R_2, R_0, X_1, X_2, and X_0 are computed looking into the system from the point of fault.

In the case of a single-line-to-ground fault, the zero sequence fault current is

$$I_0 = \frac{E}{3R_f + R_1 + R_2 + R_0 + j(X_1 + X_2 + X_0)} \quad (67)$$

In many cases, however, the effect of the resistance terms in Equation (67) is negligible. For practical purposes, the following simplified equations are sufficiently accurate and more convenient.

Zero sequence current for line-to-line-to-ground fault:

$$I_0 = \frac{E \cdot X_2}{X_1 \cdot (X_0 + X_2) + (X_2 + X_0)} \quad (68)$$

Zero sequence current for line-to-ground fault:

$$I_0 = \frac{E}{X_1 + X_2 + X_0} \quad (69)$$

[15]In most calculations it is usually permissible to assume a ration of X_2/X_1 equal to unity, and, hence, $X_1 = X_2$, especially if an appreciable percentage of the positive-sequence reactance to the point of fault is that of static apparatus and transmission lines.

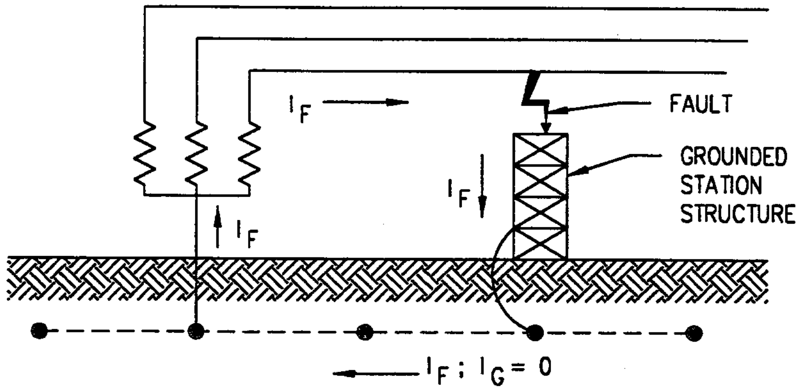


Figure 28—Fault within local substation; local neutral grounded

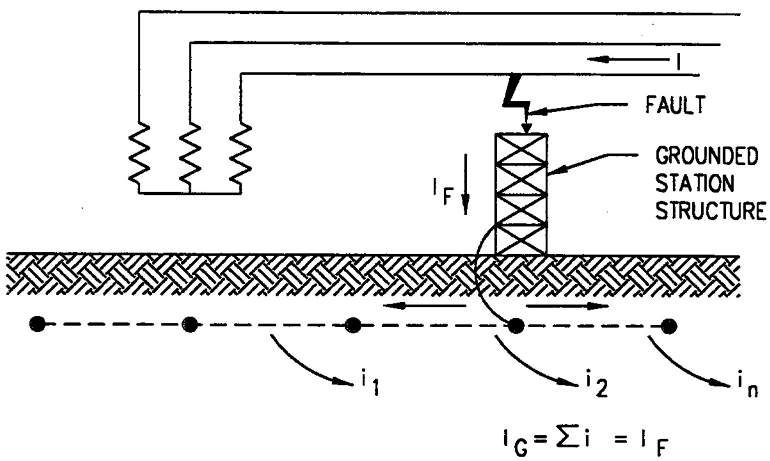


Figure 29—Fault within local substation; neutral grounded at remote location

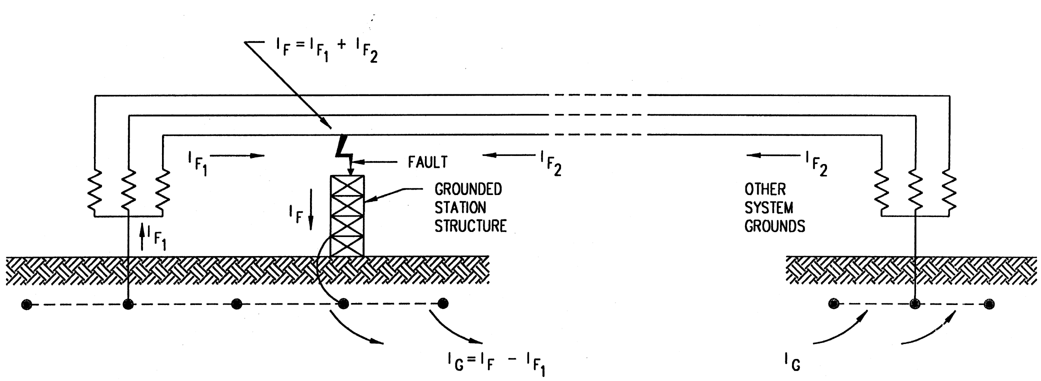


Figure 30—Fault in substation; system grounded at local substation and also at other points

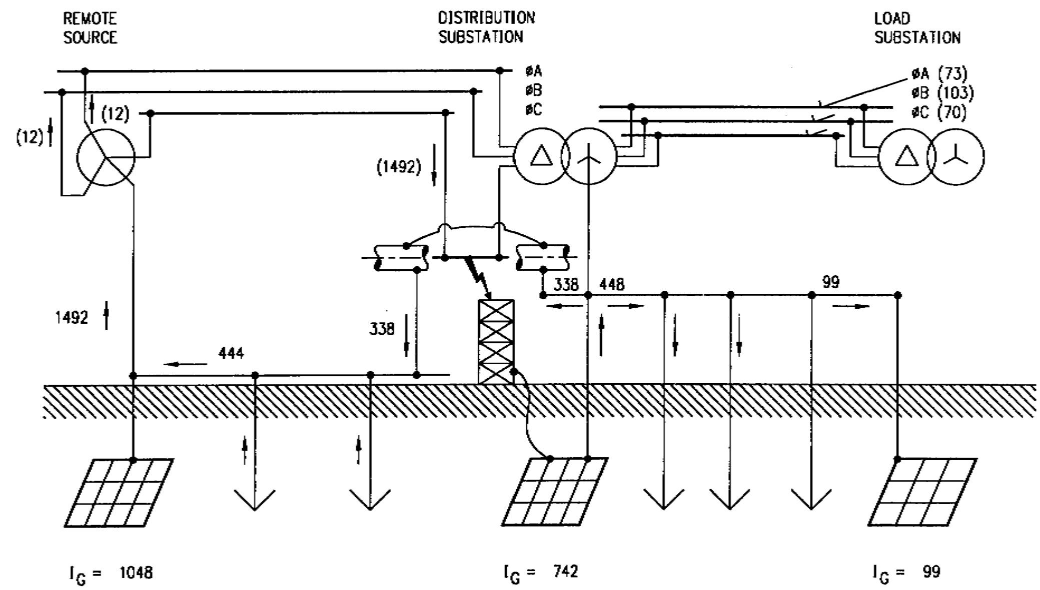


Figure 31—Typical current division for a fault on high side of distribution substation

15.4 Effect of substation ground resistance

In most cases it is sufficient to derive the maximum grid current I_G, as described in 15.2 and 15.3, by neglecting the system resistance, the substation ground resistance, and the resistance at the fault. The error thus introduced is usually small, and is always on the side of safety. However, there may be unusual cases where the predicted substation ground resistance is so large, in relation to system reactance, that it is worthwhile to take the resistance into account by including it into the more exact Equation (66) or Equation (67). This poses a problem because the substation ground system is not yet designed and its resistance is not known. However, the resistance can be estimated by the use of the approximate formulas of 14.2 or 14.3. This estimated resistance generally gives sufficient accuracy for determining the current I_g, and hence I_G.

15.5 Effect of fault resistance

If the fault is an insulation breakdown within the local substation, the only safe assumption is that the resistance of the fault be assumed zero (see Figure 28 through Figure 31).

In the case of a fault outside of the local substation area, on a line connected to the substation bus (Figure 31), it is permissible, if a conservative (minimum) value of fault resistance R_f can be assigned, to use this in the ground fault current calculations. This is done by multiplying R_f by three and adding it to the other resistance terms as indicated in the denominator of Equation (66) and Equation (67). If, however, the actual fault resistance does not maintain a value at least as great as the value of R_f used in the calculations, then the fault resistance should be neglected. Any error from neglecting R_f will, of course, be on the side of safety.

15.6 Effect of overhead ground wires and neutral conductors

Where transmission line overhead ground wires or neutral conductors are connected to the substation ground, a substantial portion of the ground fault current is diverted away from the substation ground grid. Where this situation exists, the overhead ground wires or neutral conductors should be taken into consideration in the design of the ground grid.

Connecting the substation ground to overhead ground wires or neutral conductors, or both, and through them to transmission line structures or distribution poles, will usually have the overall effect of increasing the GPR at tower bases, while lessening it at the substation. This is because each of the nearby towers will share in each voltage rise of the substation ground mat, whatever the cause, instead of being affected only by a local insulation failure or flashover at one of the towers. Conversely, when such a tower fault does occur, the effect of the connected substation ground system should decrease the magnitude of gradients near the tower bases.

15.7 Effect of direct buried pipes and cables

Buried cables with their sheaths or armor in effective contact with the ground, and buried metallic pipes will have a somewhat similar effect when they are bonded to the substation ground system, but extend beyond its perimeter.

Buried cables with their sheaths or armor in effective contact with the earth, and buried metallic pipes bonded to the substation ground system and extending beyond its perimeter will have an effect similar to that of overhead ground wires and neutrals. By conducting part of the ground fault current away from the substation, the potential rise of the grid during the fault, and the local gradients in the substation will be somewhat lessened. As discussed in Clause 17, external hazards may sometimes be introduced (Bodier [B15]; Rüdenberg [B125]).

Because of the complexities and uncertainties in the pattern of current flow, the effect is often difficult to calculate. Some guidelines to the computation of the input impedance of such current paths leaving the substation are supplied by Rüdenberg [B125] and Laurent [B97]. A more recent study of this problem is presented in EPRI EL-904 [B59], which provides methods for computing the impedance of both above-ground and buried pipes. From these values an approximate calculation can determine the division of ground current between these paths, the substation ground system, and any overhead ground wires that are present and connected.

15.8 Worst fault type and location

The worst fault type for a given grounding system is usually the one resulting in the highest value of the maximum grid current I_G. Because this current is proportional to the zero sequence or ground fault current and the current division factor, and because the current division is almost independent of the fault type, the worst fault type can be defined as the one resulting in the highest zero sequence or ground fault current flow into the earth, $3I_0$. In a given location, a single-line-to-ground fault will be the worst fault type if $Z_1 Z_0 > Z_2^2$ at the point of fault, and a line-to-line-to-ground fault will be the worst type if $Z_1 Z_0 < Z_2^2$. In the usual case where Z_2 is assumed equal to Z_1, the above comparisons reduce to $Z_0 > Z_1$, and $Z_0 < Z_2$, respectively.

Z_1, Z_2, Z_0 are defined as

$$Z_1 = R_1 + jX_1 \tag{70}$$

$$Z_2 = R_2 + jX_2 \tag{71}$$

$$Z_0 = R_0 + jX_0 \tag{72}$$

The question of the fault location producing the maximum grid current I_G involves several considerations. The worst fault location may be either on the high voltage side or on the low voltage side, and in either case may be either inside the substation or outside on a line, at a certain distance from the substation. A fault is classified as inside the substation if it is related to a metallic structure that is electrically connected to the substation grounding grid via negligible impedance. There are no universal rules for the determination of the worst fault location. The following discussion relates to some, but by no means all, possibilities.

For distribution substations with the transformer grounded only on the distribution side, the maximum grid current I_G usually occurs for a ground fault on the high-side terminals of the transformer. However, if the source of ground fault current on the high side is weak, or if a parallel operation of several transformers results in a strong ground fault current source on the low side, the maximum grid current may occur for a ground fault somewhere on the distribution circuit.

For ground faults on the low-side terminals of such a secondary grounded transformer, the transformer's contribution to the fault circulates in the substation grid conductor with negligible leakage current into the earth and, thus, has no effect on the substation GPR, as shown in Figure 28.

For ground faults outside the substation on a distribution feeder (far enough to be at remote earth with respect to the ground grid), a large portion of the fault current will return to its source (the transformer neutral) via the substation grid, thus contributing to the substation GPR.

In transmission substations with three-winding transformers or autotransformers, the problem is more complex. The maximum grid current I_G may occur for a ground fault on either the high or low side of the transformer; both locations should be checked. In either case, it can be assumed that the worst fault location is at the terminals of the transformer inside the substation, if the system contribution to the fault current is larger than that of the transformers in the substation. Conversely, the worst fault location may be outside the substation on a transmission line, if the transformer contribution dominates.

Exceptions to the above generalities exist. Therefore, for a specific system, several fault location candidates for the maximum grid current should be considered. For each candidate, the applicable value of zero sequence current I_0 (ground fault current) should be established in this step.

In a few cases, a further complication arises. The duration of the fault depends on the type of protection scheme used, the location of the fault, and the choice of using primary or back-up clearing times for the fault (shock) duration. The fault duration not only affects the decrement factor, D_f, but also the tolerable voltages, as discussed in Clause 8. If the fault clearing time for a particular fault is relatively long, the corresponding tolerable voltages may be reduced to values that make this fault condition the worst case, even though the grid current for this case is not the maximum value. This situation generally occurs where a delta-wye grounded transformer is fed from a relatively weak source of fault current and the fault occurs some distance down a rural distribution feeder. In this case, the high (delta) side fault current may be relatively low, and the low (wye grounded) side feeder faults are determined primarily by the transformer and feeder impedances. If backup clearing is considered, a feeder fault several kilometers down the feeder, depending on the high side clearing device to back-up the failure of the feeder breaker, could take several seconds to clear. The tolerable voltage for this case may be significantly lower than that for a high side fault, making the low side feeder fault the worst case for the grid design. Thus, the worst fault type and location must take into consideration not only the maximum value of grid current I_G, but also the tolerable voltages based on the fault clearing time.

15.9 Computation of current division

For the assumption of a sustained flow of the initial ground fault current, the symmetrical grid current can be expressed as

$$I_g = S_f \cdot (3I_0) \tag{73}$$

To determine I_g, the current division factor S_f must be computed.

The process of computing consists of deriving an equivalent representation of the overhead ground wires, neutrals, etc., connected to the grid and then solving the equivalent to determine what fraction of the total fault current flows between the grid and earth, and what fraction flows through the ground wires or neutrals. S_f is dependent on many parameters, some of which are

a) Location of the fault, as described in 15.8.
b) Magnitude of substation ground grid impedance, as discussed in Clause 4.
c) Buried pipes and cables in the vicinity of or directly connected to the substation ground system, as discussed in 15.7.
d) Overhead ground wires, neutrals, or other ground return paths, as discussed in 15.6.

Because of S_f, the symmetrical grid current I_g, and therefore also I_G, are closely related to the location of the fault. If the additional ground paths of items c) and d) above are neglected, the current division ratio (based on remote versus local current contributions) can be computed using traditional symmetrical components. However, the current I_g, computed using such a method may be overly pessimistic, even if the future system expansion is taken into consideration.

The remaining discussion refers only to overhead ground wires and neutral conductors, although the principles involved also apply to buried pipes, cables, or any other conducting path connected to the grid. High-voltage transmission lines are commonly provided with overhead static wires, either throughout their length or for short distances from each substation. They may be grounded at each tower along the line or they may be insulated from the towers and used for communication purposes. There are many sources that provide assistance in determining the effective impedance of a static wire as seen from the fault point (see, for instance, Carson [B17]; Clem [B19]; EEI and Bell Telephone Systems [B20]; CCITT Study Group V [B24]; Desieno, Marchenko, and Vassel [B51]; Laurent [B97]; Patel [B120]; and Verma and Mukhedkar [B149]). Many of these methods may, however, be difficult to apply by the design engineer. Because it is beyond the scope of this guide to discuss in detail the applicability of each method to all possible system configurations, only a brief description of some of the more recent methods will be given.

Endrenyi [B57][B55] presents an approach in which, for a series of identical spans, the tower impedances and overhead ground wires or neutrals are reduced to an equivalent lumped impedance. Except for estimating purposes, Endrenyi recommends including the mutuals between multiple ground conductors and introduces a coupling factor to account for the mutual impedance between the neutral conductors and the phase conductors. This technique is developed further by Verma and Mukhedkar [B149].

In the cascaded matrix method of Sebo [B129], an impedance matrix is derived for each span of the line, and the individual span matrices are cascaded into a resulting matrix representing the entire line. This technique allows a person to take into account all self and mutual impedances (except between the tower footing grounds), and the location and type of fault. A correction for the end effects of the line is suggested, using a modified screening factor.

With some limitations in applicability and accuracy, the span-by-span calculation technique can be considerably simplified. A typical approach, in which all mutual couplings between the neutral conductor and phase conductors and between neutral conductors are ignored, has been described by Garrett [B70]. In this technique, each neutral conductor is modeled by the impedance of each span and the equivalent ground impedance of each tower to form a network resembling a ladder. This ladder network is then reduced, using simple network reduction techniques, to an input impedance as seen from the fault point. The input impedance of each circuit is combined with the grid resistance and three times this resulting value is included in the zero-sequence equivalent fault impedance. The current division factor S_f is computed by applying Kirchoff's current law to obtain the current division between the grid resistance and the input impedance of each circuit. Although this, or similar approximate approaches, is limited in applicability and accuracy, in many cases it may provide a reasonable estimate of the influence of overhead ground wires and neutrals on both the resistance of the grounding system and the current division ratio.

Dawalibi [B37] provides algorithms for deriving simple equations to solve for the currents in the grid and in each tower. These equations are obtained from one or both ends of each line and do not require the large computer storage requirements of the techniques that model each span individually. Dawalibi also addresses the effects of the soil structure (that is, multilayer earth resistivities) on the self and mutual impedances of the conductors and on the current division ratio.

Meliopoulos et al. [B104] introduced an equivalent conductor to represent the effects of earth using Carson's formula. Every span in each line is modeled and the resulting network is solved for current flows. From this solution, the current division ratio is computed. The number of lines and substations modeled are limited only by the computer used to solve the network (EPRI TR-100622 [B63]).

Garrett and Patel [B73] used the method of Meliopoulos [B104] to perform a parametric analysis of the parameters affecting S_f, and to develop a set of curves of S_f vs. grid resistance for some of the most critical parameters. This provides a quick and simple method to estimate the current division that avoids the need for some of the simplifying assumptions of the other approximate methods, though the results are still only approximate. These curves, along with a few new curves and an impedance table added for this guide, are included in Annex C. Refer to Annex C for limitations on this method.

Obviously, the techniques that model the static wires, phase conductors, towers, etc., in detail will give the best evaluation of the current division factor S_f. However, the approximate methods discussed above have been compared with the detailed methods and found to give comparable answers for many simple examples. Thus, the choice of the method used to determine S_f will depend on the complexity of the system connected to the substation and the desired degree of accuracy. A simple example follows, showing the results of four of the methods described in the preceding paragraphs. In the following example, the approximate methods of Endrenyi and Garrett and Patel are compared with the results of Dawalibi's and Meliopoulos' more accurate methods.

As an example, Figure 32 shows a one-feeder distribution substation fed by single transmission line connecting the substation to a remote equivalent source (next adjacent substation). The transmission line is 20 km long and the distance between tower grounds is 0.5 km. The feeder is 4 km long and the distance between pole grounds is 0.122 km. The soil is assumed to be uniform with a resistivity of 200 Ω·m. Carson's equations are used to compute the self impedances of the phase conductors and overhead static wire, and the mutual impedance between these (transmission line only) for use with Endrenyi's formula and Garrett and Patel's split-factor curves. Annex C shows the equations used to calculate the line impedances necessary for the current split computations. The various impedances for each line section tower footing resistance, remote terminal ground resistance, and substation grid resistance are

$R_{tg} = 10.0 + j0.0$ Ω/section

$R_{dg} = 25.0 + j0.0$ Ω/section

$R_s = 3.0 + j0.0$ Ω

$R_g = 2.5 + j0.0$ Ω

$Z_1 = 3.82 + j9.21$ Ω for the 115 kV line

$Z_{0(a)} = 7.37 + j35.86$ Ω for the 115 kV line

$Z_{0(g)} = 148.24 + j66.44$ Ω for the 115 kV line

$Z_{0(ag)} = 3.56 + j33.34$ Ω for the 115 kV line

Z_0 = 12.54 + j39.72 Ω for the 115 kV line

Z_{s-1} = 1.24 + j0.55 Ω/span for the 115 kV overhead static wire

Z_{s-f} = 0.11 + j0.11 Ω/span for the 12.47 kV feeder neutral

where

R_{tg}	is the impedance to remote earth of each transmission ground electrode in Ω
R_{dg}	is the impedance to remote earth of each distribution ground electrode in Ω
R_s	is the remote terminal ground impedance (equivalent) in Ω
R_g	is the station ground impedance to remote earth in Ω
Z_1	is the equivalent positive sequence impedance for the 115 kV line in Ω
$Z_{0(a)}$	is the zero sequence self impedance for the 115 kV phase conductors in Ω
$Z_{0(g)}$	is the zero sequence self impedance for the 115 kV ground wire in Ω
$Z_{0(ag)}$	is the zero sequence mutual impedance between phase and ground conductors for the 115 kV line in Ω
Z_0	is the equivalent zero sequence impedance for the 115 kV line in Ω
Z_{s-1}	is the self impedance of the 115 kV overhead static wire in Ω/span
Z_{s-f}	is the self impedance of the 12.47 kV feeder neutral in Ω/span

Adding the 115 kV line impedances to the source impedances gives the following equivalent fault impedance at the 115 kV bus:

$$Z_{1(eq)} = 3.82 + j19.01\Omega$$

$$Z_{0(eq)} = 12.54 + j46.32\Omega$$

Thus, for a 115 kV single-line-to-ground fault

$$|3I_0| = \left|\frac{3 \cdot 115,000/\sqrt{3}}{2(3.82 + j19.01) + (12.54 + j46.32)}\right| = |534.5 - j2238.8| = 2297\text{A}$$

As shown in the figure, a single-line-to-ground fault occurs at the substation from the phase conductor bus to the substation neutral.

Using Endrenyi's [B57] method, the equivalent impedance of the overhead static wire (as seen from the fault point and ignoring the effects of coupling) is

$$Z_{eq-1} = 0.5 \cdot (1.24 + j0.55) + \sqrt{10 \cdot (1.24 + j0.55)} = 4.22 + j1.04\Omega$$

The equivalent impedance of the feeder neutral (as seen from the substation) is

$$Z_{eq-f} = 0.5 \cdot (0.11 + j0.11) + \sqrt{25 \cdot (0.11 + j0.11)} = 1.88 + j0.89\Omega$$

The resulting equivalent of the overhead static wire and feeder neutral is found by paralleling the above equivalent impedances:

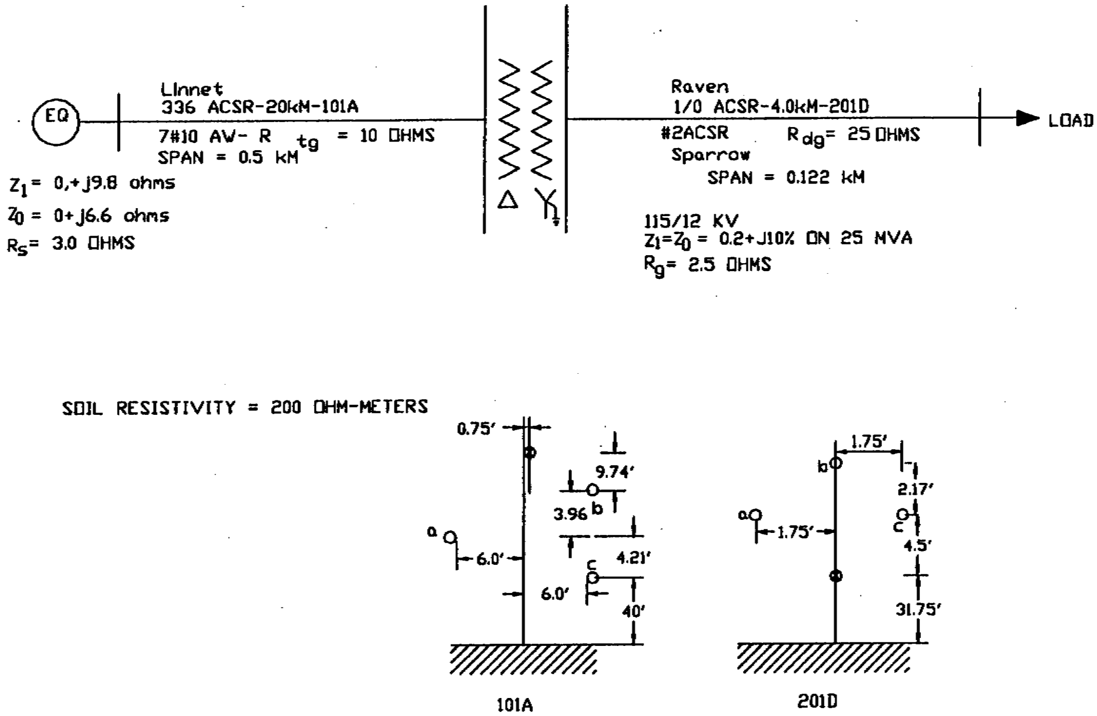


Figure 32—Example system for computation of current division factor S_f

$$Z_{eq} = \frac{1}{\frac{1}{Z_{eq-1}} + \frac{1}{Z_{eq-f}}} = 1.31 + j0.52\Omega$$

The current division factor, S_f, is

$$S_f = \left|\frac{Z_{eq}}{Z_{eq} + R_g}\right| = \left|\frac{1.31 + j0.52}{(1.31 + j0.52) + 2.5}\right| = 0.37$$

and the resulting grid current I_g is

$$I_g = S_f \cdot 3I_0 = 0.37 \cdot 2297 = 850 \text{ A}$$

Using Garrett and Patel’s table of split factor equivalents (Annex C), the equivalent of the overhead static wire and feeder neutral is

$$Z_{eq} = 0.91 + j0.485\Omega$$

and the split factor is

$$S_f = \left|\frac{Z_{eq}}{Z_{eq} + R_g}\right| = \left|\frac{0.91 + j0.485}{(0.91 + j0.485) + 2.5}\right| = 0.30$$

Thus, the grid current is

$$I_g = S_f \cdot 3I_0 = 0.30 \cdot 2297 = 689 \text{ A}$$

Using Garret and Patel's split factor curves (Figure C.3 in Annex C), the approximate split factor S_f = 0.28. Thus, the grid current is

$$I_g = S_f \cdot 3I_0 = 0.28 \cdot 2297 = 643 \text{ A}$$

Using EPRI TR-100622 [B63], the total fault current $3I_0$ is 2472 A. Approximately 34% (I_g = 836 A) of the fault current flows through grid to remote earth, so the current division factor equals 0.34. Similar results are obtained using Dawalibi [B37].

As shown above, the approximate and detailed methods are in close agreement for this example. However, for more complex systems, with both local and remote ground sources and with dissimilar lines and sources, the results may not be in close agreement (see Annex C).

15.10 Effect of asymmetry

The design of a grounding grid must consider the asymmetrical current. A decrement factor, D_f, will be derived to take into account the effect of dc current offset. In general, the asymmetrical fault current includes the subtransient, transient and steady-state ac components, and the dc offset current component. Both the subtransient and transient ac components and the dc offset decay exponentially, each having a different attenuation rate.

However, in typical applications of this guide, it is assumed that the ac component does not decay with time, but remains at its initial value. Thus, as a periodic function of time, t, the asymmetrical fault current may be expressed as

$$i_f(t) = \sqrt{2} \cdot E \cdot Y_{ac}[\sin(\omega t + \alpha - \theta) - e^{-t/T_a} \cdot \sin(\alpha - \theta)] \tag{74}$$

where

$i_f(t)$ is the asymmetrical fault current, in A, at any instant t, t in s
E is the prefault rms voltage, line-to-neutral V
ω is the system frequency in radians/s
α is the voltage angle at current initiation in radians
θ is the circuit phase angle in radians
Y_{ac} is the equivalent ac system admittance in mhos
T_a is the dc offset time constant in s [$T_a = X/(\omega R)$, for 60 Hz, $T_a = X/(120\pi R)$]

The X/R ratio to be used here is the system X/R ratio at the fault location for a given fault type. The X and R components of the system subtransient fault impedance should be used to determine the X/R ratio.

In reality, faults occur at random with respect to the voltage wave. However, the shock contact may exist at the moment the fault is initiated. Hence, to allow for the most severe condition, it is necessary to assume that the maximum possible dc offset will be present at the moment of an accidental shock contact.

Maximum dc offset occurs when: $(\alpha - \theta) = -\pi/2$

Then Equation (74) becomes

$$i_f(t) = \sqrt{2}E \cdot Y_{ac}[e^{-t/T_a} - \cos(\omega t)] \qquad (75)$$

Because the experimental data in the fibrillation threshold are based on the energy content of a symmetrical sine wave of constant amplitude, it is necessary to establish an equivalent rms value of the asymmetrical current wave for the maximum time of possible shock exposure. This value, in accordance with the definition of the effective asymmetrical fault current I_F, can be determined by integration of Equation (75) squared over the entire duration of fault t_f in s.

$$I_F = \sqrt{\frac{1}{t_f}\int_0^{t_f}[i_f(t)]^2 dt} \qquad (76)$$

where

I_F is the effective rms value of approximate asymmetrical current for the entire duration of a fault in A
t_f is the time duration of fault in s
t is the time (variable) after the initiation of fault in s

Evaluating the integral of Equation (76) in terms of Equation (75), it follows that

$$I_F = I_f \cdot \sqrt{\frac{2}{t_f}\int_0^{t_f}[i_f(t)]^2 dt} \qquad (77)$$

Therefore, the decrement factor D_f is determined by the ratio I_F/I_f, yielding

$$D_f = \frac{I_F}{I_f} \qquad (78)$$

$$D_f = \sqrt{1 + \frac{T_a}{t_f}\left(1 - e^{\frac{-2t_f}{T_a}}\right)} \qquad (79)$$

Equation (79) can be used to compute the decrement factor for specific *X/R* ratios and fault durations. Typical values of the decrement factor for various fault durations and *X/R* ratios are shown in Table 10.

For relatively long fault durations, the effect of the dc offset current can be assumed to be more than compensated by the decay of the subtransient component of ac current. A decrement factor of 1.0 can be used for fault durations of 30 cycles or more.

For closely spaced successive shocks (possibly from reclosures), early editions of this guide suggested a decrement factor computed using the shortest single fault duration, even if the time, t_s, used elsewhere in the calculations is based on the sum of the individual shock durations. However, the preceding discussion of the asymmetrical fault current decrement factor suggests that the use of the shortest fault duration in conjunction with the longest shock duration, or sum of the shock durations, may result in an overdesigned grounding system. This is especially true for faults of intermediate duration (that is, 6–30 cycles), where the decrement factor is relatively large and the ac component of current is assumed to remain at its subtransient value. Crawford and Griffith [B22] suggest that the shock duration and fault duration be assumed identical, which will result in sufficient grid design for cases involving no automatic reclosures or successive (high-speed) shocks. However, because little or no testing has been done on the effects of repetitive shocks separated by only a few cycles, the design engineer should judge whether or not to use the longest shock duration for time

t_s elsewhere in the calculations and the shortest fault duration for the time t_f in computing the decrement factor with Equation (79).

It is important that the values of the decrement factor given in Table 10 not be confused with the multiplying factors given by IEEE C37.010-1979 [B84]. The decrement factor is D_f, and is used to determine the effective current during a given time interval after inception of a fault, whereas the multiplying factors given by IEEE C37.010-1979 [B84] are used to determine the rms current at the end of this interval. Because of the decay of ac and dc transient components with time, the decrement factors determined by Equation (79) are slightly higher than the factors given by IEEE C37.010-1979 [B84] for short fault and shock durations.

Table 10—Typical values of D_f

Fault duration, t_f		**Decrement factor, D_f**			
Seconds	**Cycles at 60 Hz**	**X/R = 10**	**X/R = 20**	**X/R = 30**	**X/R = 40**
0.008 33	0.5	1.576	1.648	1.675	1.688
0.05	3	1.232	1.378	1.462	1.515
0.10	6	1.125	1.232	1.316	1.378
0.20	12	1.064	1.125	1.181	1.232
0.30	18	1.043	1.085	1.125	1.163
0.40	24	1.033	1.064	1.095	1.125
0.50	30	1.026	1.052	1.077	1.101
0.75	45	1.018	1.035	1.052	1.068
1.00	60	1.013	1.026	1.039	1.052

15.11 Effect of future changes

It is a common experience for maximum fault currents at a given location to increase as system capacity is added or new connections are made to the grid. While an increase in system capacity will increase the maximum expected fault current I_F, new connections may increase or decrease the maximum grid current I_G. One case in which the grid current may decrease with new connections is when new transmission lines are added with ground or neutral wires, or both. In general, if no margin for increase in I_G is included in the original ground system design, the design may become unsafe. Also, subsequent additions will usually be much less convenient and more expensive to install. It has been a widely accepted practice to assume the total fault current, I_F, between the grid and surrounding earth (that is, ignoring any current division) in an attempt to allow for system growth. While this assumption would be overly pessimistic for present-year conditions, it may not exceed the current I_G computed considering current division and system growth. If the system growth is taken into account and current division is ignored, the resulting grid will be overdesigned. An estimate of the future system conditions can be obtained by including all system additions forecasted.

Caution should be exercised when future changes involve such design changes as disconnection of overhead ground wires coming into the substations. Such changes may have an effect on ground fault currents and may result in an inadequate grounding system. However, future changes such as additions of incoming overhead ground wires, may decrease the current division ratio, resulting in the existing ground system being overdesigned.

16. Design of grounding system

16.1 Design criteria

As stated in 4.1, there are two main design goals to be achieved by any substation ground system under normal as well as fault conditions. These goals are

a) To provide means to dissipate electric currents into the earth without exceeding any operating and equipment limits.
b) To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.

The design procedures described in the following subclauses are aimed at achieving safety from dangerous step and touch voltages within a substation. It is pointed out in 8.2 that it is possible for transferred potentials to exceed the GPR of the substation during fault conditions. Clause 17 discusses some of the methods used to protect personnel and equipment from these transferred potentials. Thus, the design procedure described here is based on assuring safety from dangerous step and touch voltages within, and immediately outside, the substation fenced area. Because the mesh voltage is usually the worst possible touch voltage inside the substation (excluding transferred potentials), the mesh voltage will be used as the basis of this design procedure.

Step voltages are inherently less dangerous than mesh voltages. If, however, safety within the grounded area is achieved with the assistance of a high resistivity surface layer (surface material), which does not extend outside the fence, then step voltages may be dangerous. In any event, the computed step voltages should be compared with the permissible step voltage after a grid has been designed that satisfies the touch voltage criterion.

For equally spaced ground grids, the mesh voltage will increase along meshes from the center to the corner of the grid. The rate of this increase will depend on the size of the grid, number and location of ground rods, spacing of parallel conductors, diameter and depth of the conductors, and the resistivity profile of the soil. In a computer study of three typical grounding grids in uniform soil resistivity, the data shown in Table 11 were obtained. These grids were all symmetrically shaped square grids with no ground rods and equal parallel conductor spacing. The corner E_m was computed at the center of the corner mesh. The actual worst case E_m occurs slightly off-center (toward the corner of the grid), but is only slightly higher than the E_m at the center of the mesh.

As indicated in Table 11, the corner mesh voltage is generally much higher than that in the center mesh. This will be true unless the grid is unsymmetrical (has projections, is L-shaped, etc.), has ground rods located on or near the perimeter, or has extremely nonuniform conductor spacings. Thus, in the equations for the mesh voltage E_m given in 16.5, only the mesh voltage at the center of the corner mesh is used as the basis of the design procedure. Analysis based on computer programs, described in 16.8, may use this approximate corner mesh voltage, the actual corner mesh voltage, or the actual worst-case touch voltage found anywhere within the grounded area as the basis of the design procedure. In either case, the initial criterion for a safe design is to limit the computed mesh or touch voltage to below the tolerable touch voltage from Equation (32) or Equation (33).

Unless otherwise specified, the remainder of the guide will use the term mesh voltage (E_m) to mean the touch voltage at the center of the corner mesh. However, the mesh voltage may not be the worst-case touch voltage if ground rods are located near the perimeter, or if the mesh spacing near the perimeter is small. In these cases, the touch voltage at the corner of the grid may exceed the corner mesh voltage.

Table 11—Typical ratio of corner-to-corner mesh voltage

Grid number	Number of meshes	E_m corner/center
1	10 × 10	2.71
2	20 × 20	5.55
3	30 × 30	8.85

16.2 Critical parameters

The following site-dependent parameters have been found to have substantial impact on the grid design: maximum grid current I_G, fault duration t_f, shock duration t_s, soil resistivity ρ, surface material resistivity (ρ_s), and grid geometry. Several parameters define the geometry of the grid, but the area of the grounding system, the conductor spacing, and the depth of the ground grid have the most impact on the mesh voltage, while parameters such as the conductor diameter and the thickness of the surfacing material have less impact (AIEE Working Group [B3]; Dawalibi, Bauchard, and Mukhedkar [B45]; Dawalibi and Mukhedkar [B43]; EPRI EL-3099 [B61]). A brief discussion or review of the critical parameters is given in 16.2.1–16.2.5.

16.2.1 Maximum grid current (I_G)

The evaluation of the maximum design value of ground fault current that flows through the substation grounding grid into the earth, I_G, has been described in Clause 15. In determining the maximum current I_G, by means of Equation (64), consideration should be given to the resistance of the ground grid, division of the ground fault current between the alternate return paths and the grid, and the decrement factor.

16.2.2 Fault duration (t_f) and shock duration (t_s)

The fault duration and shock duration are normally assumed equal, unless the fault duration is the sum of successive shocks, such as from reclosures. The selection of t_f should reflect fast clearing time for transmission substations and slow clearing times for distribution and industrial substations. The choices t_f and t_s should result in the most pessimistic combination of fault current decrement factor and allowable body current. Typical values for t_f and t_s range from 0.25 s to 1.0 s. More detailed information is given in 5.2–6.4 and 15.10 on the selection of t_f and t_s.

16.2.3 Soil resistivity (ρ)

The grid resistance and the voltage gradients within a substation are directly dependent on the soil resistivity. Because in reality soil resistivity will vary horizontally as well as vertically, sufficient data must be gathered for a substation yard. The Wenner method described in 13.3 is widely used (James J. Biddle Co. [B102]; Wenner [B150]).

Because the equations for E_m and E_s given in 16.5 assume uniform soil resistivity, the equations can employ only a single value for the resistivity. Refer to 13.4.1 for guidance in determining an approximate uniform soil resistivity.

16.2.4 Resistivity of surface layer (ρ_s)

A layer of surface material helps in limiting the body current by adding resistance to the equivalent body resistance. Refer to 7.4 and 12.5 for more details on the application of this parameter.

16.2.5 Grid geometry

In general, the limitation on the physical parameters of a ground grid are based on economics and the physical limitations of the installation of the grid. The economic limitation is obvious. It is impractical to install a copper plate grounding system. Clause 18 describes some of the limitations encountered in the installation of a grid. For example, the digging of the trenches into which the conductor material is laid limits the conductor spacing to approximately 2 m or more. Typical conductor spacings range from 3 m to 15 m, while typical grid depths range from 0.5 m to 1.5 m. For the typical conductors ranging from 2/0 AWG (67 mm^2) to 500 kcmil (253 mm^2), the conductor diameter has negligible effect on the mesh voltage. The area of the grounding system is the single most important geometrical factor in determining the resistance of the grid. The larger the area grounded, the lower the grid resistance and, thus, the lower the GPR.

16.3 Index of design parameters

Table 12 contains a summary of the design parameters used in the design procedure.

16.4 Design procedure

The block diagram of Figure 33 illustrates the sequences of steps to design the ground grid. The parameters shown in the block diagram are identified in the index presented in Table 12. The following describes each step of the procedure:

— Step 1: The property map and general location plan of the substation should provide good estimates of the area to be grounded. A soil resistivity test, described in Clause 13, will determine the soil resistivity profile and the soil model needed (that is, uniform or two-layer model).

— Step 2: The conductor size is determined by equations given in 11.3. The fault current $3I_0$ should be the maximum expected future fault current that will be conducted by any conductor in the grounding system, and the time, t_c, should reflect the maximum possible clearing time (including backup).

— Step 3: The tolerable touch and step voltages are determined by equations given in 8.3 and 8.4. The choice of time, t_s, is based on the judgment of the design engineer, with guidance from 5.2–6.3.

— Step 4: The preliminary design should include a conductor loop surrounding the entire grounded area, plus adequate cross conductors to provide convenient access for equipment grounds, etc. The initial estimates of conductor spacing and ground rod locations should be based on the current I_G and the area being grounded.

— Step 5: Estimates of the preliminary resistance of the grounding system in uniform soil can be determined by the equations given in 14.2 and 14.3. For the final design, more accurate estimates of the resistance may be desired. Computer analysis based on modeling the components of the grounding system in detail can compute the resistance with a high degree of accuracy, assuming the soil model is chosen correctly.

— Step 6: The current I_G is determined by the equations given in Clause 15. To prevent overdesign of the grounding system, only that portion of the total fault current, $3I_0$, that flows through the grid to remote earth should be used in designing the grid. The current I_G should, however, reflect the worst fault type and location, the decrement factor, and any future system expansion.

— Step 7: If the GPR of the preliminary design is below the tolerable touch voltage, no further analysis is necessary. Only additional conductor required to provide access to equipment grounds is necessary.

— Step 8: The calculation of the mesh and step voltages for the grid as designed can be done by the approximate analysis techniques described in 16.5 for uniform soil, or by the more accurate computer analysis techniques, as demonstrated in 16.8. Further discussion of the calculations are reserved for those sections.

— Step 9: If the computed mesh voltage is below the tolerable touch voltage, the design may be complete (see Step 10). If the computed mesh voltage is greater than the tolerable touch voltage, the preliminary design should be revised (see Step 11).

— Step 10: If both the computed touch and step voltages are below the tolerable voltages, the design needs only the refinements required to provide access to equipment grounds. If not, the preliminary design must be revised (see Step 11).

— Step 11: If either the step or touch tolerable limits are exceeded, revision of the grid design is required. These revisions may include smaller conductor spacings, additional ground rods, etc. More discussion on the revision of the grid design to satisfy the step and touch voltage limits is given in 16.6.

— Step 12: After satisfying the step and touch voltage requirements, additional grid and ground rods may be required. The additional grid conductors may be required if the grid design does not include conductors near equipment to be grounded. Additional ground rods may be required at the base of surge arresters, transformer neutrals, etc. The final design should also be reviewed to eliminate hazards due to transferred potential and hazards associated with special areas of concern. See Clause 17.

Table 12—Index of design parameters

Symbol	Description	Clause number
ρ	Soil resistivity, Ω·m	Clause 13
ρ_s	Surface layer resistivity, Ω·m	7.4, 12.5
$3I_0$	Symmetrical fault current in substation for conductor sizing, A	15.3
A	Total area enclosed by ground grid, m^2	14.2
C_s	Surface layer derating factor	7.4
d	Diameter of grid conductor, m	16.5
D	Spacing between parallel conductors, m	16.5
D_f	Decrement factor for determining I_G	15.1.4, 15.10
D_m	Maximum distance between any two points on the grid, m	16.5
E_m	Mesh voltage at the center of the corner mesh for the simplified method, V	16.5
E_s	Step voltage between a point above the outer corner of the grid and a point 1 m diagonally outside the grid for the simplified method, V	16.5
E_{step50}	Tolerable step voltage for human with 50 kg body weight, V	8.3

Table 12—Index of design parameters (continued)

Symbol	Description	Clause number
E_{step70}	Tolerable step voltage for human with 70 kg body weight, V	8.3
$E_{touch50}$	Tolerable touch voltage for human with 50 kg body weight, V	8.3
$E_{touch70}$	Tolerable touch voltage for human with 70 kg body weight, V	8.3
h	Depth of ground grid conductors, m	14.2
h_s	Surface layer thickness, m	7.4
I_G	Maximum grid current that flows between ground grid and surrounding earth (including dc offset), A	15.1.4
I_g	Symmetrical grid current, A	15.1.6
K	Reflection factor between different resistivities	7.4
K_h	Corrective weighting factor that emphasizes the effects of grid depth, simplified method	16.5
K_i	Correction factor for grid geometry, simplified method	16.5
K_{ii}	Corrective weighting factor that adjusts for the effects of inner conductors on the corner mesh, simplified method	16.5
K_m	Spacing factor for mesh voltage, simplified method	16.5
K_s	Spacing factor for step voltage, simplified method	16.5
L_c	Total length of grid conductor, m	14.3
L_M	Effective length of $L_c + L_R$ for mesh voltage, m	16.5
L_R	Total length of ground rods, m	16.5
L_r	Length of ground rod at each location, m	14.3, 16.5
L_S	Effective length of $L_c + L_R$ for step voltage, m	16.5
L_T	Total effective length of grounding system conductor, including grid and ground rods, m	14.2

Table 12—Index of design parameters (continued)

Symbol	Description	Clause number
L_x	Maximum length of grid conductor in x direction, m	16.5
L_y	Maximum length of grid conductors in y direction, m	16.5
n	Geometric factor composed of factors n_a, n_b, n_c, and n_d	16.5
n_R	Number of rods placed in area A	14.3
R_g	Resistance of grounding system, Ω	14.1–14.4
S_f	Fault current division factor (split factor)	15.1.3
t_c	Duration of fault current for sizing ground conductor, s	11.3
t_f	Duration of fault current for determining decrement factor, s	15.10
t_s	Duration of shock for determining allowable body current, s	5.2–6.3

16.5 Calculation of maximum step and mesh voltages

Computer algorithms for determining the grid resistance and the mesh and step voltages have been developed in EPRI TR-100622 [B63]; Dawalibi and Mukhedkar [B42]; Garrett and Holley [B71]; Heppe [B81]; and Joy, Meliopoulos, and Webb [B91]. These algorithms required considerable storage capability and were relatively expensive to execute, but improvements in the solution algorithms and the proliferation of powerful desktop computers have alleviated most of these concerns.

In some cases, it is not economically justifiable to use these computer algorithms, or the designer may not have access to a computer with the required capabilities. This subclause, in conjunction with Annex D, describes approximate equations for determining the design parameters and establishing corresponding values of E_m and E_s without the necessity of using a computer.

16.5.1 Mesh voltage (E_m)

The mesh voltage values are obtained as a product of the geometrical factor, K_m; a corrective factor, K_i, which accounts for some of the error introduced by the assumptions made in deriving K_m; the soil resistivity, ρ; and the average current per unit of effective buried length of the grounding system conductor (I_G/L_M).

$$E_m = \frac{\rho \cdot K_m \cdot K_i \cdot I_G}{L_M} \tag{80}$$

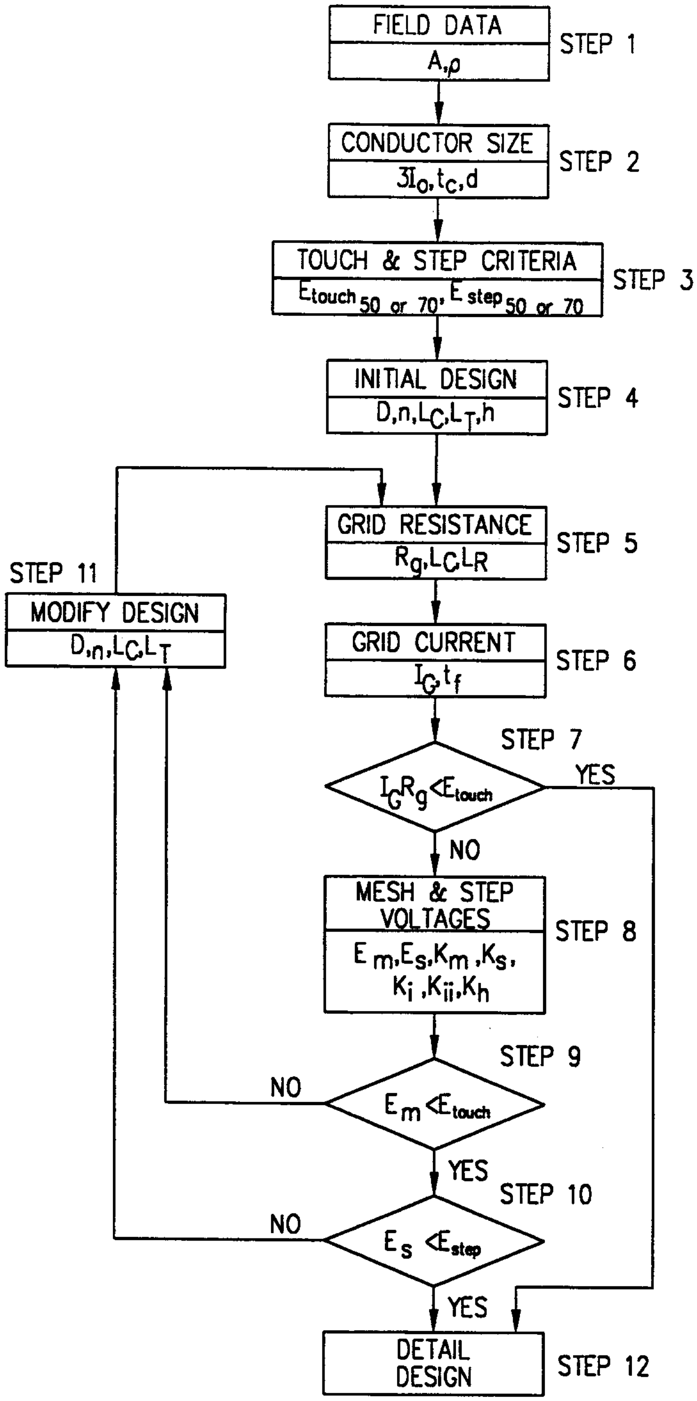


Figure 33—Design procedure block diagram

The geometrical factor K_m (Sverak [B132]), is as follows:

$$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 \cdot h)^2}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right] \tag{81}$$

For grids with ground rods along the perimeter, or for grids with ground rods in the grid corners, as well as both along the perimeter and throughout the grid area

$K_{ii} = 1$

For grids with no ground rods or grids with only a few ground rods, none located in the corners or on the perimeter.

$$K_{ii} = \frac{1}{(2 \cdot n)^{\frac{2}{n}}} \tag{82}$$

$$K_h = \sqrt{1 + \frac{h}{h_o}} \quad h_o = 1\text{m (grid reference depth)} \tag{83}$$

Using four grid shape components developed in Thapar, Gerez, Balakrishnan, and Blank [B144], the effective number of parallel conductors in a given grid, n, can be made applicable to rectangular or irregularly shaped grids that represent the number of parallel conductors of an equivalent rectangular grid.

$$n = n_a \cdot n_b \cdot n_c \cdot n_d \tag{84}$$

where

$$n_a = \frac{2 \cdot L_C}{L_p} \tag{85}$$

n_b = 1 for square grids
n_c = 1 for square and rectangular grids
n_d = 1 for square, rectangular and L-shaped grids

Otherwise

$$n_b = \sqrt{\frac{L_p}{4 \cdot \sqrt{A}}} \tag{86}$$

$$n_c = \left[\frac{L_x \cdot L_y}{A}\right]^{\frac{0.7 \cdot A}{L_x \cdot L_y}} \tag{87}$$

$$n_d = \frac{D_m}{\sqrt{L_x^2 + L_y^2}} \tag{88}$$

L_C is the total length of the conductor in the horizontal grid in m
L_p is the peripheral length of the grid in m

A is the area of the grid in m^2
L_x is the maximum length of the grid in the x direction in m
L_y is the maximum length of the grid in the y direction in m
D_m is the maximum distance between any two points on the grid in m

and D, h, and d are defined in Table 12.

The irregularity factor, K_i, used in conjunction with the above defined n is

$$K_i = 0.644 + 0.148 \cdot n \quad (89)$$

For grids with no ground rods, or grids with only a few ground rods scattered throughout the grid, but none located in the corners or along the perimeter of the grid, the effective buried length, L_M, is

$$L_M = L_C + L_R \quad (90)$$

where

L_R is the total length of all ground rods in m

For grids with ground rods in the corners, as well as along the perimeter and throughout the grid, the effective buried length, L_M, is

$$L_M = L_C + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right]L_R \quad (91)$$

where

L_r is the length of each ground rod in m

16.5.2 Step voltage (E_S)

The step voltage values are obtained as a product of the geometrical factor, K_s; the corrective factor, K_i; the soil resistivity, ρ; and the average current per unit of buried length of grounding system conductor (I_G/L_S).

$$E_s = \frac{\rho \cdot K_s \cdot K_i \cdot I_G}{L_S} \quad (92)$$

For grids with or without ground rods, the effective buried conductor length, L_S, is

$$L_s = 0.75 \cdot L_C + 0.85 \cdot L_R \quad (93)$$

The maximum step voltage is assumed to occur over a distance of 1 m, beginning at and extending outside of the perimeter conductor at the angle bisecting the most extreme corner of the grid. For the usual burial depth of 0.25 m < h < 2.5 m (Sverak [B132]), K_s is

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \cdot h} + \frac{1}{D + h} + \frac{1}{D}(1 - 0.5^{n-2})\right] \quad (94)$$

16.6 Refinement of preliminary design

If calculations based on the preliminary design indicate that dangerous potential differences can exist within the substation, the following possible remedies should be studied and applied where appropriate:

a) *Decrease total grid resistance:* A decrease in total grid resistance will decrease the maximum GPR and, hence, the maximum transferred voltage. The most effective way to decrease ground grid resistance is by increasing the area occupied by the grid. Deep driven rods or wells may be used if the available area is limited and the rods penetrate lower resistivity layers. A decrease in substation resistance may or may not decrease appreciably the local gradients, depending on the method used.

b) *Closer grid spacings:* By employing closer spacing of grid conductors, the condition of the continuous plate can be approached more closely. Dangerous potentials within the substation can thus be eliminated at a cost. The problem at the perimeter may be more difficult, especially at a small substation when resistivity is high. However, it is usually possible, by burying the grid ground conductor outside the fence line, to ensure that the steeper gradients immediately outside this grid perimeter do not contribute to the more dangerous touch contacts. Another effective and economical way to control gradients is to increase the density of ground rods at the perimeter. This density may be decreased toward the center of the grid. Another approach to controlling perimeter gradients and step potentials is to bury two or more parallel conductors around the perimeter at successively greater depth as distance from the substation is increased. Another approach is to vary the grid conductor spacing with closer conductors near the perimeter of the grid (AIEE Working Group [B3]; Biegelmeier and Rotter [B8]; Laurent [B97]; Sverak [B131]).

c) *Diverting a greater part of the fault current to other paths:* By connecting overhead ground wires of transmission lines or by decreasing the tower footing resistances in the vicinity of the substation, part of the fault current will be diverted from the grid. In connection with the latter, however, the effect on fault gradients near tower footings should be weighed.

d) *Limiting total fault current:* If feasible, limiting the total fault current will decrease the GPR and all gradients in proportion. Other factors, however, will usually make this impractical. Moreover, if accomplished at the expense of greater fault clearing time, the danger may be increased rather than diminished.

e) *Barring access to limited areas:* Barring access to certain areas, where practical, will reduce the probability of hazards to personnel.

16.7 Application of equations for E_m and E_s

Several simplifying assumptions are made in deriving the equations for E_m and E_s. The equations were compared with more accurate computer results from cases with various grid shapes, mesh sizes, numbers of ground rods, and lengths of ground rods, and found to be consistently better than the previous equations. These cases included square, rectangular, triangular, T-shaped, and L-shaped grids. Cases were run with and without ground rods. The total ground rod length was varied with different numbers of ground rod locations and different ground rod lengths. The area of the grids was varied from 6.25 m^2 to 10 000 m^2. The number of meshes along a side was varied from 1 to 40. The mesh size was varied from 2.5 m to 22.5 m. All cases assumed a uniform soil model and uniform conductor spacing. Most practical examples of grid design were considered. The comparisons found the equations to track the computer results with acceptable accuracy.

16.8 Use of computer analysis in grid design

Dawalibi and Mukhedkar [B42]; EPRI TR-100622 [B63]; and Heppe [B80] describe computer algorithms for modeling grounding systems. In general, these algorithms are based on

a) Modeling the individual components comprising the grounding system (grid conductors, ground rods, etc.).
b) Forming a set of equations describing the interaction of these components.
c) Solving for the ground-fault current flowing from each component into the earth.
d) Computing the potential at any desired surface point due to all the individual components.

The accuracy of the computer algorithm is dependent on how well the soil model and physical layout reflect actual field conditions.

There are several reasons that justify the use of more accurate computer algorithms in designing the grounding system. These reasons include

a) Parameters exceed the limitations of the equations.
b) A two-layer or multilayer soil model is preferred due to significant variations in soil resistivity.
c) Uneven grid conductor or ground rod spacings cannot be analyzed using the approximate methods of 16.5.
d) More flexibility in determining local danger points may be desired.
e) Presence of buried metallic structures or conductor not connected to the grounding system, which introduces complexity to the system.

17. Special areas of concern

Before the final grounding grid design calculations are completed, there still remains the important task of investigating possible special areas of concern in the substation grounding network. This includes an investigation of grounding techniques for substation fence, switch operating shafts, rails, pipelines, and cable sheaths. The effects of transferred potentials should also be considered.

17.1 Service areas

The problems associated with step and touch voltage exposure to persons outside a substation fence are much the same as those to persons within fenced substation areas.

Occasionally, a fence will be installed to enclose a much larger area than initially utilized in a substation and a grounding grid will be constructed only in the utilized area and along the substation fence. The remaining unprotected areas within the fenced area are often used as storage, staging, or general service areas. Step and touch potentials should be checked to determine if additional grounds are needed in these areas.

A reduced substation grid, which does not include the service area, has both initial cost advantages and future savings resulting from not having the problems associated with “working around” a previously installed total area grid system when future expansion is required into the service area. However, a reduced grid provides less personnel protection compared to a complete substation grid, which includes the service area. Also, because of the smaller area and less conductor length, a service area grid and reduced substation grid will have a higher overall resistance compared to a complete substation grid, which includes the service area.

17.2 Switch shaft and operating handle grounding

Operating handles of switches represent a significant concern if the handles are not adequately grounded. Because the manual operation of a switch requires the presence of an operator near a grounded structure, several things could occur that may result in a fault to the structure, thus subjecting the operator to an electrical shock. This includes the opening of an energized circuit, mechanical failure, electrical breakdown of a switch insulator, or attempting to interrupt a greater value of line-charging current or transformer magnetizing current than the switch can safely interrupt.

It is relatively easy to protect against these hazards when the operating handle is within a reasonably extensive substation ground grid area. If the grounding system has been designed in accordance with this standard, touch and step voltages near the operating handle should be within safe limits. However, quite often additional means are taken to provide a greater safety factor for the operator. For example, the switch operating shaft can be connected to a ground mat (as discussed in 9.1.3) on which the operator stands when operating the switch. The ground mat is connected directly to the ground grid and the switch operating shaft. This technique provides a direct bypass to ground across the person operating the switch. The grounding path from the switch shaft to the ground grid must be adequately sized to carry the ground fault current for the required duration. Refer to Figure 34 for a typical switch shaft grounding practice.

The practices for grounding switch operating shafts are varied. The results of a questionnaire issued in 1985 indicated that 78 out of 79 utilities that responded required grounding of substation air switch operating shafts to the grounding grid. The methodology for accomplishing this grounding was almost equally divided among those responding to the questionnaire. Approximately half of the utilities provided a direct jumper between the switch shaft and the ground mat, while the other half provided a jumper from the switch shaft to the adjacent grounded structural steel. The steel is used as part of the conducting path. Approximately 90% of the utilities utilized a braid for grounding the switch shaft. The remaining 10% utilized a braidless grounding device. A typical braided ground is shown in Figure 35 and a braidless grounding device is shown in Figure 36.

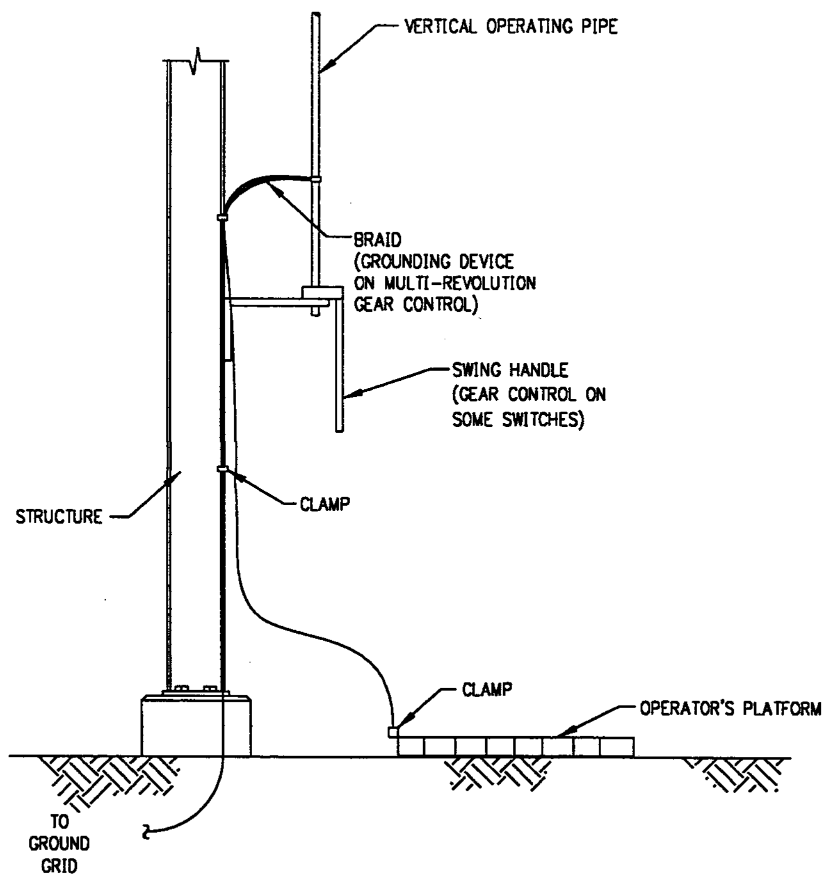


Figure 34—Typical switch shaft grounding

Figure 35—Typical braided ground

Figure 36—Typical braidless grounding device

17.3 Grounding of substation fence

Fence grounding is of major importance because the fence is usually accessible to the general public. The substation grounding design should be such that the touch potential on the fence is within the calculated tolerable limit of touch potential. Step potential is usually not a concern at the fence perimeter, but should be checked to verify that a problem does not exist.

Several philosophies exist with regard to grounding of substation fence. The National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-1997) requires grounding metal fences used to enclose electric supply substations having energized electrical conductors or equipment. This metal fence grounding requirement may be accomplished by bonding the fence to the substation grounding grid or to a separate underground conductor below or near the fence line using the methods described in the NESC. The various fence grounding practices are that the

- Fence is within the ground grid area and is connected to the substation ground grid.
- Fence is outside of ground grid area and is connected to the substation ground grid.
- Fence is outside of ground grid area, but is not connected to the substation ground grid. The fence is connected to a separate grounding conductor.
- Fence is outside of ground grid area, but is not connected to the substation ground grid. The fence is not connected to a separate grounding conductor. The contact of the fence post through the fence post concrete to earth is relied on for an effective ground.

If the latter two practices on fence grounding are to be followed, i.e., if the fence and its associated grounds are not to be coupled in any way to the main ground grid (except through the soil), then three factors require consideration:

Is the falling of an energized line on the fence a danger that must be considered?

Construction of transmission lines over private fences is common and reliable. The number of lines crossing a substation fence may be greater, but the spans are often shorter and dead-ended at one or both ends. Hence, the danger of a line falling on a fence is usually not of great concern. If one is to design against this danger, then very close coupling of the fence to adjacent ground throughout its length is necessary. Touch and step potentials on both sides of the fence must be within the acceptable limit for a fault current of essentially the same maximum value as for the substation. This is somewhat impractical because the fence is not tied to the main ground grid in the substation and the adjacent earth would be required to dissipate the fault current through the local fence grounding system.

May hazardous potentials exist at the fence during other types of faults because the fence line crosses the normal equipotential contours?

Fences do not follow the normal equipotential lines on the surface of the earth which result from fault current flowing to and from the substation grounding grid. If coupling of the fence to ground is based solely on the contact between the fence posts and the surrounding earth, the fence might, under a fault condition, attain the potential of the ground where the coupling was relatively good, and thereby attain a high voltage in relation to the adjacent ground surface at locations where the coupling was not as good. The current flowing in the earth and fence, and the subsequent touch voltage on the fence are less than would result from an energized line falling on the fence; however, the touch voltage may exceed the allowable value and would, hence, be unsafe.

In practice, can complete metallic isolation of the fence and substation ground grid be assured at all times?

It may be somewhat impractical to expect complete metallic isolation of the fence and the substation ground grid. The chance of an inadvertent electrical connection between the grid and the fence areas may exist. This inadvertent electrical connection may be from metallic conduits, water pipes, etc. These metallic items could transfer main grid potential to the fence and hence dangerous local potential differences could exist on the fence during a fault. If the fence is not closely coupled to the nearby ground by its own adequate ground system then any such inadvertent connections to the main grid could create a hazard along the entire fence length under a fault condition. This hazard could be only partially negated by utilizing insulated joints in the fence at regular intervals. However, this does not appear to be a practical solution to the possible hazard.

Several different practices are followed by various companies in regard to fence grounding. Some companies ground only the fence posts, using various types of connectors as described elsewhere in this guide. Other companies ground the fence posts, fabric and barbed wire. The grounding grid should extend to cover the swing of all substation gates. The gate posts should be securely bonded to the adjacent fence post utilizing a flexible connection.

To illustrate the effect of various fence grounding practices on fence touch potential, five fence grounding examples were analyzed using computer analysis. The fence grounding techniques analyzed were

— Case 1: Inclusion of fence within the ground grid area. The outer ground wire is 0.91 m (3 ft) outside of the fence perimeter. The fence is connected to the ground grid. Refer to Figure 37 and Figure 38 for grid layout.
— Case 2: Ground grid and fence perimeter approximately coincide. The outer ground wire is directly alongside the fence perimeter. The fence is connected to the ground grid. Refer to Figure 39 and Figure 40 for grid layout.
— Case 3: The outer ground grid wire is 0.91 m (3 ft) inside the fence perimeter. The fence is connected to the ground grid. Refer to Figure 41 and Figure 42 for grid layout.
— Case 4: Ground grid is inside of fence area. The outer ground grid wire is 6.7 m (22 ft) inside the fence perimeter. The fence is connected to the ground grid. Refer to Figure 43 and Figure 44 for grid layout.
— Case 5: Ground grid is inside of fence area. The outer ground grid wire is 6.7 m (22 ft) inside the fence perimeter. The fence is locally grounded but not connected to the ground grid. Refer to Figure 45 and Figure 46 for grid layout.

The fenced area for each case is a square having sides of 43.9 m (144 ft). The test calculations are based on the following parameters:

$\rho = 60\ \Omega\cdot\text{m}$
$I_G = 5000$ A
$h_s = 0.076$ m
$r_s = 3000\ \Omega\cdot\text{m}$, extending 0.91 m (3 ft) beyond the fence
$R_g = 0.66$ W for cases 1–4
$R_g = 0.98$ W for case 5
$t_s = 0.5$ s
$D_f = 1.0$

The factor C_s for derating the nominal value of surface layer resistivity is dependent on the thickness and resistivity of the surface material and the soil resistivity, and is computed using Equation (29) and Figure 11:

$$K = \frac{\rho - \rho_s}{\rho + \rho_s}$$

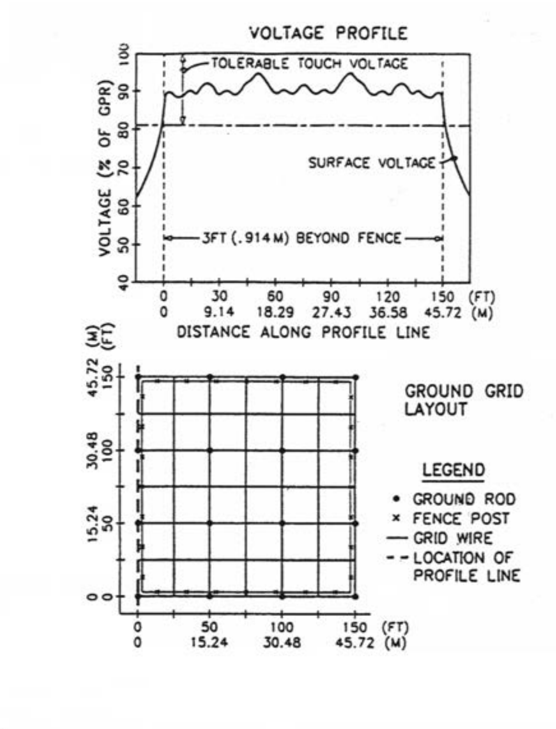


Figure 37—Case 1, plot 1

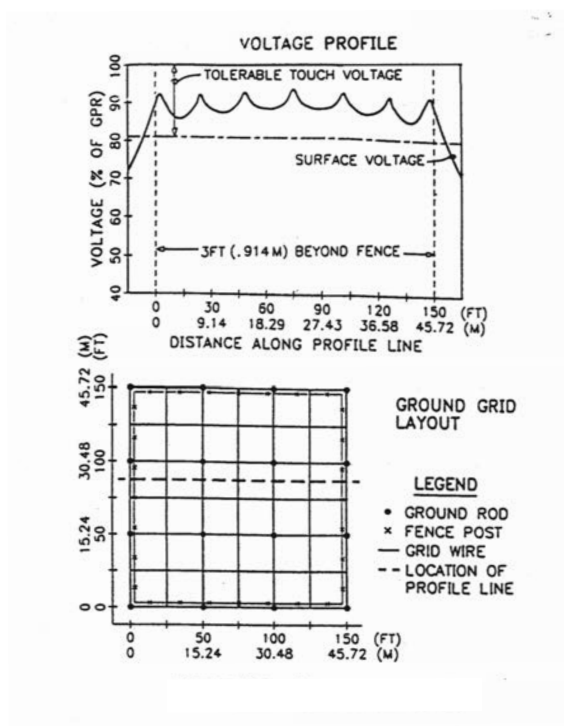


Figure 38—Case 1, plot 2

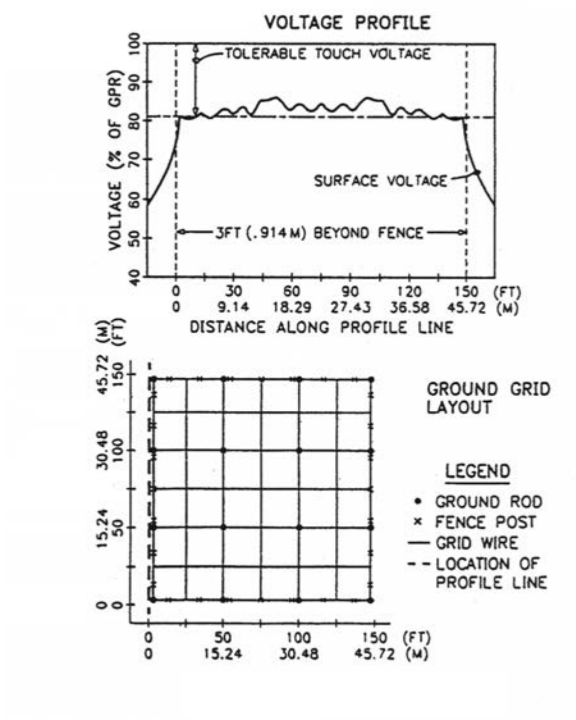


Figure 39—Case 2, plot 1

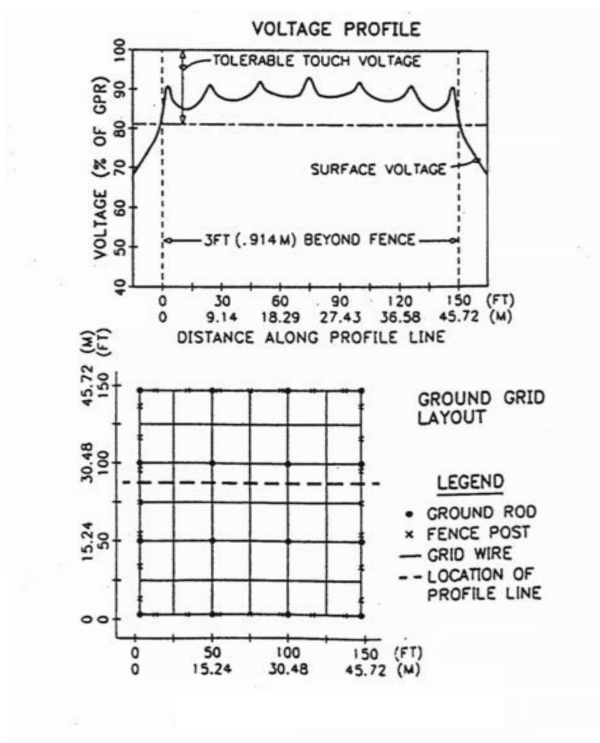


Figure 40—Case 2, plot 2

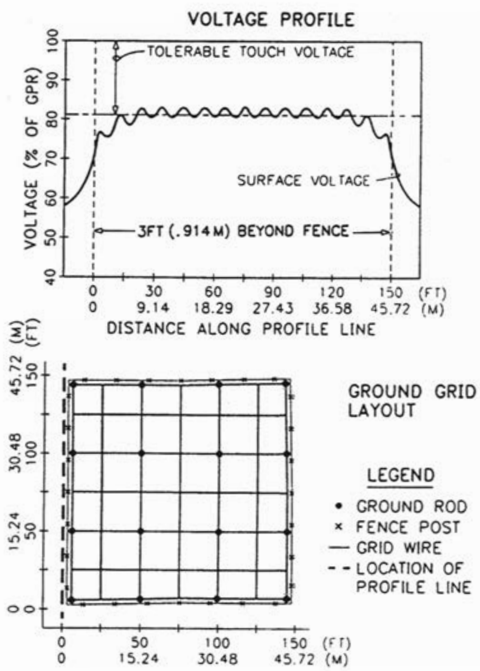


Figure 41—Case 3, plot 1

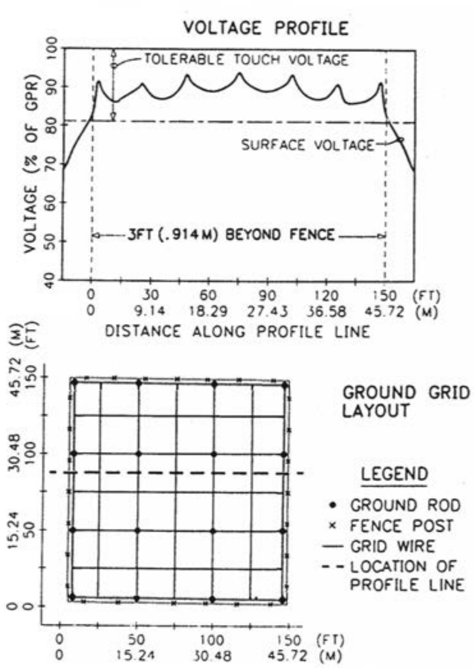


Figure 42—Case 3, plot 2

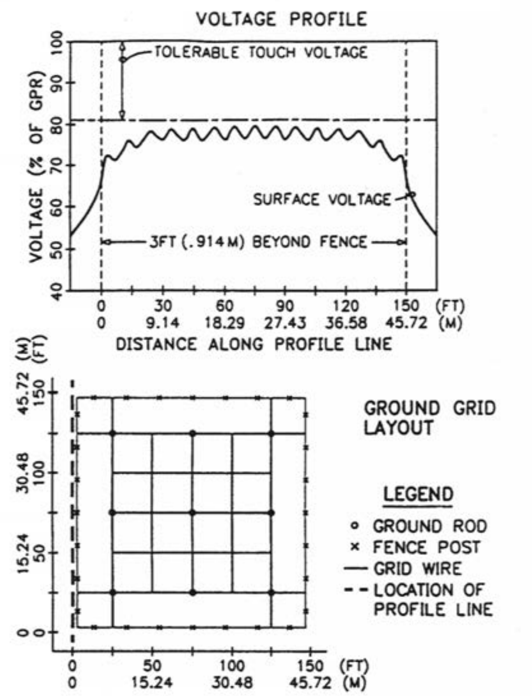


Figure 43—Case 4, plot 1

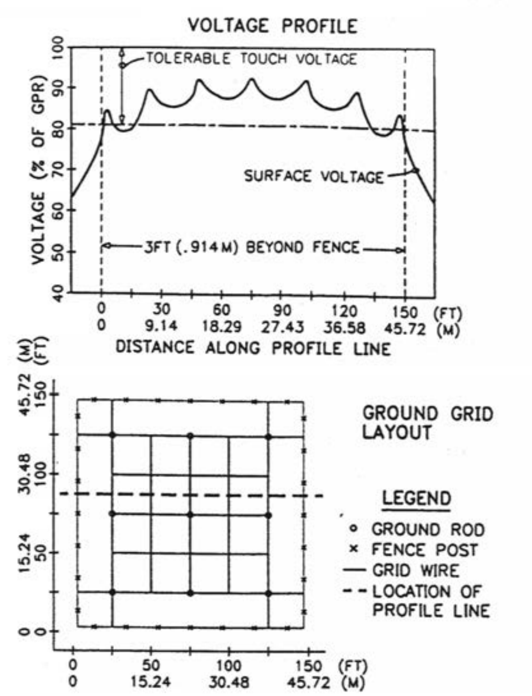


Figure 44—Case 4, plot 2

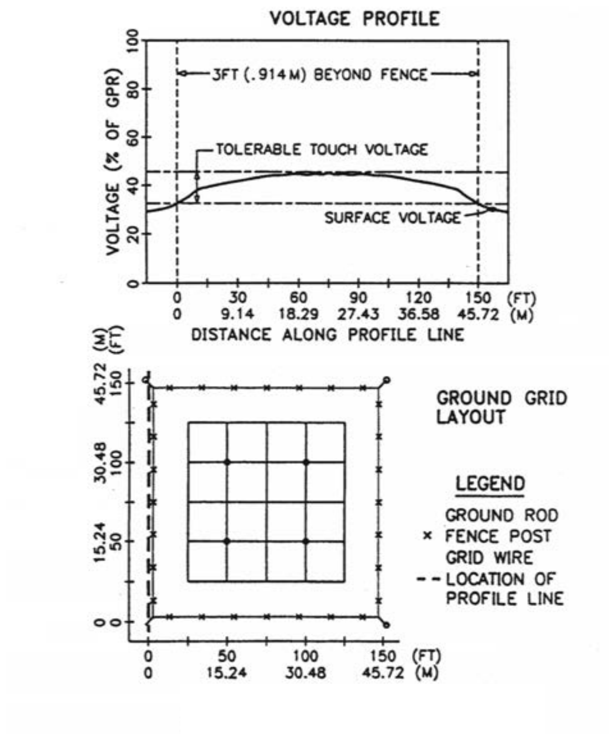


Figure 45—Case 5, plot 1

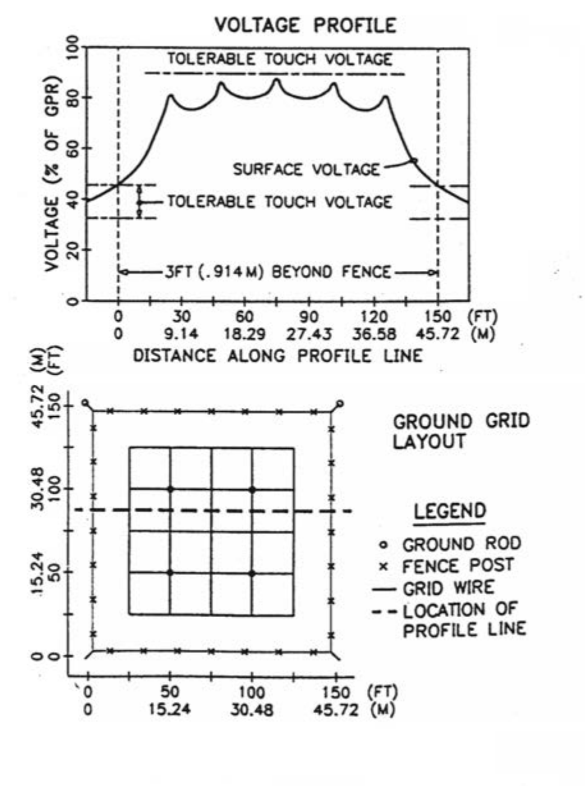


Figure 46—Case 5, plot 2

$$K = \frac{60 - 3000}{60 + 3000} = 0.961$$

$$C_s = 0.62$$

The allowable step and touch voltages are calculated using Equation (29) and Equation (32). For test cases 1–5:

$$E_{step50} = (1000 + 6C_s \cdot \rho_s)0.116 / \sqrt{t_s} = 1995 \text{ V}$$

$$E_{touch50} = (1000 + 1.5C_s \cdot \rho_s)0.116 / \sqrt{t_s} = 622 \text{ V}$$

The actual step voltage E_s and actual mesh voltage E_m are calculated as a function of the GPR in percent, using the following equations:

$$E_s = R_g \cdot I_g \frac{E_s(\%)}{100} D_f$$

$$E_m = R_g \cdot I_g \frac{E_m(\%)}{100} D_f$$

where

E_s (%) is the step potential in terms of percent of GPR
E_m (%) is the mesh potentials in terms of percent of GPR

Equating the actual step and mesh voltage equations to the tolerable step and touch voltage values ($E_{step} = E_s$ and $E_{touch} = E_m$) and solving for E_s(%) and E_m(%), the equations become

$$E_s(\%) = \frac{E_{step}(100)}{R_g \cdot I_g \cdot D_f}$$

$$E_m(\%) = \frac{E_{touch}(100)}{R_g \cdot I_g \cdot D_f}$$

Substituting the assumed parameters for these test cases yields the following:

For cases 1–4

$E_s(\%) = 60.5$

$E_m(\%) = 18.8$

For case 5

$E_s(\%) = 40.7$

$E_m(\%) = 12.7$

The actual step and mesh voltages as a percent of GPR must be less than 60.5% and 18.8%, respectively, for cases 1–4 and less than 40.7% and 12.7%, respectively, for case 5.

For each test case, two voltage profiles were computed at the following locations:

— A line parallel to and 0.91 m (3 ft) outside of fence.
— A line through the grid from one side to the other, parallel to the grid wires.

17.4 Results of voltage profiles for fence grounding

The results of the voltage profiles along the surface of the earth for test case 1 are shown in Figure 37 and Figure 38. The results for both profiles indicate that the touch potential on the fence for a person standing 0.91 m (3 ft) from the fence (approximately one arm's length) is less than the tolerable touch voltage and hence safe. The voltage profiles illustrate how the voltage above remote earth decreases rapidly as one leaves the substation grounding grid area. As seen in Figure 37, the step voltage is no greater than 3–4% and is far below the tolerable step voltage percent of 60.5% of GPR. Because step voltage is usually not the concern in regard to fence grounding, it will not be analyzed in the remaining test cases.

The results of the voltage profiles for test case 2 are shown in Figure 39 and Figure 40. The voltage profile in Figure 40 for a line through the grid from one side to the other indicates that the touch potential 0.91 m (3 ft) outside of the fence is very nearly equal to the allowable touch voltage. However, as seen in Figure 39 for a voltage profile along the fence and 0.91 m (3 ft) away from it, it is clear that the touch voltages on certain areas of the fence are not safe for a person to contact. By comparing Figure 37 and Figure 39, one can clearly see the effect of having a ground grid wire 0.91 m (3 ft) outside of the fence and around the fence perimeter.

The results of the voltage profiles for test case 3 are shown in Figure 41 and Figure 42. These results are very similar to those of test case 2 and illustrate that the touch potential on the fence is generally not safe in several areas for a person to contact.

The results of the voltage profiles for test case 4 are shown in Figure 43 and Figure 44. These results again illustrate that the touch potential on the fence during a fault condition is not safe to contact. It can be seen by comparing Figure 37, Figure 39, Figure 41, and Figure 43 that the touch potential along the length of the fence increases as the outer ground grid wire is moved inward toward the substation.

The results of the voltage profiles for test case 5 are shown in Figure 45 and Figure 46. The tolerable touch voltage has decreased from 18.8% to 12.7% because of an increase in the substation grid resistance. The grid resistance increase is a result of less wire and reduced area in the grid for test case 5. According to the computer program results, the potential rise on the isolated, separately grounded fence during a ground fault condition is 43.7% of GPR, which is shown as a horizontal line on the graphs. The potential rise on the fence is caused by the coupling through the earth from the ground grid to the fence. As shown in Figure 45, the potential rise on the earth 0.91 m (3 ft) beyond the fence corner caused by a ground fault condition is 30.5% of GPR. The largest difference in voltage between the fence and the earth occurs at the corner and is 13.2% of GPR, which is 0.5% greater than the allowable touch voltage of 12.7%. It is also important to note that if the fence should ever inadvertently become metallically connected to the ground grid, the potential on the fence could reach 100% of GPR and the results would be similar to those shown in case 4 (Figure 43 and Figure 44).

Test cases studied for an isolated ungrounded fence yield very similar results as the test cases run for an isolated, separately grounded fence shown in Figure 45 and Figure 46.

17.5 Control cable sheath grounding

Metallic cable sheaths, unless effectively grounded, may attain dangerous voltages with respect to ground. These voltages may result from insulation failure, charges due to electrostatic induction, and flow of currents in the sheath, or from the voltage rise during faults discharging to the substation ground system to which the sheaths are connected. All grounding connections should be made to the shield in such a way as to provide a permanent low-resistance bond. The wire or strap used to connect the cable shield ground connection to the permanent ground must be sized to carry the available fault current.

Sheath currents on single-conductor cables can be reduced by grounding one end of the sheaths only, when the cable length is not excessive. For long cables, the sheath should be grounded at both ends and at each splice. Refer to IEEE Std 525-1992.

The sheaths of shielded control cables should be grounded at both ends to eliminate induced potentials. If the control cable sheath is grounded at widely separated points, large potential gradients in the ground grid during faults may cause excessive sheath currents to flow. One solution is to run a separate conductor in parallel with the control cable connected to the two sheath ground points. The current will then be diverted away from the sheath. This separate conductor (usually bare copper) is typically routed along the top of the inside wall of the cable trench or above direct-buried conductors.

Nonshielded cables are subject to transient induced voltage magnitudes of 190% or more than the induced voltages on shielded cables (Mitani [B109]). Induced voltages in nonshielded cables can be reduced by as much as 60% by grounding both ends of an unused wire. The effects of fault currents on the conditions to be encountered with any of these grounding arrangements can only be determined by careful analysis of each specific case.

17.6 GIS bus extensions

A number of unique problems are encountered in the grounding of a GIS vis-a-vis conventional substations. The grounded metal enclosure of GIS equipment can be a source of dangerous touch voltages during fault conditions. Refer to Clause 10 for techniques of evaluating touch voltages in GIS.

17.7 Surge arrester grounding

Surge arresters should always be provided with a reliable low-resistance ground connection. Arresters should be connected as close as possible to the terminals of the apparatus to be protected and have as short and direct a path to the grounding system as practical. While many utilities provide separate ground leads from arresters mounted on metal structures, other utilities use the arrester mounting structures as the surge arrester ground path because the large cross section of the steel members provides a lower resistance path than a copper cable of the usual size. In these cases it is important to ensure adequate electric connections from the structure to both arrester ground lead and ground grid; and also to be sure that the steel cross-sectional area is adequate for conductivity, and that no high resistance is introduced into joints from paint films, rust, etc.

17.8 Separate grounds

The practice of having separate grounds within a substation area is rarely used for the following reasons:

a) Higher resistances for separate safety and system grounds are produced than would be the case for a single uniform ground system.

b) In the event of insulation failures in the substation, high currents could still flow in the safety ground.

c) Because of a high degree of coupling between separate electrodes in the same area, the safety objective of keeping the GPR of the safety grounds low for line faults would not be accomplished.

d) Often dangerous potentials would be possible between nearby grounded points because decoupling of the separate grounds is possible, at least to some extent.

17.9 Transferred potentials

A serious hazard may result during a ground fault from the transfer of potential between the substation ground grid area and outside locations. This transferred potential may be transmitted by communication circuits, conduit, pipes, metallic fences, low-voltage neutral wires, etc. The danger is usually from contact of the touch type. A transferred potential problem generally occurs when a person standing at a remote location away from the substation area touches a conductor connected to the substation grounding grid. The importance of the problem results from the very high magnitude of potential difference, which is often possible. This potential difference may equal or exceed (due to induced voltage on unshielded communication circuits, pipes, etc.) the GPR of the substation during a fault condition. The basic shock situation for transferred potential is shown in Figure 12.

An investigation into possible transferred potential hazards is essential in the design of a safe substation grounding network. Various means can be taken to protect against the danger of transferred potentials. The following subclauses offer a brief discussion of the various transferred potential hazards and means to eliminate the hazard.

17.9.1 Communication circuits

For communications circuits, methods have been developed involving protective devices and isolating and neutralizing transformers to safeguard personnel and communications terminal equipment. These will not be discussed here except to emphasize the importance of adequate insulation and isolation from accidental contact of any of these devices and their wiring, which may reach a high voltage with respect to local ground. The introduction of fiber optics to isolate the substation communications terminal from the remote terminal can eliminate the transfer of high potentials. Fiber optics should be considered when potentials cannot be easily controlled by more conventional means. Refer to IEEE Std 487-1992 for more detailed information.

17.9.2 Rails

Rails entering the substation can create a hazard at a remote point by transferring all or a portion of the GPR from the substation to a remote point during a ground fault. Similarly, if grounded remotely, a hazard can be introduced into the substation area by transferring remote earth potential to within the substation. These hazards can be eliminated by removing the track sections into the substation after initial use, or by using removable track sections where the rails leave the ground grid area. However, insulating flanges, as discussed in the following paragraphs, should also be utilized to provide as much protection as possible when the railroad track is intact for use.

Insulating splices or flanges are manufactured by a variety of vendors. The general practice is to install two or three sets of these devices such that a rail car would not shunt a single set. Investigation of these insulating splices has shown that they are primarily designed for electrical isolation of one track from another for signal scheme purposes. The typical insulated joint consists of a section of track made from an insulated material called an end post, installed between rail ends. The side members bolting the joint are also insulated from the rail sections. The breakdown voltage of the insulating joints should be considered in each application. The insulating joints must be capable of withstanding the potential difference between remote earth and the potential transferred to the joint.

It should be noted, however, that insulating flanges are not recommended as the primary means of protection, as they may create their own hazardous situations (Garrett and Wallace [B72]). If the track sections outside the substation and beyond the insulating flange are in contact with the soil, a hazardous voltage may exist between that rail section and a rail section or perimeter fence grounded to the substation grid during a fault. If the rails are not bonded to the substation grid, a hazardous voltage may exist between the rails and grounded structures within the substation during a fault. Other situations are discussed in Garret and Wallace [B72] that may result in hazardous voltages. Thus, removal of rail sections at the perimeter of the grounding system is recommended.

17.9.3 Low-voltage neutral wires

Hazards are possible where low-voltage feeders or secondary circuits, serving points outside the substation area, have their neutrals connected to the substation ground. When the potential of the substation ground grid rises as the result of ground-fault current flow, all or a large part of this potential rise may then appear at remote points as a dangerous voltage between this "grounded" neutral wire and the adjacent earth; moreover, where other connections to earth are also provided, the flow of fault current through these may, under unfavorable conditions, create gradient hazards at points remote from the substation.

To avoid these difficulties, the low voltage neutral may be isolated from ground at the substation itself; always provided, however, that this does not result in slowing down the clearing time for low voltage faults to the point where the total hazard is increased rather than diminished. If the low-voltage neutral is isolated from that substation ground, it then becomes necessary to avoid hazards at the substation due to the introduction, via the neutral wire, of remote earth potential. This implies that this neutral, in and near the substation, should be treated as a "live" conductor. It should be insulated from the substation ground system by insulation adequate to withstand the GPR; and it should be located so as to minimize the danger of being contacted by personnel.

17.9.4 Portable equipment and tools supplied from substation

Similar hazards need to be considered in the case of portable mining, excavating, or material handling equipment, or portable tools, which are supplied electrically from the substation and are used outside of the area of the grid where the mesh potential is held within safe limits. Such loads are often supplied by temporary pole lines or long portable cables. An example is often seen when an addition to an existing substation is being constructed.

A hazardous transferred potential might appear between equipment and the nearby earth during a fault, if the neutral or grounding wire to the equipment is also connected to the substation ground. In cases such as these, it is common to isolate the supply circuits from the substation ground; to ground the neutrals and equipment to earth at the site of the work; and to make sure that the maximum fault current to the local ground is limited to a low value that will not itself cause gradient hazards.

17.9.5 Piping

Pipelines and metallic conduits should always be connected to the substation grounding system to avoid hazards within the substation area. Transferred potentials may be reduced or stopped at the substation boundary by inserting insulating sections of sufficient length to avoid shunting by the adjacent soil. The insulating sections must be capable of withstanding the potential difference between remote earth and the substation.

17.9.6 Auxiliary buildings

Auxiliary buildings can be treated as part of the substation for grounding purposes, or as separate installations, depending on circumstances. If the buildings and substation are relatively close, and especially if the buildings are linked directly to the substation by water pipes, cable sheaths, phone lines, etc., it is appropriate to treat such buildings and their immediate area as part of the substation. As such, the buildings should be grounded using the same safety criteria as the substation. If the buildings are not as close, and if such conducting links are lacking, it may be decided to treat such buildings as separate units with their own local safety grounds. If served electrically from the substation, they should have their own distribution transformers of a type to provide adequate insulation against transfer of the substation GPR. Secondary neutrals would, in this case, be connected to the local ground at the auxiliary buildings only.

17.9.7 Fences

Substation fences have been extended to other areas of a site at some locations. This also presents a possible transferred potential hazard if the fence is connected to the substation grounding grid.

To lessen this hazard, the substation fence should be insulated from the fence leaving the substation area. It is recommended that insulating sections be installed to prevent the transfer of potential through the soil and large enough to prevent someone from bridging the insulating section.

An example of the potential profile of a fence connected to a substation grounding grid and leaving the substation area is shown in Figure 47. As can be seen, the touch potential on the fence after it leaves the substation grid area of influence is not safe to contact.

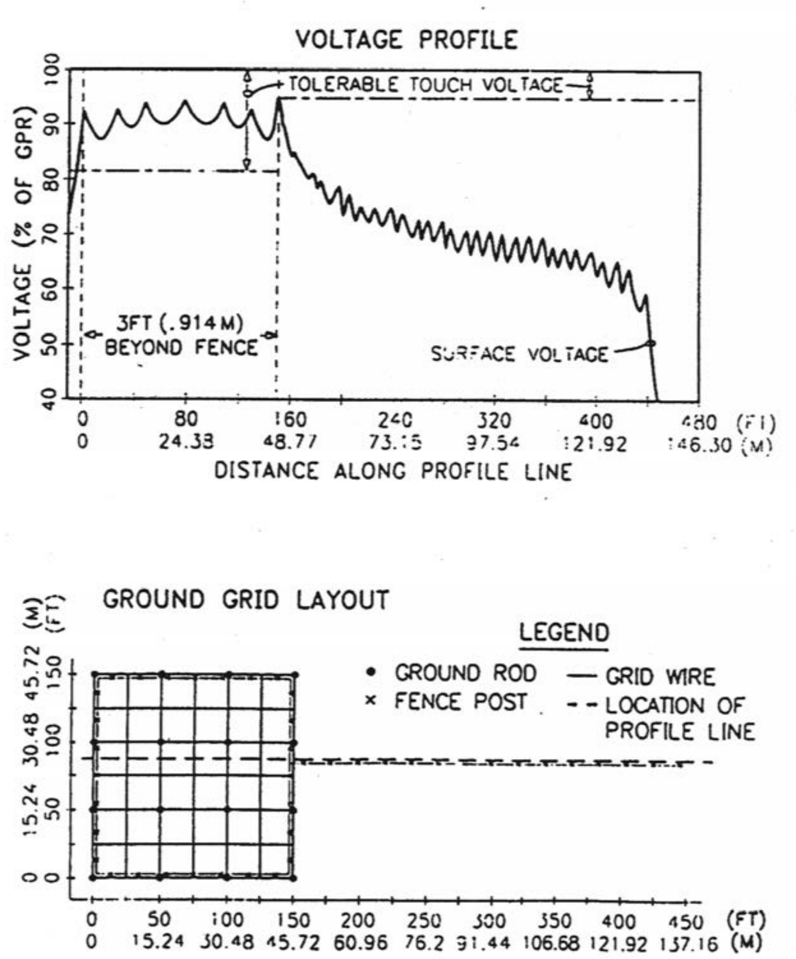


Figure 47—Transfer potential on a fence

18. Construction of a grounding system

The method of construction, or combination of methods chosen, will depend on a number of factors, such as size of a grid, type of soil, size of conductor, depth of burial, availability of equipment, cost of labor, and any physical or safety restrictions due to nearby existing structures or energized equipment.

There are two commonly employed methods to install the ground grid. These are the trench method and the cable plowing method. Both of these methods employ machines. Where these machines are not employed due to lack of space to move them or small size of the job site, the ground grid is installed by hand digging.

18.1 Ground grid construction—trench method

Flags are staked on the perimeter along two sides to identify the spacing between parallel conductors. These markers also serve as a guide for the trenching machine. The trenches are dug using a trenching machine usually along the side having the larger number of parallel conductors. These trenches are dug to the specified depth (usually about 0.5 m or 1.5 ft). Conductors are installed in these ditches and ground rods are driven and connected to the conductors. Pigtails for equipment grounds may also be placed at this time. These initial ditches are then backfilled with dirt up to the location of the cross connections.

The next step is to dig cross-conductor ditches (often to a shallower depth), once again using markers as a guide. Care must be taken when digging these ditches to avoid snagging the conductor laid in the backfilled ditches at cross points. The conductors are installed in the ditches and any remaining ground rods are driven and connected to the conductors. Remaining pigtails are also connected to these conductors. Cross-type connections are made between perpendicular conductor runs. The ditches are then backfilled with dirt.

An alternative method consists of confining the work to a small section of the total yard and completing this section entirely before moving to a new area. In this event, the trenches are all dug at the same depth prior to any conductor being placed. Installation of conductors and ground rods are the same as described in the preceding paragraphs.

18.2 Ground grid construction—conductor plowing method

Another procedure for the installation of ground conductors, which may prove economical and quick when conditions are favorable and proper equipment is available, is to plow the conductors in. A special narrow plow is used, which may be either attached to, or drawn by, a tractor or four-wheel drive truck, if there is sufficient maneuvering room. The plow may also be drawn by a winch placed at the edge of the yard. The conductor may be laid on the ground in front of the plow, or a reel of conductor may be mounted on the tractor or truck, or on a sled pulled ahead of the plow. The conductor is then fed into the ground along the blade of the plow to the bottom of the cut. Another method is to attach the end of the conductor to the bottom of the plow blade, and pull it along the bottom of the cut as the plow progresses. In this case, care should be taken to ensure that the conductor does not work its way upward through the loosened soil.

The cross conductors are plowed in at slightly less depth to avoid damage to previously laid conductors. The points of crossing, or points where ground rods are to be installed, are then uncovered, and connections are made as described in 18.3.

With adequate equipment, and the absence of heavy rock, this method is suitable for all of the conductor sizes and burial depths normally used. The reader can find additional information in IEEE Std 590-1992 [B85].

18.3 Installation of connections, pigtails, and ground rods

Once the conductors are placed in their trenches, the required connections are then made. Generally, the points of crossing require a cross-type connection, while tee connections are used for taps to a straight conductor run located along the perimeter. Types of connections are many and varied and depend on the joint, the material being joined, and the standard practice of the utility concerned (see 11.4).

Pigtails are left at appropriate locations for grounding connections to structures or equipment. These pigtails may be the same cable size as the underground grid or a different size depending on the number of grounds per device, the magnitude of the ground fault current, and the design practices of the utility concerned. The pigtails are then readily accessible after backfilling to make above-grade connections.

The installation of the ground rods is usually accomplished by using a hydraulic hammer, air hammer, or other mechanical device. The joining of two ground rods is done either by using the exothermic method or a threaded or threadless coupler. The connection between the ground rod and grid conductor can be made using various methods.

18.4 Construction sequence consideration for ground grid installation

A ground grid is normally installed after the yard is graded, foundations are poured, and deeper underground pipes and conduits are installed and backfilled. The security fence may be installed before or after the ground grid installation. In cases where deeper underground pipes and conduits are not installed before ground grid installation, an attempt should be made to coordinate the trenching procedure in a logical manner.

18.5 Safety considerations during subsequent excavations

As shown in 7.4, the insulating value of a layer of clean surface material or gravel is an aid to safety under ground fault conditions. Therefore, when an excavation is necessary after a rock surfacing has been applied, care should be taken to avoid mixing the lower resistivity soil from the excavation with the surrounding rock surfacing material.

During subsequent excavations there are more chances to snag the ground conductor. In such a case a check should be made to determine if there is a break in the conductor and joints. A break in the conductor or joints, or both, must be immediately repaired. A temporary ground connection should be placed around the break before it is repaired. The temporary ground connection should be suitable for the application and installed according to safe grounding practices, because a voltage may exist between the two ground conductor ends.

19. Field measurements of a constructed grounding system

19.1 Measurements of grounding system impedance

As has already been indicated, only approximate results can usually be expected from a precalculation of substation ground impedance. A careful measurement of the impedance of the installation as constructed is therefore desirable, though not always practical if the grid is connected to or influenced by other buried metallic structures.

In this clause only general methods are discussed. For more detailed information refer to IEEE Std 81-1983. Several important points of this guide have been used here, where applicable. While in this clause the ohmic value is referred to as resistance, it should be remembered that there is a reactive component that should be taken into consideration when the ohmic value of the ground under test is less than 0.5 Ω, and the area is relatively large. This reactive component has little effect on grounds with an impedance higher than 0.5 Ω.

19.1.1 Two-point method

This method measures the total resistance of the grounding system and an auxiliary ground. The measured value in ohms is then expressed as the resistance of the grounding system because the resistance of the auxiliary ground is presumed to be negligible.

This method is subject to large errors for a low value of the grounding system resistance or when grounds are close to each other, but it may be useful if a “go or no go” type of test is all that is needed.

19.1.2 Three-point method

This method involves the use of two test electrodes with their resistances designated as r_2 and r_3 and with the electrode to be measured designated as r_1. The resistance between each pair of electrodes is measured and designated as r_{12}, r_{13}, and r_{23}, where $r_{12} = r_1 + r_2$, etc. Solving the simultaneous equations, it follows that

$$r_1 = \frac{(r_{12}) + (r_{13}) - (r_{23})}{2} \tag{95}$$

Therefore, by measuring the resistance of each pair of ground electrodes in series and substituting these values in Equation (95), the value of r_1 can be determined.

If the two test electrodes have substantially higher resistances than the electrode under test, the errors of the individual measurements will be greatly magnified in the final results. In addition, this method can give erroneous values, such as zero or negative resistance, if the electrodes are not separated by a sufficiently large distance. Consequently, this method becomes difficult for large substations.

19.1.3 Ratio method

This method compares the resistance of the electrode under test to that of a known resistance, generally by the same electrode configuration as in the fall-of-potential method described in 19.1.5. Being a comparison method, the ohmic readings are independent of the test current magnitude provided that the test current is high enough to give adequate sensitivity.

19.1.4 Staged-fault tests

It may be necessary to stage a high-current test where specific information is desired for a particular groundng design. This test would also give quantities from which the ground impedance could readily be determined.

This type of test would require the use of an oscilloscope that would record the voltage between selected points. However, the magnitude of the voltage may be quite large and require a potential transformer to step down the voltage to a manageable level. The maximum voltage and potential transformer ratio should be determined in advance of the staged-fault test so that no test equipment is overstressed. The fall-of-potential test can be used to determine the expected voltage of a staged-fault test.

The location of the actual points to be measured is, of course, dependent on the information desired; but in all cases due allowance should be made for coupling between test circuits.

19.1.5 Fall-of-potential method

This method has several variations and is applicable to all types of ground resistance measurements (see Figure 48). Basically, the ground resistance measurement consists of measuring the resistance of the grounding system with respect to a remote ground electrode. The remote electrode is theoretically at an infinite distance from the grounding system where the earth current density approaches zero. Although the fall-of-potential method is universally used, it presents many difficulties and sources of error when used to measure the resistance of large grounding systems usually encountered in practice. These difficulties occur mainly because of the size and configuration of the grounding system and soil heterogeneity.

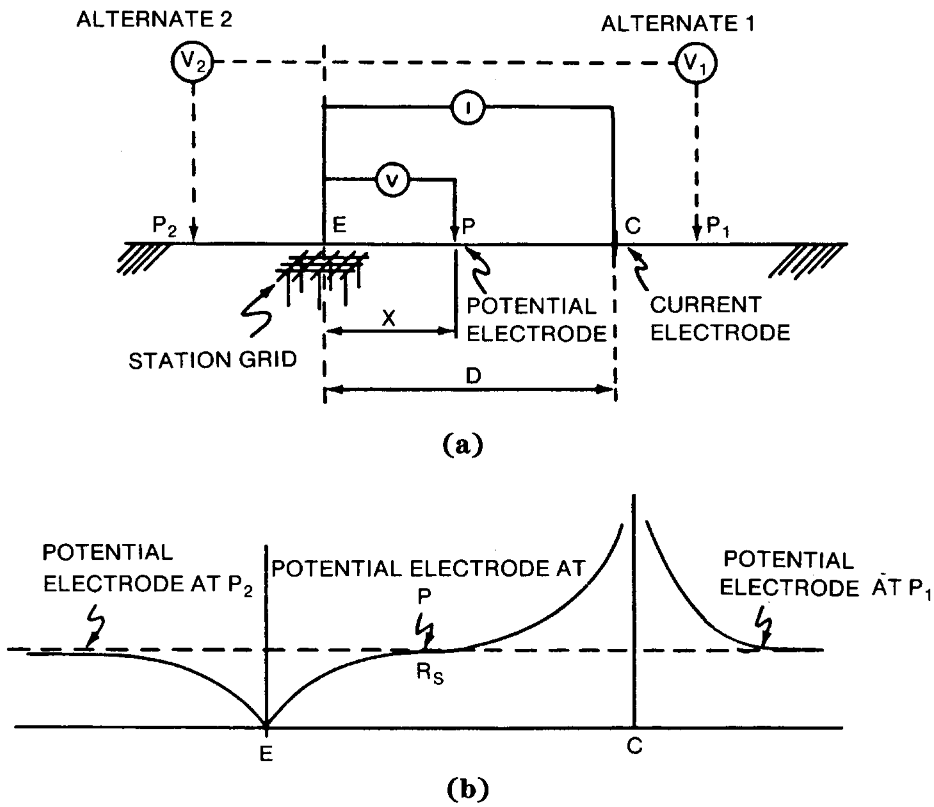


Figure 48—(a) Fall of potential method and (b) Earth surface potentials for various spacings "X"

If the distance D is large enough with respect to the grounding system, the center part of the fall-of-potential curve tends to be nearly horizontal, but it may appear to do so also because of lack of sensitivity of the instruments used. It is usually accepted, although not always correctly, that the nearly horizontal section of the curve gives the resistance R_g. For large grounding systems, large distances D may not be practical or even possible and as a result, the nearly horizontal section of the curve will not exist. In this case, accurate measurements will not be obtained unless one has already a good idea of the exact probe position P.

For measuring resistance, the current source is connected between the substation ground mat E and a current electrode located at a distance of several hundred meters from the substation. The potential-measuring circuit is then connected between the substation mat E and a potential electrode P, with measurements being made at various locations of the electrode outside the substation. This potential electrode may be moved toward the current electrode in equal increments of distance, starting near the substation, and the resistance readings obtained at the various locations may be plotted against distance from the substation. The resulting graph should resemble curve EPC of Figure 48(b). From E to P, the voltage per ampere of test current rises, but the voltage gradient decreases reaching a minimum at P. Continuing toward C, the effect of current converging on the current test probe becomes apparent and a rising voltage gradient is observed as the current probe is approached. The slowly rising, nearly horizontal portion of the graph, if any, represents a zone where the interaction of the tested and return electrodes is small. When the return electrode is placed at a finite distance from the grounding system and the potential probe is driven at a specific location, then an accurate measurement of the resistance is obtained. Unfortunately, the exact location of the potential electrode is well defined only for some ideal cases such as hemispherical or very small electrodes buried in uniform or two layer soils (Dawalibi and Mukhedkar [B39][B44]). The case of a large grounding system buried in uniform soil assuming uniform current density distribution in the conductors has been analyzed by Curdts and Tagg [B23][B137][B138][B139]. In practice, however, grounding systems consist of a complex arrangement of vertical ground rods and horizontal conductors, usually buried in nonuniform soils.

For large grounding grids the spacings required may not be practical or even possible, especially where the transmission line overhead ground wires and feeder neutrals connected to substation ground effectively extend the area of influence. Consequently, the so-called flat portion of the curve will not be obtained and other methods of interpretation must be used. Previous work has shown that when soil is not uniform and separation is not large compared to ground system dimensions, the 61.8% rule, which corresponds to the so called flat portion of the curve, may no longer apply (Dawalibi and Mukhedkar [B39][B44]). Locations varying from 10% to 90% were found to be quite possible. These methods are discussed in IEEE Std 81-1983.

It should be noted that placement of the potential probe P at the opposite side with respect to electrode C (that is, at P_2) will always result in a measured apparent resistance smaller than the actual resistance. In addition, when P is located on the same side as electrode C (that is, at P_1), there is a particular location that gives the actual resistance.

The primary advantage of the fall-of-potential method is that the potential and current electrodes may have substantially higher resistance than the ground system being tested without significantly affecting the accuracy of the measurements.

19.2 Field survey of potential contours and touch and step voltages

The best assurance that a substation is safe would come from actual field tests of step and touch voltages with a heavy current load on the ground mat. Because of the expense, few utilities are likely to make these tests as a routine practice. If, however, large discrepancies between calculated and measured resistance or known anomalies in the ground resistivities throw doubt on the calculated step and touch voltages, then such tests may be considered. This is especially true when the computed values are close to tolerable limits, and further improvement of the ground to provide a larger safety factor would be difficult or costly.

In such situations, it may be worthwhile to load the grounding system with a test current (preferably in the order of about 100 A) and actually take measurements of potential gradients at selected locations throughout the substation and around its perimeter. An EPRI project (EPRI TR-100622 [B63]) included such a field test. The project included comparisons of the field test results with a computer solution. The method of measurement was found to be quite feasible and gives good results (EPRI TR-100622 [B63]; Patel [B120]; Meliopoulos, Patel, and Cokkonides [B106])

The basic method for such gradient measurements involves passing a test current through the substation ground via a remote current electrode, as in substation ground resistance measurements, and measuring the resulting touch and step voltages. To obtain the potentials existing under actual fault conditions, the test values are multiplied by the ratio of actual ground-fault current to test current.

Since the potentials of interest are those existing at the surface of the earth, the potential probe used is of a type that makes a surface contact.

The relatively high contact resistances involved generally rule out the use of instruments designed for ground resistance measurements since they operate over a limited range of potential probe resistance. To use a voltmeter-ammeter method, it is usually necessary to have a high-impedance voltmeter, and use test currents high enough to overcome the effects of residual ground currents.

Several methods of measuring and recording voltages may be used. Using a high-impedance voltmeter, profiles and contours of open-circuit contact voltages may be plotted for the entire substation. By assuming suitably conservative values of body-and-foot-to-ground resistances, and safe body current, the maximum safe value to open-circuit contact voltage can be determined and hazardous touch and step voltages can be located on the potential map.

Langer [B96] and Bodier [B15] have described measurement techniques in which the effect of actual contact and body resistances are simulated. The operator wears rubber gloves and rubber-soled boots equipped with metallic-mesh contact surfaces. Voltages between these metal contact surfaces are measured by a vacuum tube voltmeter shunted by a resistance equal to an assumed value of body resistance and current is measured by a milliammeter. The ratio of shock current to total ground current is thus determined. More recent test and results are described in EPRI TR-100863 [B64].

By including foot-to-earth contact resistances as a part of the test procedure, the effect of variations in surface conductivity is taken into account. Thus, the additional safety factor provided by surface coverings of surface material, pavement, etc., is included in the test results.

Additional information on making field measurements of potentials is available in IEEE Std 81-1983.

19.3 Assessment of field measurements for safe design

With the figure for measured resistance available, the maximum GPR can be recalculated. If substantially different from that based on the computed resistance, the precautions taken against transferred potentials may need review.

The measured resistance does not provide a direct means of rechecking the computed step and touch potentials, as these are derived from the resistivity. However, if the difference between the computed and measured substation grid resistance is very large, the resistance or resistivity figures may come under suspicion, the latter being, in general, less reliable. Each case will have to be judged on its merits to determine whether the discrepancy is such as to warrant further investigation or additional measurement of the resistivities, employment of larger safety factors, or direct measurement of danger potentials or shock currents as described in 19.2.

19.4 Ground grid integrity test

Many times, solid-state relays, telephone equipment, event recorder circuits, or power supply units in the control house get damaged due to a lightning surge or a fault if the substation has a poor grounding system. Typically, the ground grid integrity test is performed following such an event. Evaluation of older ground grids using this test is also common in the utility industry. Sometimes, following an installation of a large ground grid, this test is performed to ensure the integrity before the substation is approved for operation. The integrity test is a necessity to detect any open circuit or isolated structure or equipment in a substation.

A typical test set is comprised of a variable voltage source (0–35 V, 0–300 A), voltage and current measuring devices, and two test leads. One of the two test leads is connected to a reference ground riser, generally a transformer case ground. The other test lead then connects to the ground riser to be tested. The test consists of flowing 300 A (typically) between the connected risers and measuring the voltage drop across the ground circuit including the test leads. The measurement of the current division at the riser being tested using a clamp-on ammeter provides additional data to evaluate the ground path. Keeping the reference riser connected, the second test lead is moved around to test risers at other equipment and structures until the entire substation ground grid is tested. Often, a cable tracer is employed to locate the unknown or broken ground conductor. The cable tracer detects the magnetic field produced by the test current and generates an equivalent noise, which can be heard through headphones. Absence of the noise is indicative of a broken ground wire or open connection.

It is necessary to determine the voltage drop of the test leads. This is done by shorting the leads across the test set and measuring the voltage drop by flowing 300 A in the loop. This one-time measurement yields the series impedance of the test leads. To obtain a correct impedance value, the test lead impedance is subtracted from the measured impedance between the risers. Though the integrity test is the most practical and convenient test to perform, its results can only be analyzed subjectively. One way to evaluate a ground grid is to compare the impedance values with each other and determine the test risers, which have abnormally high impedance values. One can also evaluate a ground grid by comparing the voltage drop with a known reference value (typically 1.5 V/50 ft between test risers) and determining the weak ties between the risers. Measured current divisions can indicate if there is a high impedance or open path in either direction. More information on this method can be found in Gill [B76].

19.5 Periodic checks of installed grounding system

Some utilities recheck substation ground resistance periodically after completion of construction. It is also well advised to review the ground system from time to time for possible changes in system conditions that may affect the maximum value of ground current, as well as extensions to the substation itself that may affect the maximum current, the substation ground resistance, or local potential differences.

20. Physical scale models

It often is difficult to draw valid conclusions concerning a general grounding problem solely from actual field data. The lack of consistent results caused by the inability to control the test, such as weather conditions, and other variables affecting the condition of the soil, and difficulties in data collecting, all hamper the ability to run and duplicate tests. Because it is helpful to have verification of theoretical assumptions or computer techniques, or both, scale models have been used to bridge the gap. The use of small models can be used to determine the resistance and potential profiles of ground grid arrangements.

The early scale model tests used water to represent uniform soil. The use of small models in large tanks gave consistent results and enabled various models and conditions to be tested and the effects of different parameters to be observed.

In the late 1960s, a two-layer laboratory model was developed at École Polytechnique to verify computer techniques. This method used concrete blocks to represent the lower layer of soil (Mukhedkar, Gervais, and Dejean [B111]). A technique later developed by Ohio State University used agar, a gelatin-like substance frequently used in biological studies, to simulate the lower levels of soil. In this project, accurate uniform and two-layer soil models were used to study the effects of many parameters on resistance and surface potentials (EPRI EL-3099 [B61]).

The results of model tests have shown that scale models can be effectively used for parametric studies for grounding grid design and for verifying computer simulations of ground grid parameters (Sverak, Booream, and Kasten [B134]).

Annex A

(informative)

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Annex B

(informative)

Sample calculations

This annex illustrates the application of equations, tables, and graphs for designing a substation grounding system. The specific objectives are as follows:

a) To show the application of principal equations of this guide for several refinements of the design concept toward a satisfactory final design solution.
b) To illustrate the typical differences to be expected between results obtained using the simplified calculations of this guide and the more rigorous computer solutions.
c) To illustrate such design conditions for which the use of simplified calculations of this guide would not be appropriate for a safe design, as some of the equations may only be used with caution.

In view of these objectives, the following series of examples (B.1–B.4) neither represents, nor is intended to be, the best or most efficient way to design a grounding system.

A computer-based grounding program described in EPRI TR-100622 [B63] was used to model the grids in these examples.

For the series of examples (B.1–B.4), the design data are as follows:

Fault duration t_f	= 0.5 s
Positive sequence equivalent system impedance Z_1	= 4.0 + j10.0 Ω (115 kV side)
Zero sequence equivalent system impedance Z_0	= 10.0 + j40.0 Ω (115 kV side)
Current division factor S_f	= 0.6
Line-to-line voltage at worst-fault location	= 115,000 V
Soil resistivity ρ	= 400 Ω·m
Crushed rock resistivity (wet) ρ_s	= 2500 Ω·m
Thickness of crushed rock surfacing h_s	= 0.102 m (4 in)
Depth of grid burial h	= 0.5 m
Available grounding area A	= 63 m × 84 m
Transformer impedance, (Z_1 and Z_0)	= 0.034 + j1.014 Ω (13 kV)
(Z = 9% at 15 MVA, 115/13 kV)	

The crushed-rock resistivity is assumed to be a conservative estimate based on actual measurements of typical rock samples. The equivalent system fault impedances and current division factor S_f are determined for the worst-fault type and location, including any conceivable system additions over the next 25 years. Thus, no additional safety factor for system growth is added. In addition, it is assumed that the substation will not be cleared by circuit breakers with an automatic reclosing scheme. Thus, the fault duration and shock duration are equal.

B.1 Square grid without ground rods—Example 1

Using the step-by-step procedure as described in 16.4 and illustrated in Figure 33, the following design evaluations can be made.

Step 1: Field data. Although the substation grounding grid is to be located within a rectangle of 63 m × 84 m (5292 m^2), for the initial design assessment it may be expedient to assume a square 70 m × 70 m grid with no ground rods. Consequently, the area occupied by such a grid is A = 4900 m^2. An average soil resistivity of 400 Ω·m is assumed, based on soil resistivity measurements.

Step 2: Conductor size. Ignoring the station resistance, the symmetrical ground fault current $I_f \approx 3I_0$, is computed using Equation (67)

$$I_0 = \frac{E}{3 \cdot R_f + (R_1 + R_2 + R_0) + j(X_1 + X_2 + X_0)} \tag{B.1}$$

For the 115 kV bus fault

$$3I_0 = \frac{(3)(115,000/\sqrt{3})}{3(0) + (4.0 + 4.0 + 10.0) + j(10.0 + 10.0 + 40.0)}$$

and, hence

$|3I_0|$ = 3180 A, and the X/R ratio = 3.33

For the 13 kV bus fault, the 115 kV equivalent fault impedances must be transferred to the 13 kV side of the transformer. It should be noted that, due to the delta-wye connection of the transformer, only the positive sequence 115 kV fault impedance is transferred. Thus

$$Z_1 = \left(\frac{13}{115}\right)^2 (4.0 + j10.0) + 0.034 + j1.014 = 0.085 + j1.142$$

$$Z_0 = 0.034 + j1.014$$

$$3I_0 = \frac{(3)(13,000/\sqrt{3})}{3(0) + (0.085 + 0.085 + 0.034) + j(1.142 + 1.142 + 1.014)}$$

and, hence

$|3I_0| = 6814$ A, and the X/R ratio is 16.2

The 13 kV bus fault value of 6814 A should be used to size the grounding conductor.

Using Table 10 for a fault duration of 0.5 s, the decrement factor D_f is approximately 1.0; thus, the rms asymmetrical fault current is also 6814 A. This current magnitude will be used to determine the minimum diameter of ground conductors.

Assuming the use of copper wire and an ambient temperature of 40 °C, Equation (42) and Table 2 are used to obtain the required conductor cross-sectional area. For 0.5 s and a melting temperature of 1084 °C for hard-drawn copper, the required cross-sectional area in circular mils is

$$A_{kcmil} = I \cdot K_f \sqrt{t_c} \tag{B.2}$$

$$A_{kcmil} = 6.814 \cdot 7.06\sqrt{0.5} = 34.02 kcmil$$

34.02 kcmil = 17.2 mm^2

Because $A_{mm^2} = \pi d^2/4$, the conductor diameter is approximately 4.7 mm, or 0.0047 m if it is solid conductor.

Based on this computation, a copper wire as small as size #4 AWG could be used, but due to the mechanical strength and ruggedness requirements, a larger 2/0 AWG stranded conductor with diameter d = 0.0105 m (0.414 in) is usually preferred as a minimum.

Consequently, at this stage, the designer may opt to check if, alternately, the use of a less conductive (30%) copper-clad steel wire and the imposition of a more conservative maximum temperature limit of 700 °C will still permit the use of a conductor with diameter d = 0.01 m.

Using Equation (41) and Table 1 gives

$$A_{kcmil} = I\frac{197.4}{\sqrt{\left(\frac{TCAP}{t_c\alpha_r\rho_r}\right)\ln\left(\frac{K_o+T_m}{K_o+T_a}\right)}} \tag{B.3}$$

$$A_{kcmil} = 6.184\frac{197.4}{\sqrt{\frac{3.85}{(0.5)(0.00378)(5.862)}\left[\ln\left(\frac{245+700}{245+40}\right)\right]}} = 65.9 kcmils \text{ or } 33.4 \text{ mm}^2$$

In this case, d_{min} = 6.5 mm, or 0.0065 m solid conductor, which is less than d = 0.01 m desired. Hence, a 30% copper-clad steel wire of approximately 2/0 AWG size is a viable alternative for grid wires, even if a conservative maximum temperature limit of 700 °C is imposed.

Step 3: Touch and step criteria. For a 0.102 m (4 in) layer of crushed rock surfacing, with resistivity of 2500 Ω·m, and for an earth with resistivity of 400 Ω·m, the reflection factor K is computed using Equation (21)

$$K = \frac{\rho-\rho_s}{\rho+\rho_s} \tag{B.4}$$

$$K = \frac{400-2500}{400+2500} = -0.72$$

Figure 11 indicates for K = –0.72 the resistivity of crushed rock is to be derated by a reduction factor $C_s \approx$ 0.74. The reduction factor C_s can also be approximated using Equation (27)

$$C_s = 1-\frac{0.09\left(1-\frac{\rho}{\rho_s}\right)}{2h_s+0.09} \tag{B.5}$$

$$C_s = 1-\frac{0.09\left(1-\frac{400}{2500}\right)}{2(0.102)+0.09}$$

Assuming that for the particular station the location of grounded facilities within the fenced property[17] is such that the person's weight can be expected to be at least 70 kg, Equation (30) and Equation (33) may be used to compute the tolerable step and touch voltages, respectively, as follows:

$$E_{step70} = (1000 + 6C_s\rho_s)0.157/\sqrt{t_s} \tag{B.6}$$

$$E_{step70} = [(1000 + 6(0.74)2500)]0.157/\sqrt{0.5} = 2686.6 \text{ V}$$

$$E_{step70} = (1000 + 1.5C_s\rho_s)0.157/\sqrt{t_s} \tag{B.7}$$

$$E_{step70} = [(1000 + 1.5(0.74)2500)]0.157/\sqrt{0.5} = 838.2 \text{ V}$$

Step 4: Initial design. Assume a preliminary layout of 70 m × 70 m grid with equally spaced conductors, as shown in Figure B.1, with spacing D = 7 m, grid burial depth h = 0.5 m, and no ground rods. The total length of buried conductor, L_T, is 2 × 11 × 70 m = 1540 m.

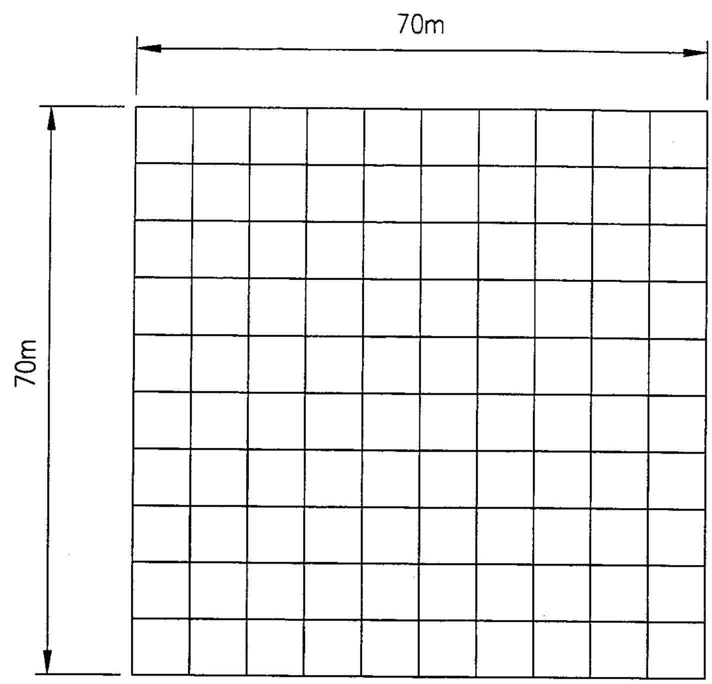


Figure B.1—Square grid without ground rods

Step 5: Determination of grid resistance. Using Equation (52) for L = 1540 m, and grid area A = 4900 m^2, the resistance is

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right] \tag{B.8}$$

[17]That is, not accessible to the general public.

$$R_g = 400\left[\frac{1}{1540} + \frac{1}{\sqrt{20 \cdot 4900}}\left(1 + \frac{1}{1 + 0.5\sqrt{20/4900}}\right)\right] = 2.78\ \Omega$$

Step 6: Maximum grid current I_G. Per the procedure and definitions of 15.1, the maximum grid current I_G is determined by combining Equation (63) and Equation (64). Referring to Step 2, for $D_f = 1.0$, and the given current division factor $S_f = 0.6$,

$$S_f = \frac{I_g}{3 \cdot I_0} \tag{B.9}$$

and

$$I_G = D_f \cdot I_g \tag{B.10}$$

Though the 13 kV bus fault value of 6814 A is greater than the 115 kV bus fault value of 3180 A, it is recalled from Clause 15 that the wye-grounded 13 kV transformer winding is a “local” source of fault current and does not contribute to the GPR. Thus, the maximum grid current is based on 3180 A.

$$I_G = D_f \cdot S_f \cdot 3 \cdot I_0 \tag{B.11}$$

$$I_G = (1)(0.6)(3180) = 1908\ \text{A}$$

Step 7: GPR. Now it is necessary to compare the product of I_G and R_g, or GPR, to the tolerable touch voltage, $E_{touch70}$

$$GPR = I_G \cdot R_g \tag{B.12}$$

$$GPR = 1908 \cdot 2.78 = 5304\ \text{V}$$

which far exceeds 838 V, determined in Step 3 as the safe value of $E_{touch70}$. Therefore, further design evaluations are necessary.

Step 8: Mesh voltage. Using Equation (81) through Equation (83), K_m is computed

$$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\left[\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 + h)^2}{8 \cdot D \cdot h} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]\right] \tag{B.13}$$

where

$$K_{ii} = \frac{1}{(2 \cdot n)^{\frac{2}{n}}} \tag{B.14}$$

$$K_{ii} = \frac{1}{(2 \cdot 11)^{2/11}} = 0.57$$

and

$$K_h = \sqrt{1 + \frac{h}{h_0}} \tag{B.15}$$

$$K_h = \sqrt{1 + \frac{0.5}{1.0}} = 1.225$$

$$K_m = \frac{1}{2\pi} \cdot \left[\ln\left[\frac{7^2}{16 \cdot 0.5 \cdot 0.01} + \frac{(7 + 2 \cdot 0.5)^2}{8 \cdot 7 \cdot 0.01} - \frac{0.5}{4 \cdot 0.01}\right] + \frac{0.57}{1.225}\ln\left[\frac{8}{\pi(2 \cdot 11 - 1)}\right]\right]$$

The factor K_i is computed using Equation (84) through Equation (89)

$$K_i = 0.644 + 0.148 \cdot n \qquad \text{(B.16)}$$

where

$$n = n_a \cdot n_b \cdot n_c \cdot n_d \qquad \text{(B.17)}$$

$$n_a = \frac{2 \cdot L_C}{L_P} \qquad \text{(B.18)}$$

$$n_a = \frac{2 \cdot 1540}{280}$$

$n_b = 1$ for square grid
$n_c = 1$ for square grid
$n_d = 1$ for square grid

and

$$n = 11 \cdot 1 \cdot 1 \cdot 1 = 11$$

$$K_i = 0.644 + 0.148 \cdot 11 = 2.272$$

Finally, E_m is computed using Equation (80) and Equation (90)

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + L_R} \qquad \text{(B.19)}$$

$$E_m = \frac{400 \cdot 1908 \cdot 0.89 \cdot 2.272}{1540} = 1002.1 \text{ V}$$

Step 9: E_m vs. E_{touch}. The mesh voltage is higher than the tolerable touch voltage (that is, 1002.1 V versus 838.2 V). The grid design must be modified.

For comparison, the EPRI TR-100622 [B63] computer program resulted in 2.67 Ω and 984.3 V for the grid resistance and touch voltage, respectively, for this example.

B.2 Square grid with ground rods—Example 2

In the previous example, B.1, Step 10 of the design procedure has not been reached due to the failure to meet the criterion of Step 9. Generally, there are two approaches to modifying the grid design to meet the tolerable touch voltage requirements

a) Reduce the GPR to a value below the tolerable touch voltage or to a value low enough to result in a value of E_m below the tolerable touch voltage.
b) Reduce the available ground fault current.

Usually reduction of the available ground fault current is difficult or impractical to achieve, so the grid is modified by changing any or all of the following: grid conductor spacing, total conductor length, grid depth, addition of ground rods, etc. In this example, the preliminary design will be modified to include 20 ground rods, each 7.5 m (24.6 ft) long, around the perimeter of the grid, as shown in Figure B.2.

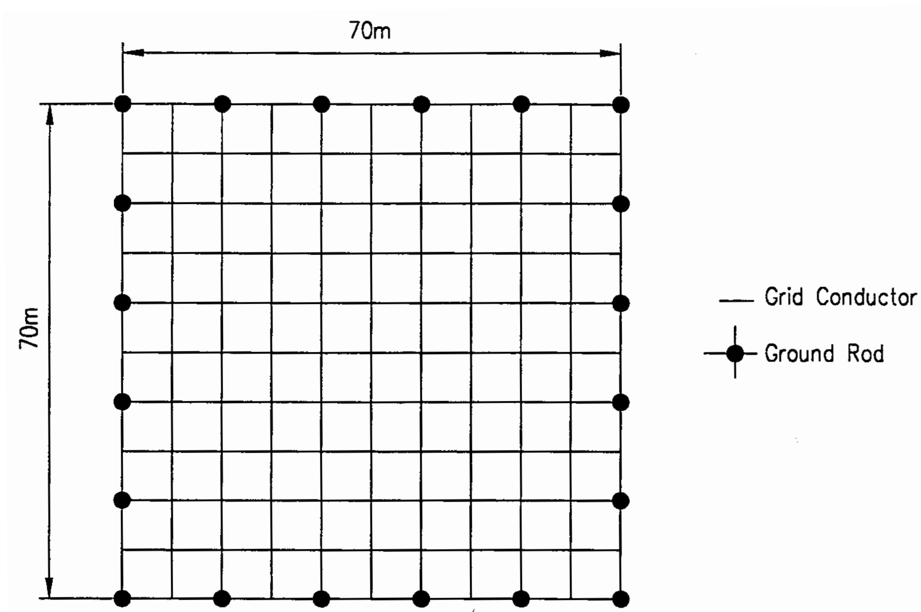


Figure B.2—Square grid with 20 7.5 m rods

Step 5. Using Equation (52) for $L_T = 1540 + 20 \cdot 7.5 = 1690$ m, and $A = 4900$ m^2 yields the following value of grid resistance R_g:

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right] \quad \text{(B.20)}$$

$$R_g = 400\left[\frac{1}{1690} + \frac{1}{\sqrt{20 \cdot 4900}}\left(1 + \frac{1}{1 + 0.5\sqrt{\frac{20}{4900}}}\right)\right] = 2.75\ \Omega$$

Steps 6 and 7. The revised GPR is (1908)(2.75) = 5247 V, which is still much greater than 838.2 V.

Step 8. Using Equation (81) and Equation (83), K_m is computed

$$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\left[\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 \cdot h)}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]\right] \quad \text{(B.21)}$$

where

K_{ii} = 1.0 with rods

and

$$K_h = \sqrt{1 + \frac{h}{h_0}} \quad \text{(B.22)}$$

$$K_h = \sqrt{1 + \frac{0.5}{1.0}} = 1.225$$

$$K_m = \frac{1}{2\pi}\left[\ln\left[\frac{7^2}{16 \cdot 0.5 \cdot 0.01} + \frac{(7 + 2 \cdot 0.5)^2}{8 \cdot 7 \cdot 0.01} - \frac{0.5}{4 \cdot 0.01}\right] + \frac{1.0}{1.225}\ln\left[\frac{8}{\pi(2 \cdot 11 - 1)}\right]\right] = 0.77$$

This time, E_m is computed using Equation (80) and Equation (91)

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + \left[1.55 + 1.22 \cdot \left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] \cdot L_R} \quad \text{(B.23)}$$

$$E_m = \frac{400 \cdot 1908 \cdot 0.77 \cdot 2.272}{1540 + \left[1.55 + 1.22\left(\frac{7.5}{\sqrt{70^2 + 70^2}}\right)\right]150} = 747.4 \text{ V}$$

Because the step voltage has not been calculated yet, Equation (89) and Equation (92) through Equation (94) are used to compute K_i, E_s, L_S, and K_s, respectively. Note that the value for K_i is still 2.272 (same as for mesh voltage).

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \cdot h} + \frac{1}{D + h} + \frac{1}{D}(1 - 0.5^{n-2})\right] \quad \text{(B.24)}$$

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \cdot 0.5} + \frac{1}{7 + 0.5} + \frac{1}{7}(1 - 0.5^{11-2})\right] = 0.406$$

Then

$$E_s = \frac{\rho \cdot I_G \cdot K_s \cdot K_i}{0.75 \cdot L_C + 0.85 \cdot L_R} \quad \text{(B.25)}$$

$$E_s = \frac{400 \cdot 1908 \cdot 0.406 \cdot 2.272}{0.75 \cdot 1540 + 0.85 \cdot 150} = 548.9 \text{ V}$$

Step 9: E_m vs. E_{touch}. Now the calculated corner mesh voltage is lower than the tolerable touch voltage (747.4 V versus 838.2 V), and we are ready to proceed to Step 10.

Step 10: E_s vs. E_{step}. The computed E_s is well below the tolerable step voltage determined in Step 3 of Example 1. That is, 548.9 V is much less than 2686.6 V.

Step 11: Modify design. Not necessary for this example.

Step 12: Detailed design. A safe design has been obtained. At this point, all equipment pigtails, additional ground rods for surge arresters, etc., should be added to complete the grid design details.

For comparison, the computer program of EPRI TR-100622 [B63] resulted in 2.52 Ω, 756.2 V and 459.1 V for the grid resistance, touch voltage and step voltage, respectively, for this example.

B.3 Rectangular grid with ground rods—Example 3

In this example the preliminary grid design will be reconciled in terms of the actual shape of the grounding area as an alternative design. Realizing that the full grounding area is only about 8% larger than that used in the previous calculations, most of the conclusions from Example 2 can be used for arriving at a suitable final design solution.

Choosing, again, spacing D = 7 m, for a rectangular 63 m × 84 m grid, the grid wire pattern is 10 × 13, and the grid conductor combined length is 13 × 63 m + 10 × 84 m = 1659 m. Assume the use of 38 ground rods, each 10 m long, as shown in Figure B.3.

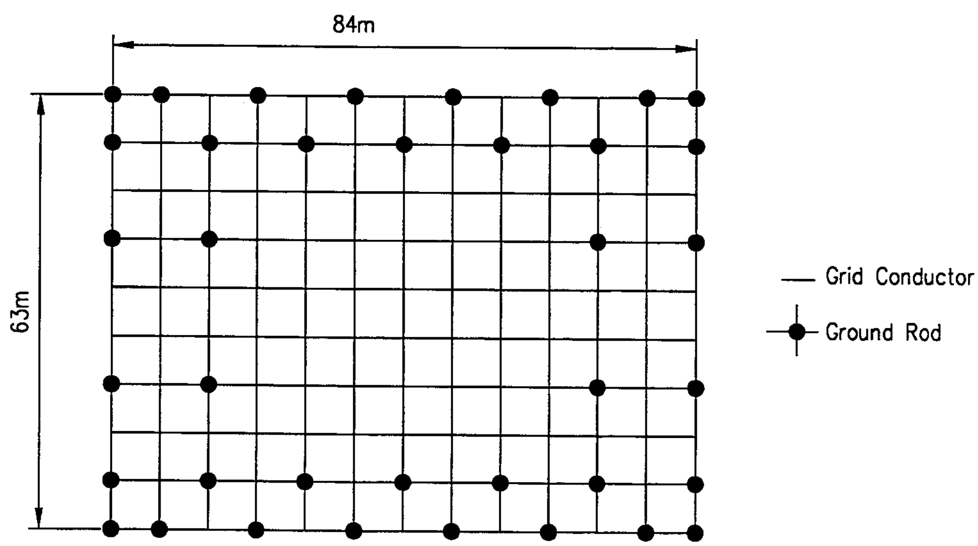


Figure B.3—Rectangular grid with thirty-eight 10 m ground rods

Step 5. Again, using Equation (52), but for L_T = 1659 m + (38)(10 m) = 2039 m and A = 63 m × 84 m = 5292 m^2, gives

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right] \tag{B.26}$$

$$R_g = 400\left[\frac{1}{2039} + \frac{1}{\sqrt{20 \cdot 5292}}\left(1 + \frac{1}{1 + 0.5\sqrt{20/5292}}\right)\right] = 2.62\ \Omega$$

Steps 6 and 7. Using I_G = 1908 A as before, and R_g = 2.62 Ω, the GPR = (1908)(2.62) = 4998.96 V, which is much greater than 838.2 V.

Step 8. For the particular design arrangement shown in Figure B.3, the equations of 16.5.1 can again be used to estimate the corner mesh voltage. However, because the grid is rectangular, the value of n to be used in the mesh voltage computation will be different, based on the factors determined using Equation (84) through Equation (88).

$$n = n_a \cdot n_b \cdot n_c \cdot n_d \qquad \text{(B.27)}$$

$$n_a = \frac{2 \cdot L_C}{L_p} \qquad \text{(B.28)}$$

$$n_a = \frac{2 \cdot 1659}{294} = 11.29$$

$$n_b = \sqrt{\frac{L_p}{4 \cdot \sqrt{A}}} \qquad \text{(B.29)}$$

$$n_b = \sqrt{\frac{294}{4 \cdot \sqrt{5292}}} = 1.005$$

n_c = 1 for rectangular grid

n_d = 1 for rectangular grid

$$n = 11.29 \cdot 1.005 \cdot 1 \cdot 1 = 11.35$$

Now K_m is computed using Equation (81) and Equation (83)

$$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\left[\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 \cdot h)}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]\right] \qquad \text{(B.30)}$$

where

$$K_{ii} = 1 \text{ for a grid with ground rods}$$

$$K_h = \sqrt{1 + \frac{0.5}{1.0}} = 1.225$$

$$K_m = \frac{1}{2\pi}\left[\ln\left[\frac{7^2}{16 \cdot 0.5 \cdot 0.01} + \frac{(7 + 2 \cdot 0.5)^2}{8 \cdot 7 \cdot 0.01} - \frac{0.5}{4 \cdot 0.01}\right] + \frac{1.0}{1.225}\ln\left[\frac{8}{\pi(2 \cdot 11.35 - 1)}\right]\right] = 0.77$$

Equation (89) is used to compute K_i

$$K_i = 0.644 + 0.148 \cdot n \tag{B.31}$$

$$K_i = 0.644 + 0.148 \cdot 11.35 = 2.324$$

Finally, E_m is computed using Equation (80) and Equation (91)

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + \left[1.55 + 1.22 \cdot \left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] \cdot L_R} \tag{B.32}$$

$$E_m = \frac{400 \cdot 1908 \cdot 0.77 \cdot 2.324}{1659 + \left[1.55 + 1.22\left(\frac{10}{\sqrt{63^2 + 84^2}}\right)\right]380} = 595.8 \text{ V}$$

Step 9. This calculated mesh voltage is well below the $E_{touch70}$ limit of 838.2, but uses 119 m of additional conductor and 230 m of additional ground rods, as compared with the previous example. Thus, the mesh spacing could be reduced, the number and/or length of ground rods could be reduced, or both to achieve the same margin of safety as example 2.

The remaining steps are the same as demonstrated in example 2 and will not be repeated here.

For comparison, the computer program of EPRI TR-100622 [B63] resulted in 2.28 Ω, 519.4 V and 349.7 V for the grid resistance, touch voltage, and step voltage, respectively, for this example.

B.4 L-shaped grid with ground rods—Example 4

In this example the design of Example 2 is modified to illustrate the use of the equations for an L-shaped grid with ground rods. The total area and mesh spacing are the same as that of Example 2, and the ground rods are located only around the perimeter of the grid, as shown in Figure B.4. All other parameters are the same as Example 2, except the number of rods (24). Thus, Steps 1–4 are the same as example 2, and this example begins with Step 5.

Step 5. Using Equation (52) for L_T = 1575 m + (24)(7.5 m) = 1755 m and A = 4900 m^2, gives

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right] \tag{B.33}$$

$$R_g = 400\left[\frac{1}{1755} + \frac{1}{\sqrt{20 \cdot 4900}}\left(1 + \frac{1}{1 + 0.5\sqrt{20/4900}}\right)\right] = 2.74 \ \Omega$$

Steps 6 and 7. The revised GPR is (1908)(2.74) = 5228 V, which is much greater than the tolerable touch voltage of 838.2 V.

Step 8. Using Equation (84) through Equation (88), and Equation (81) and Equation (89), n, K_m, and K_i are computed

$$n = n_a = n_b \cdot n_c \cdot n_d \tag{B.34}$$

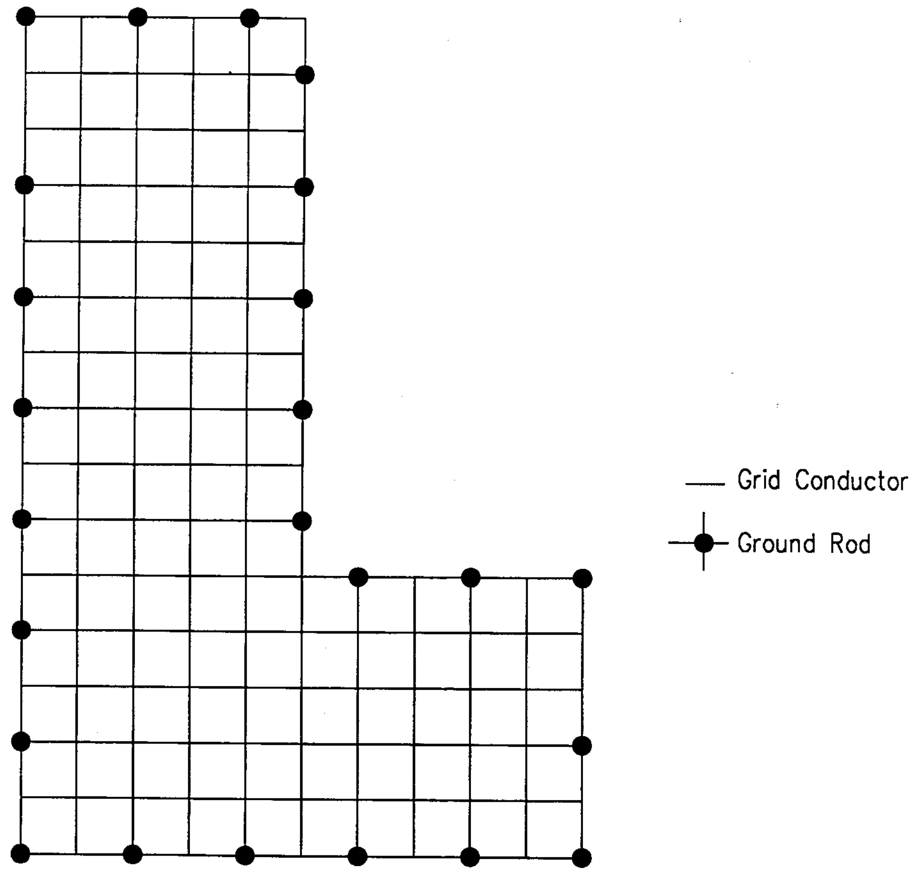


Figure B.4—L-shaped grid with 24 7.5 ground rods

$$n_a = \frac{2 \cdot L_C}{L_p} \tag{B.35}$$

$$n_a = \frac{2 \cdot 1575}{350} = 9$$

$$n_b = \sqrt{\frac{L_p}{4 \cdot \sqrt{A}}} \tag{B.36}$$

$$n_b = \sqrt{\frac{350}{4 \cdot \sqrt{4900}}} = 1.12$$

$$n_c = \left[\frac{L_x \cdot L_y}{A}\right]^{\frac{0.7 \cdot A}{L_x \cdot L_y}} \tag{B.37}$$

$$n_c = \left[\frac{70 \cdot 105}{4900}\right]^{\frac{0.7(4900)}{70(105)}} = 1.21$$

$n_d = 1$ for L-shaped grid

$n = (9)(1.12)(1.21)(1) = 12.2$

Now K_m is computed using Equation (81) and Equation (83)

$K_{ii} = 1$

$$K_h = \sqrt{1 + \frac{0.5}{1.0}} = 1.225$$

$$K_m = \frac{1}{2 \cdot \pi}\left[\ln\left[\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 \cdot h)^2}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]\right] \quad \text{(B.38)}$$

$$K_m = \frac{1}{2\pi}\left[\ln\left[\frac{7^2}{16(0.5)0.01} + \frac{(7 + 2(0.5))^2}{8(7)0.01} - \frac{0.5}{4(0.01)}\right] + \frac{1.0}{1.225} \cdot \ln\left[\frac{8}{\pi(2(12.2) - 1)}\right]\right] = 0.76$$

Equation (89) is used to compute K_i

$$K_i = 0.644 + 0.148 \cdot n \quad \text{(B.39)}$$

$$K_i = 0.644 + 0.148(12.2) = 2.45$$

Finally, E_m is computed using Equation (81) and Equation (91)

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + \left[1.55 + 1.22 \cdot i\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] \cdot L_R} \quad \text{(B.40)}$$

$$E_m = \frac{(400)(1908)(0.76)(2.45)}{1575 + \left[1.55 + 1.22\left(\frac{7.5}{\sqrt{70^2 + 105^2}}\right)\right]180} = 761.1 \text{ V}$$

Equation (92) through Equation (94) are used to compute E_s, L_s and K_s, respectively. It should be noted that the value for K_i is still 2.45 (same as for mesh voltage).

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \cdot h} + \frac{1}{D + h} + \frac{1}{D}(1 - 0.5^{n-2})\right] \quad \text{(B.41)}$$

$$K_s = \frac{1}{\pi}\left[\frac{1}{2(0.5)} + \frac{1}{7 + 0.5} + \frac{1}{7}(1 - 0.5^{12.2-2})\right] = 0.41$$

Then

$$E_s = \frac{\rho \cdot I_G \cdot K_s \cdot K_i}{0.75 \cdot L_C + 0.85 \cdot L_R} \quad \text{(B.42)}$$

$$E_s = \frac{(400)(1908)(0.41)(2.45)}{0.75(1575) + 0.85(180)} = 574.6 \text{ V}$$

Step 9. Note that this is close to the results of Example 2, and is lower than the tolerable $E_{touch70}$ limit of 838.2 V. Proceed to Step 10.

Step 10. The computed E_s is well below the tolerable step voltage determined in Step 3 of example 1. That is, 574.6 V is much less than 2686.6 V.

Step 11. Not required for this example.

Step 12. A safe design has been obtained and final details can now be added to the design.

For comparison, a computer program of EPRI TR-100622 [B63] gives results of 2.34 Ω, 742.9 V and 441.8 V for the grid resistance, touch voltage, and step voltage, respectively, for this example.

B.5 Equally spaced grid with ground rods in two-layer soil—exhibit 1

Using the computer program of EPRI TR-100622 [B63], an equally spaced grid in two-layer soil was modeled.

As shown in Figure B.5, the 61 m × 61 m (200 ft × 200 ft) grid consisted of four meshes per side, and had nine ground rods, each 9.2 m (30 ft) long. The diameter of ground rods was 0.0127 m (0.5 in). The grid consisted of four meshes per side, formed by wires of a 0.01 m diameter, buried 0.5 m below the earth's surface. The depth of the upper layer 300 Ω·m soil was 4.6 m (15 ft); the lower soil had resistivity of 100 Ω·m.

The computer-calculated values of resistance, corner mesh voltage, and maximum step voltage, are as follows:

R_g = 1.353 Ω E_m = 49.66% of GPR E_s = 18.33% of GPR

As can be determined from Figure B.6, the mesh voltage coordinates were X = –75.00 ft, and Y= –75.00 ft, that is, near the center of the corner mesh. The maximum step voltage (not shown) was calculated outside the grid, between the grid corner (X, Y = –100 ft) and the point at X, Y = –102.12 ft, that is, approximately over 1 m distance in a diagonal direction away from the grid corner.

B.6 Unequally spaced grid with ground rods in uniform soil—exhibit 2

Using the computer program of EPRI TR-100622 [B63], a square grid with unequally spaced conductors was modeled as shown in Figure B.7.

The computer output included the grid resistance, a surface voltage profile, the step voltage, and the corner mesh voltage.

As shown in Figure B.8, the corner mesh voltage is only 9.29% of the GPR, while the maximum touch voltage, occurring above the largest interior mesh, is 17.08% of the GPR.

The maximum touch voltage, thus, did not occur in the corner mesh. For other choices of conductor spacings, the maximum touch voltage may occur above some other meshes. Therefore, for unequal spacings, the touch voltages must be investigated over the entire grid, and the simplified criterion for checking the corner mesh voltage alone is not sufficient. On the other hand, the resistance R_g is not too dependent on the exact configuration of grid conductors and ground rods. For instance, were R_g estimated by equation (54) for a combined length of grid conductors and ground rods L_T = 18 × 91.44 m + 25 × 9.2 m = 1876 m, the calculated value of 1.61 Ω would be less than 14% higher than the value of 1.416 Ω calculated by the computer program of EPRI TR-100622 [B63].

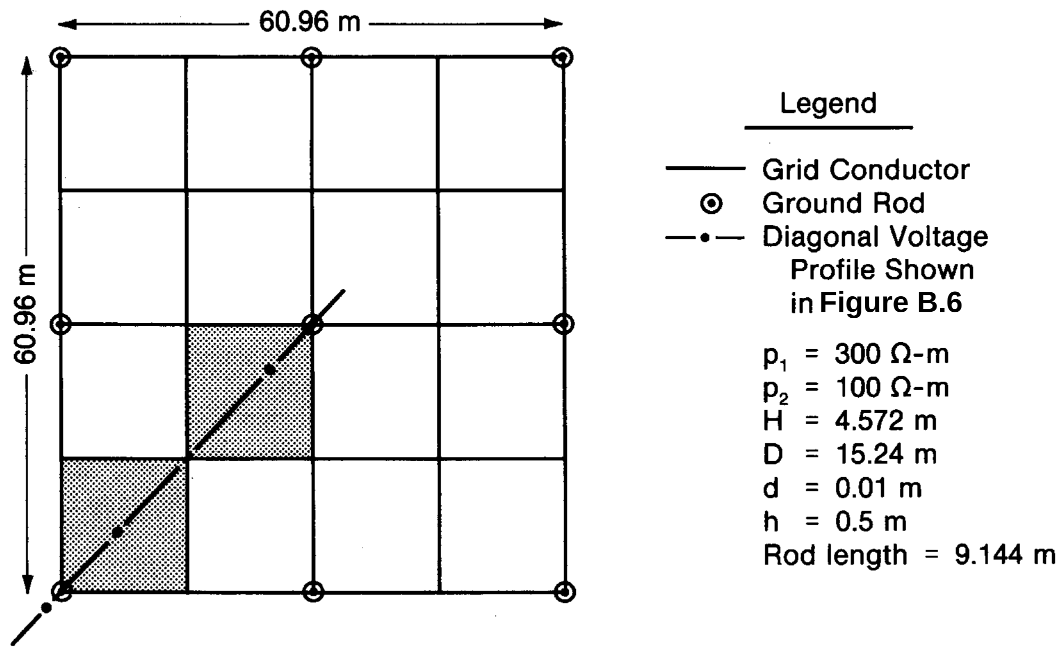


Figure B.5—Equally spaced square grid with nine rods in two-layer soil

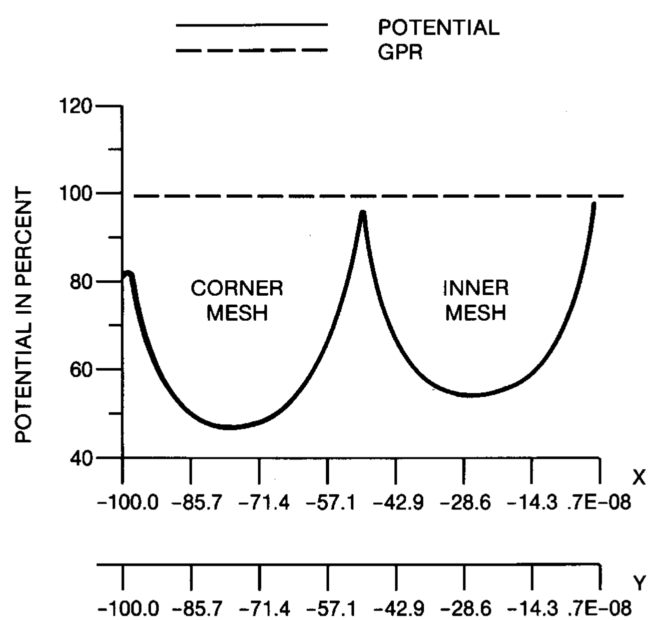


Figure B.6—Diagonal voltage profile for the grid of Figure B.5 in two-layer soil

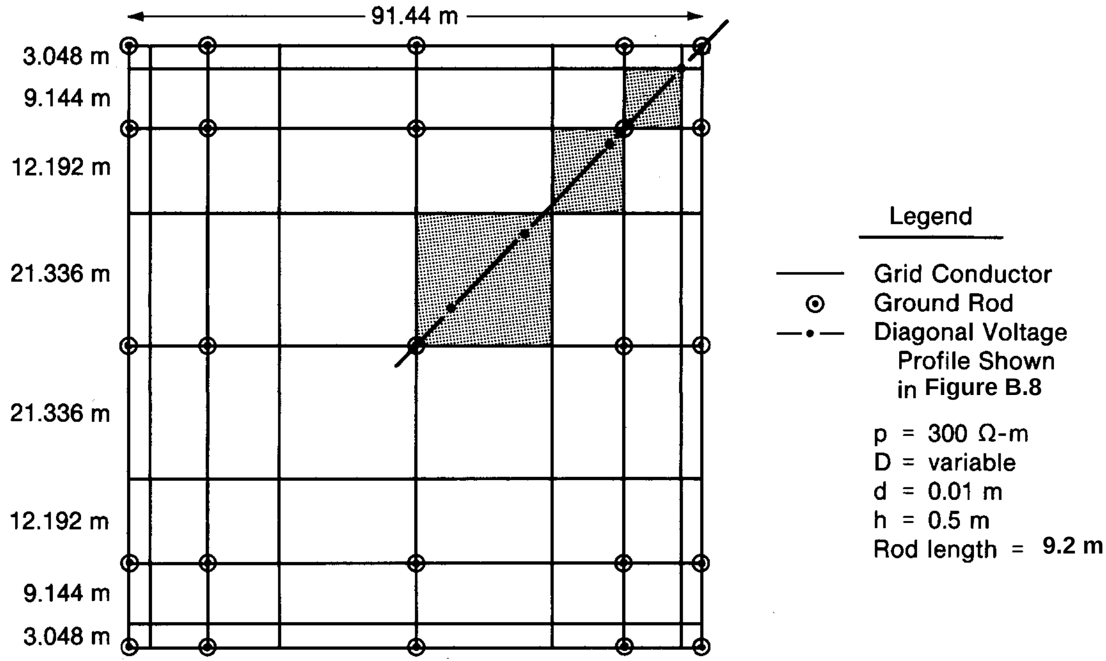


Figure B.7—Unequally spaced square grid with twenty-five 9.2 m rods

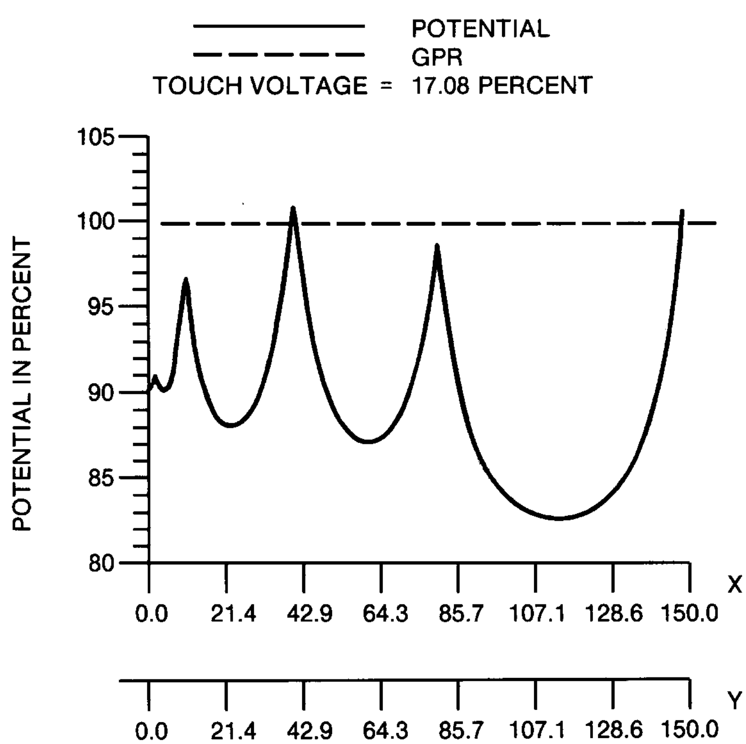


Figure B.8—Diagonal voltage profile for an unequally spaced grid of Figure B.7

Annex C

(informative)

Graphical and approximate analysis of current division

C.1 Introduction

A graphical method for determining the maximum grid current, based on results obtained using a computer program of EPRI TR-100622 [B63] has been developed. This method attempts to correlate the substation zero sequence fault obtained from a standard short circuit study to the actual current flowing between the grounding system and surrounding earth. The original presentation of this concept was published in Garret, Myers, and Patel [B73]. That paper describes the parametric analysis performed and the resulting basis for the assumptions used to develop the curves. Additional curves have since been developed to address other system configurations. The following is an explanation of the use of the graphs shown in Figure C.1 through Figure C.22.

The graphs are divided into the following four categories:

- — Category A: 100% remote and 0% local fault current contribution, representing typical distribution substations with delta-wye transformer, with X transmission lines and Y feeders (Figure C.1 through Figure C.16)
- — Category B: 75% remote and 25% local ground fault current contribution (Figure C.17 and Figure C.18)
- — Category C: 50% remote and 50% local ground fault current contribution (Figure C.19 and Figure C.20)
- — Category D: 25% remote and 75% local ground fault current contribution (Figure C.21 and Figure C.22)

Categories B–D represent typical transmission substations or generating plants with X transmission lines (feeders are considered to be transmission lines in these cases), and with local sources of zero sequence current, such as auto transformers, three winding transformers, generators (grounded-wye GSUs), etc. Category A works well for practical cases. Categories B–D are rough approximations, and the accuracy depends on several system parameters (particularly the source of the local ground fault current).

The following assumptions were used to obtain the graphs:

a) Transmission line length of 23.5 mi (37.82 km) and a distance between grounds of 500 ft (152 m).

b) Transmission tower footing resistance of 15 or 100 Ω.

c) Transmission line structure single pole with 1–7#10 alumoweld shield wire and 336.4 kcmil, 26/7 ACSR conductor.

d) Distribution line length of 2.5 mi (4 km) and a distance between grounds of 400 ft (122 m).

e) Distribution pole footing resistance of 25 Ω or 200 Ω.

f) Distribution pole three-phase triangular layout, with one 336.4 kcmil, 26/7 ACSR phase and 1/0 ACSR neutral conductor.

g) Soil resistivity of 100 Ω·m.

h) Substation grounding system resistances of 0.1 Ω, 0.5 Ω, 1.0 Ω, 5.0 Ω,10.0 Ω, and 25.0 Ω.

i) Number of transmission lines varied from 0, 1, 2, 4, 8, 12, and 16.

j) Number of distribution lines varied from 0, 1, 2, 4, 8, 12, and 16.

k) One remote source for each two transmission lines.

C.2 How to use the graphs and equivalent impedance table

Referring to Figure C.1 through Figure C.22, a family of curves is plotted, with each curve representing a different number of transmission lines or distribution feeders. The abscissa is a range of grounding system resistances from 0.1 Ω to 25.0 Ω. The ordinate is the percent of the total zero sequence substation bus ground fault current which flows between the grounding system and surrounding earth (i.e., the grid current I_g).

When using Category A curves and Table C.1, only the delta-connected bus fault current should be used as the multiplier of the split factor, because this fault current is the one that is from remote sources and is the basis of these curves. When using Category B–D curves, the fault current and contributions should be determined for all transmission voltage levels and the case resulting in the highest grid current should be used.

Table C.1 shows the equivalent transmission and distribution ground system impedance at 1 Ω for 100% remote contribution with X transmission lines and Y distribution feeders. The first column of impedances is for transmission line ground electrode resistance R_{tg} of 15 Ω and distribution feeder ground electrode resistance R_{dg} of 25 Ω. The second column of impedances is for R_{tg} of 100 Ω and R_{dg} of 200 Ω. To determine the GPR with current splits, parallel the grid resistance with the appropriate impedance from the table and multiply this value by the total fault current. For example, a substation with one transmission line and two distribution feeders has a ground grid resistance of 5 Ω, a total fault current of 1600 A, R_{tg} of 15 Ω, and R_{dg} of 25 *W*. From Table C.1, the equivalent impedance of the transmission and distribution ground system is 0.54 +*j*0.33 Ω. The magnitude of the equivalent total ground impedance is

$$|Z_g| = \left|\frac{(5.0)(0.54 + j0.33)}{5.0 + 0.54 + j0.33}\right| = 0.57\Omega$$

and the GPR is

$$GPR = (0.57)(1600) = 912\text{ V}$$

To calculate the grid current, divide the GPR by the ground grid resistance.

$$I_g = \frac{912}{5} = 182\text{ A}$$

The grid current may also be computed directly by current division.

$$|I_g| = 1600 \cdot \left|\frac{(0.54 + j0.33)}{5.0 + 0.54 + j0.33}\right| = 182\text{ A}$$

C.3 Examples

To illustrate the use of the graphical analysis, consider a substation with two transmission lines and three distribution feeders, and a ground grid resistance of 1 Ω, as shown in Figure C.23. Using EPRI TR-100622 [B63], the maximum grid current is 2354.6 A, with the total bus ground fault is 9148.7 A. The system in question has two transmission lines with R_{tg} of 15 Ω and R_{dg} of 25 Ω. Figure C.3 shows curves for two lines/

two feeders and two lines/four feeders. Thus, interpolation is necessary for this example. From Figure C.3, we see that the approximate split factor S_f is (32+23)/2 or 27.5%. The maximum grid current is

$$I_g = (9148.7)(0.275) = 2516 \text{ A}$$

Using Table C.1, the equivalent impedance of the transmission and distribution ground system for two lines and two distribution feeders is 0.455 + *j*0.241 W, and for two lines and four distribution feeders is 0.27 + *j*0.165 Ω. The average of the split factors for these two cases will be used.

$$S_f = \left|\frac{0.455 + j0.241}{1.0 + 0.455 + j0.241}\right| = 0.349$$

$$S_f = \left|\frac{0.27 + j0.165)}{1.0 + 0.27 + j0.165}\right| = 0.247$$

Thus, S_f = (0.349 +0.247)/2 = 0.298 or 29.8%

The resulting grid current using this method is

$$I_g = (9148.7)(0.298) = 2726$$

Both methods compare favorably with the value of 2354.6 A or 26% of $3I_0$ from the computer program, though the equivalent impedance method is generally more conservative.

Next consider the more complex system shown in Figure C.24. This example is similar to the first, except that the distribution substation is replaced with a local source of generation, such as a cogeneration plant. For this example, there is both local and remote sources of ground fault current, so the percent of local vs. remote ground fault current contribution must be computed. The computer program of EPRI TR-100622 [B63] computed a total fault current of 19 269.6 A at the 115kV bus, with 48.7% contributed by the local source and 51.3% contributed by the remote sources. The closest curves are for 50/50 split (Figure C.19). For a grid resistance of 0.9 Ω, the split factor is determined from the curve for two lines and no feeders $-S_f$ = 29%. The maximum grid current is

$$I_g = (19\,269.6)(0.29) = 5588 \text{ A}$$

For this case, the computer program results in a value of 4034.8 A, or 21% of $3I_0$. This does not compare as well as the case with 100% remote contribution, but is still closer than using the total fault current, or even the remote or local contribution. The equivalent impedance method (Table C.1) does not work as well for cases other than 100% remote contribution, and is not included in Table C.1.

C.4 Equations for computing line impedances

The following equations are found in the ABB T&D Reference Book, Fourth Edition [B1]. The definitions of the terms used in the equations are

GMD	is the geometric mean distance between the phase conductors in ft
GMR	is the geometric mean radius of the conductor in ft
d_{ab}	is the distance between conductors a and b in ft
r_a	is the ac resistance of the conductor at frequency f
x_a	is the inductive reactance of the conductor to one foot spacing at frequency f

f	is the frequency in Hz
D_e	is the equivalent depth of earth return in ft
r	is the soil resistivity in Ω·m

The positive sequence impedance, Z_1, of a transmission line (with earth return), ignoring the effects of overhead shield wires, is

$$Z_1 = r_a + jx_a + jx_d \;\; \Omega/\text{mi} \tag{C.1}$$

where

$$x_a = 0.2794 \cdot \log_{10}\frac{1}{GMR}$$

and

$$GMD = 0.2794 \cdot \frac{f}{60} \cdot \log_{10}\sqrt[3]{d_{ab} \cdot d_{bc} \cdot d_{ca}}$$

The zero sequence self impedance, $Z_{0(a)}$, of the transmission line (with earth return), with no overhead shield wires is

$$Z_{0(a)} = r_a + r_e + jx_a + jx_e - 2 \cdot x_d \;\; \Omega/\text{mi} \tag{C.2}$$

where

$$r_e = 0.00477 \cdot f$$

and

$$x_e = 0.006985 \cdot f \cdot \log_{10}\left(4.6655 \cdot 10^6 \cdot \frac{\rho}{f}\right)$$

and r_a, x_a, and x_d are as defined above using characteristics of the phase conductors.

The zero sequence self impedance, $Z_{0(g)}$, of one overhead shield wire (with earth return) is

$$Z_{0(g)} = 3 \cdot r_a + r_e + j3 \cdot x_a + jx_e \;\; \Omega/\text{mi} \tag{C.3}$$

where r_a and x_a are as defined above using characteristics of the overhead shield wire, and r_e and x_e are as defined above.

The zero sequence self impedance, $Z_{0(g)}$, of two overhead shield wires (with earth return) is

$$Z_{0(g)} = \frac{3}{2} \cdot r_a + r_e + j\frac{3}{2} \cdot x_a + jx_e - j\frac{3}{2} \cdot x_d \;\; \Omega/\text{mi} \tag{C.4}$$

where

$$x_d = 0.2794 \cdot \frac{f}{60} \cdot \log_{10}d_{xy}$$

d_{xy} is the distance between the two overhead shield wires, r_a and x_a are as defined above using characteristics of the overhead shield wire, and r_e and x_e are as defined above.

The zero sequence mutual impedance, $Z_{0(ag)}$ between one circuit and n shield wires (with earth return) is

$$Z_{0(ag)} = r_e + jx_e - j3 \cdot x_d \quad \Omega/\text{mi} \tag{C.5}$$

where

$$x_d = 0.2794 \cdot \frac{f}{60} \cdot \log_{10}\left(\sqrt[3-n]{d_{ag1} \cdot d_{bg1} \cdot d_{cg1} \ldots d_{agn} \cdot d_{bgn} \cdot d_{cgn}}\right)$$

d_{ag1} is the distance between phase *a* and the first overhead shield wire, etc., and r_e and x_e are as defined above.

Then, the zero sequence impedance of one circuit with *n* shield wires (and earth return) is

$$Z_0 = Z_{0(a)} - \frac{Z_{0(ag)}^2}{Z_{0(g)}} \Omega/\text{mi} \tag{C.6}$$

These equations for Z_1 and Z_0 are used, along with appropriate impedances for transformers, generators, etc., to compute the equivalent fault impedance.

To compute the impedance of an overhead shield wire or feeder neutral for use in Endrenyi's formula, the simple self impedance (with earth return) of the conductor is used.

$$Z_s = r_c + \frac{r_e}{3} + jx_a + j\frac{x_e}{3} \quad \Omega/\text{mi} \tag{C.7}$$

where

r_a and x_a are as defined above using characteristics of the overhead shield wire or feeder neutral, and r_e and x_e are as defined above.

Table C.1—Approximate equivalent impedances of transmission line overhead shield wires and distribution feeder neutrals

Number of transmission lines	Number of distribution neutrals	R_{tg} = 15; R_{dg} = 25; $R + jx$ (Ω)	R_{tg} = 15; R_{dg} = 25; $R + jx$ (Ω)
1	1	0.91 + *j*.485	3.27 + *j*.652
1	2	0.54 + *j*0.33	2.18 + *j*.412
1	4	0.295 + *j*0.20	1.32 + *j*.244
1	8	0.15 + *j*0.11	0.732 + *j*.133
1	12	0.10 + *j*.076	0.507 + *j*.091
1	16	0.079 + *j*.057	0.387 + *j*.069
2	1	0.685 + *j*.302	2.18 + *j*.442
2	2	0.455 + *j*.241	1.63 + *j*.324
2	4	0.27 + *j*.165	1.09 + *j*.208
2	8	0.15 + *j*0.10	0.685 + *j*.122
2	12	0.10 + *j*0.07	0.47 + *j*.087
2	16	0.08 + *j*.055	0.366 + *j*.067
4	1	0.45 + *j*0.16	1.30 + *j*.273
4	2	0.34 + *j*0.15	1.09 + *j*0.22
4	4	0.23 + *j*0.12	0.817 + *j*0.16
4	8	0.134 + *j*.083	0.546 + *j*.103
4	12	0.095 + *j*.061	0.41 + *j*.077
4	16	0.073 + *j*0.05	0.329 + *j*0.06
8	1	0.27 + *j*0.08	0.72 + *j*.152
8	2	0.23 + *j*0.08	0.65 + *j*.134
8	4	0.17 + *j*.076	0.543 + *j*0.11
8	8	0.114 + *j*.061	0.408 + *j*.079
8	12	0.085 + *j*.049	0.327 + *j*.064
8	16	0.067 + *j*.041	0.273 + *j*.052
12	1	0.191 + *j*.054	0.498 + *j*.106

Table C.1—Approximate equivalent impedances of transmission line overhead shield wires and distribution feeder neutrals (continued)

Number of transmission lines	Number of distribution neutrals	$R_{tg} = 15$; $R_{dg} = 25$; $R + jx$ (Ω)	$R_{tg} = 15$; $R_{dg} = 25$; $R + jx$ (Ω)
12	2	0.17 + *j*.055	.462 + *j*.097
12	4	0.14 + *j*.053	.406 + *j*.083
12	8	.098 + *j*.047	.326 + *j*.066
12	12	.077 + *j*.041	.272 + *j*.053
12	16	.062 + *j*.035	.234 + *j*.046
16	1	.148 + *j*0.04	.380 + *j*.082
16	2	.135 + *j*.041	.360 + *j*.076
16	4	.113 + *j*.041	.325 + *j*.067
16	8	.086 + *j*.038	.272 + *j*.055
16	12	.068 + *j*.034	.233 + *j*.047
16	16	.057 + *j*0.03	.203 + *j*.040
1	0	2.64 + *j*0.60	6.44 + *j*1.37
2	0	1.30 + *j*0.29	3.23 + *j*0.70
4	0	.65 + *j*.15	1.61 + *j*.348
8	0	.327 + *j*.074	.808 + *j*.175
12	0	0.22 + *j*.049	.539 + *j*.117
16	0	.163 + *j*.037	.403 + *j*.087
0	1	1.29 + *j*.967	6.57 + *j*1.17
0	2	.643 + *j*.484	3.29 + *j*0.58
0	4	.322 + *j*.242	1.65 + *j*.291
0	8	.161 + *j*.121	.826 + *j*.148
0	12	.108 + *j*.081	.549 + *j*.099
0	16	.080 + *j*.061	.412 + *j*.074

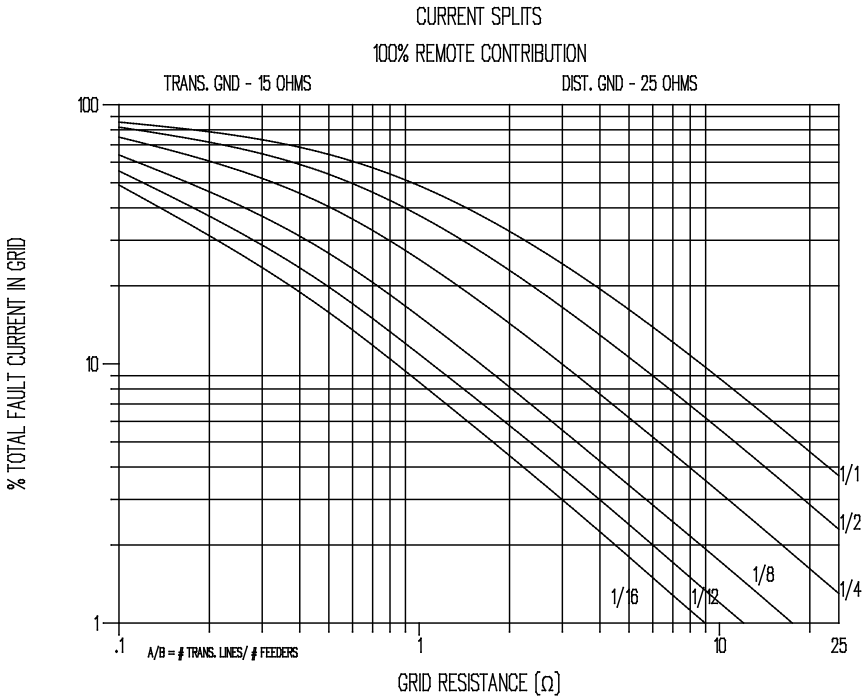


Figure C.1—Curves to approximate split factor S_f

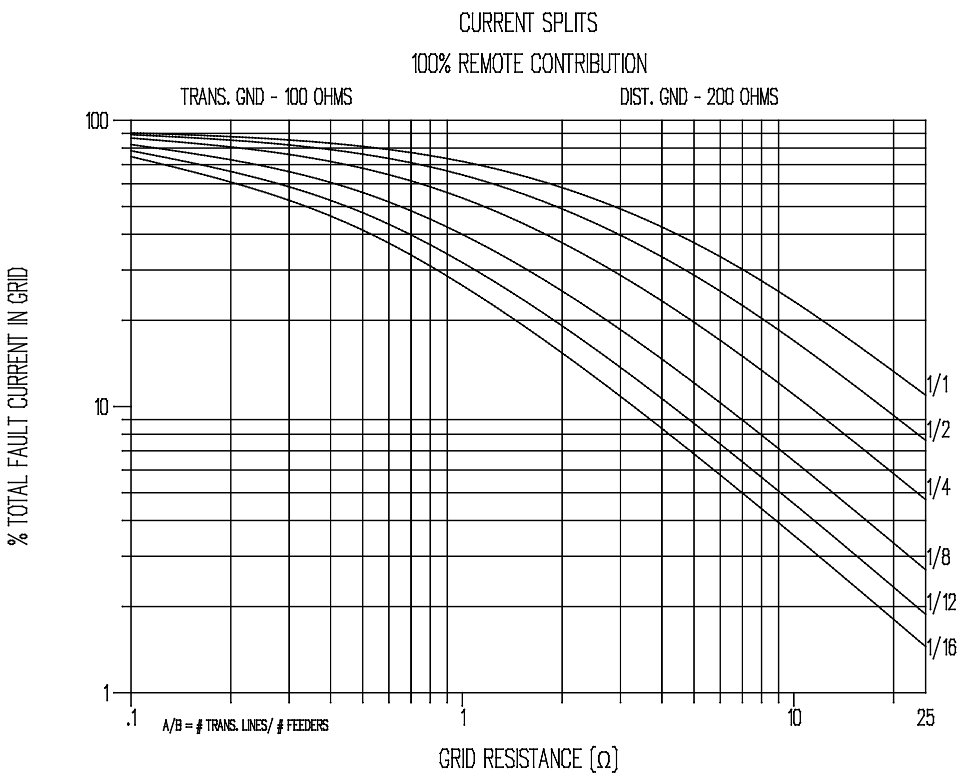


Figure C.2—Curves to approximate split factor S_f

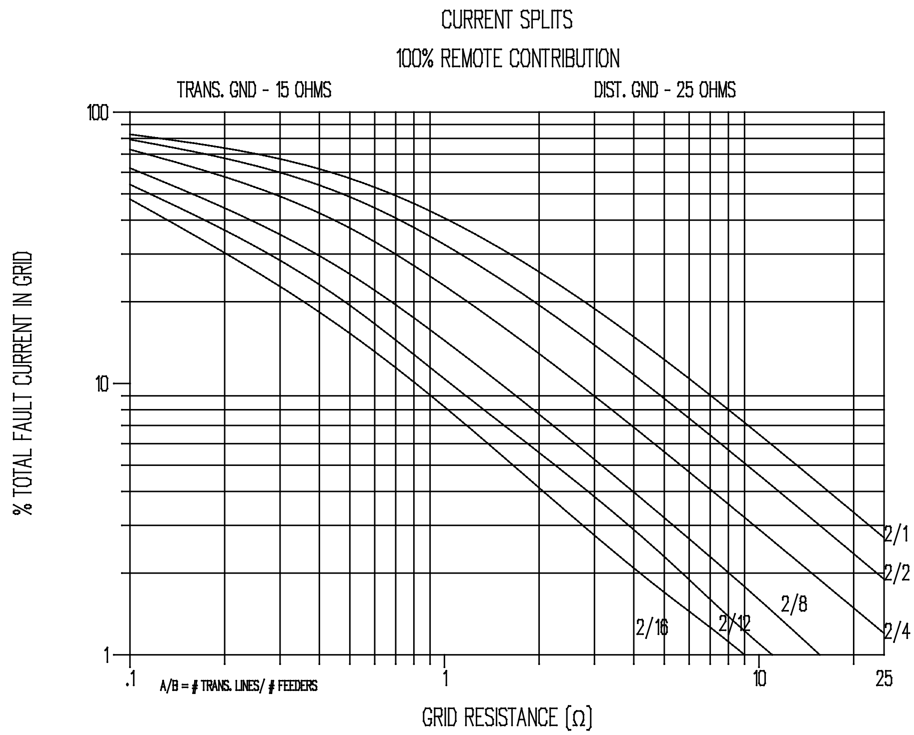


Figure C.3—Curves to approximate split factor S_f

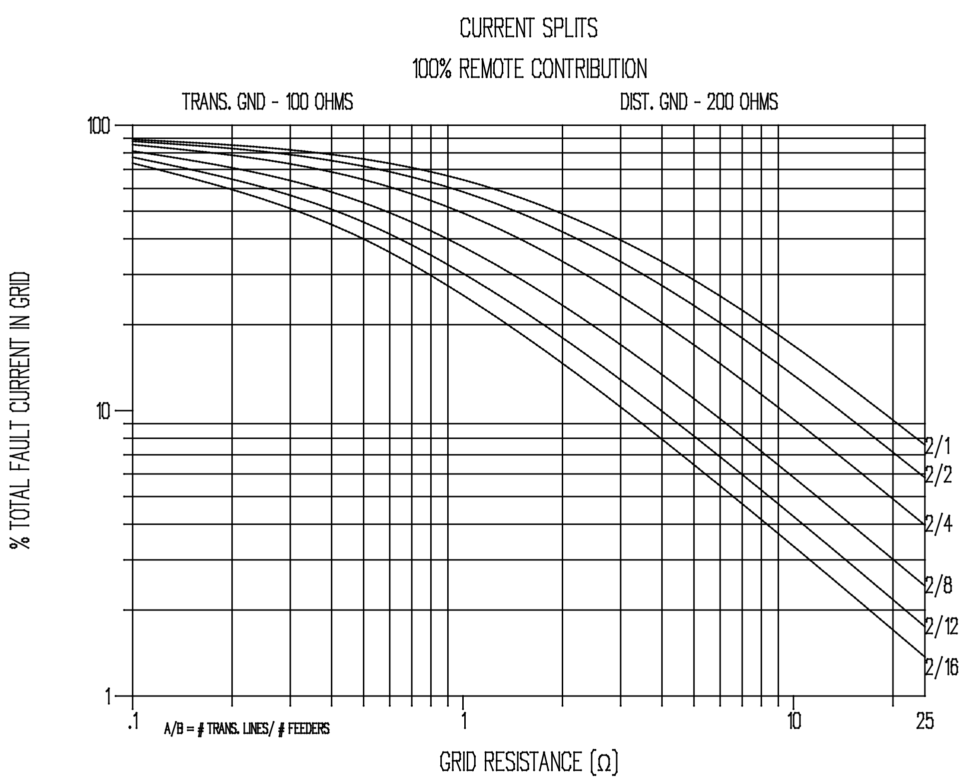


Figure C.4—Curves to approximate split factor S_f

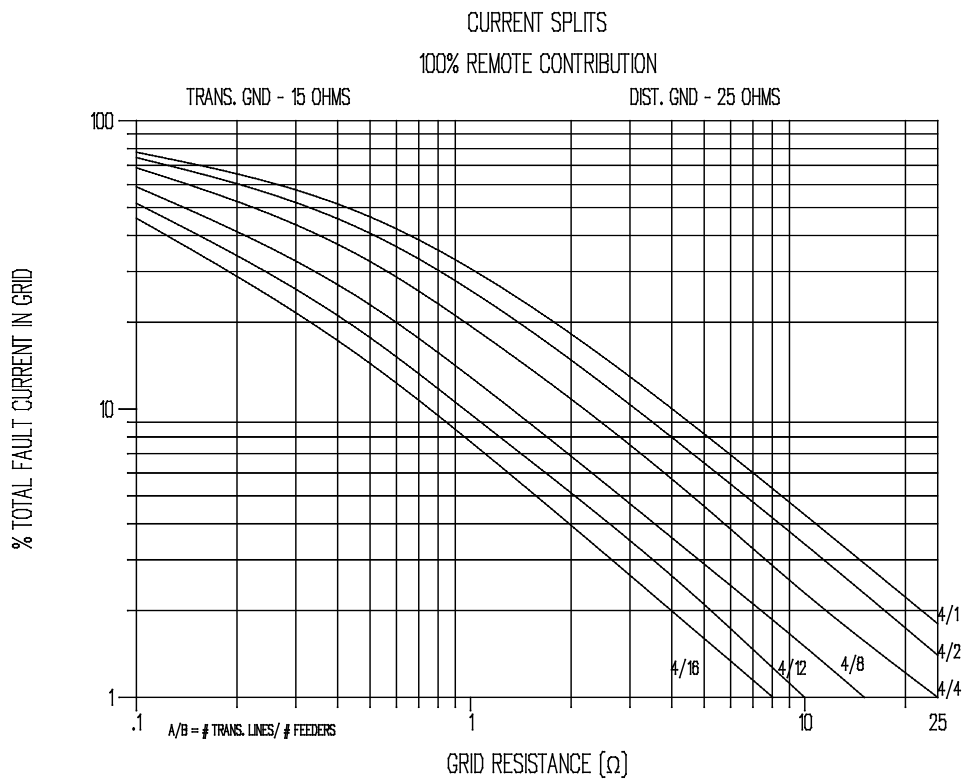


Figure C.5—Curves to approximate split factor S_f

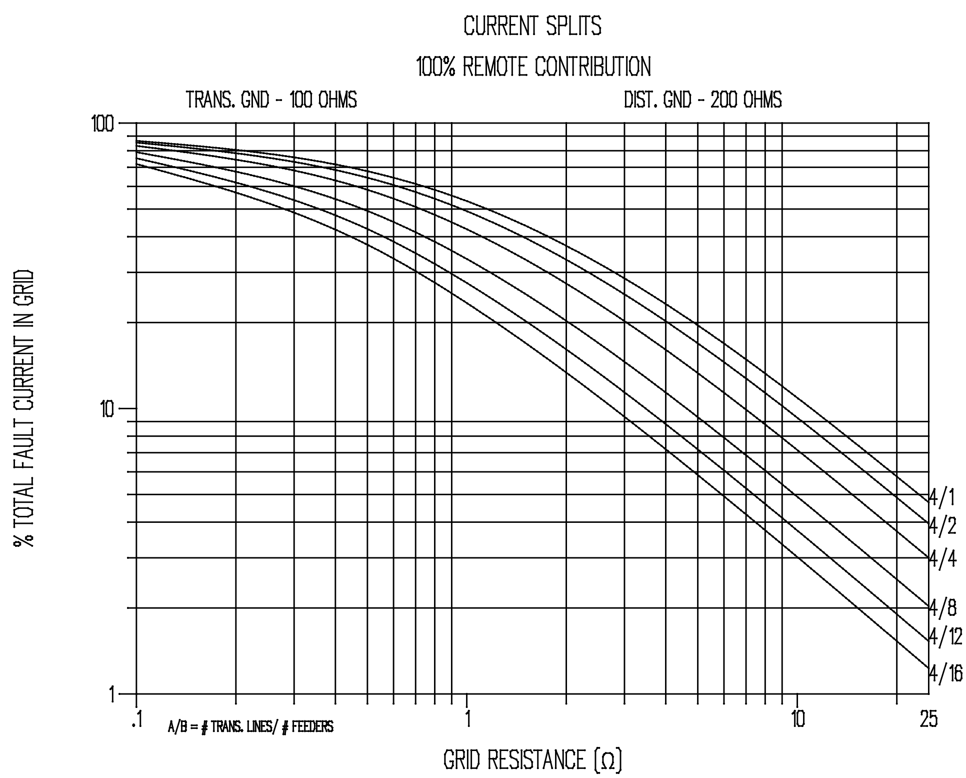


Figure C.6—Curves to approximate split factor S_f

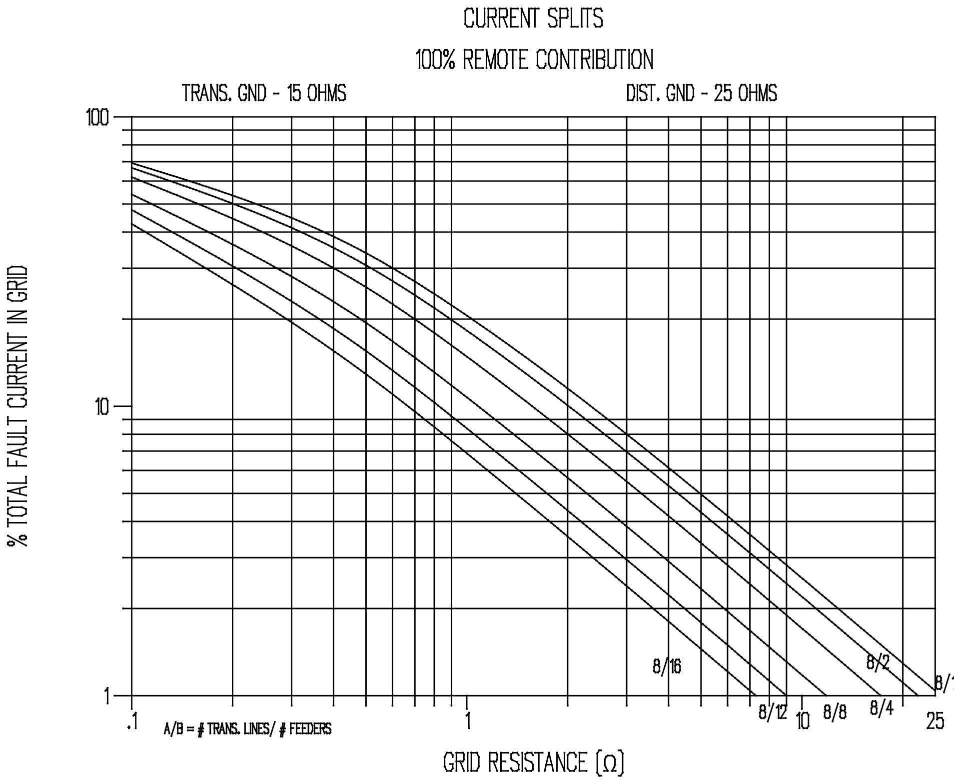


Figure C.7—Curves to approximate split factor S_f

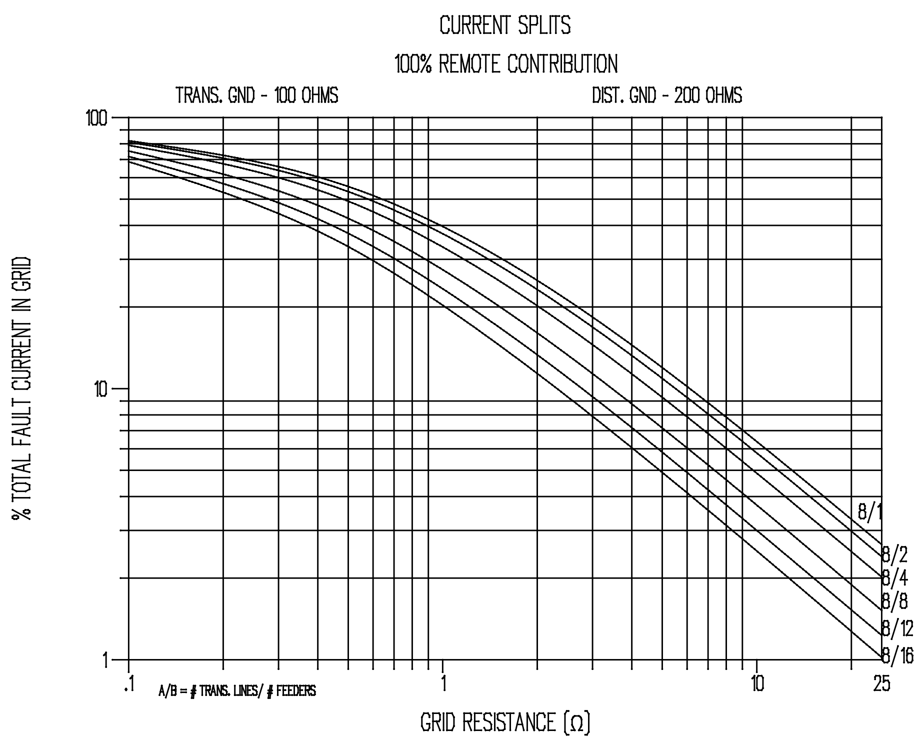


Figure C.8—Curves to approximate split factor S_f

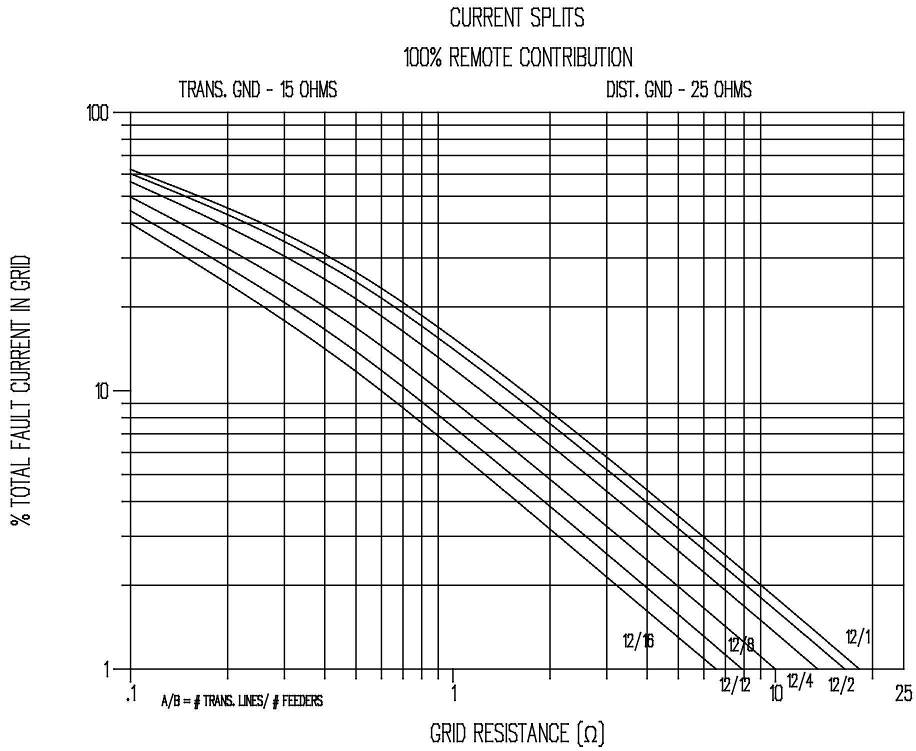


Figure C.9—Curves to approximate split factor S_f

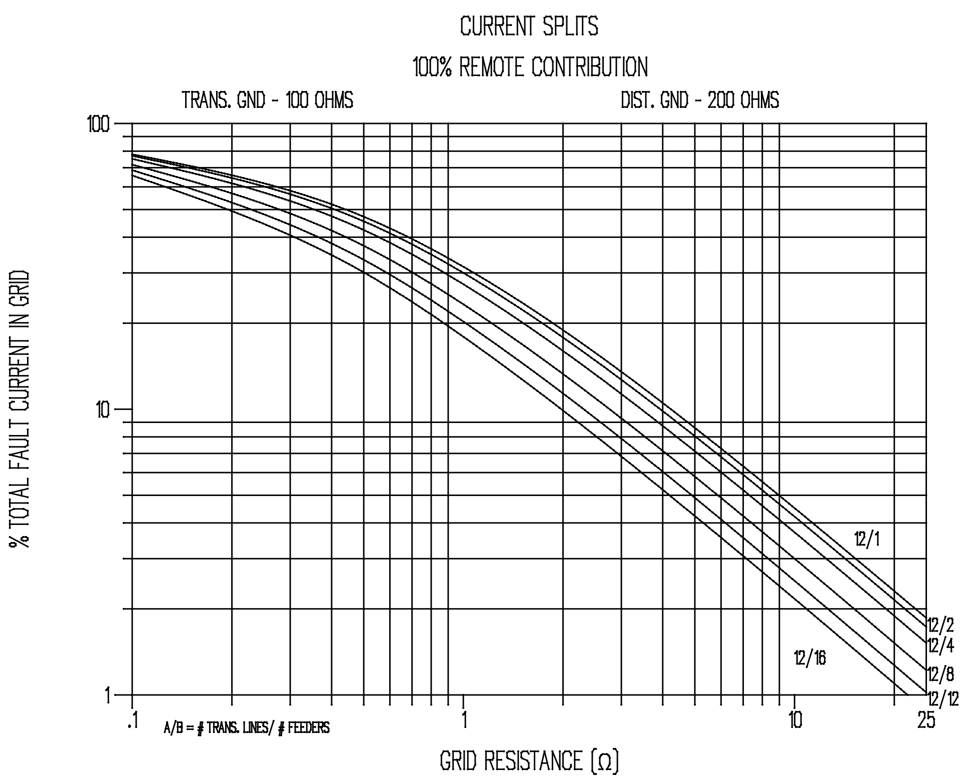


Figure C.10—Curves to approximate split factor S_f

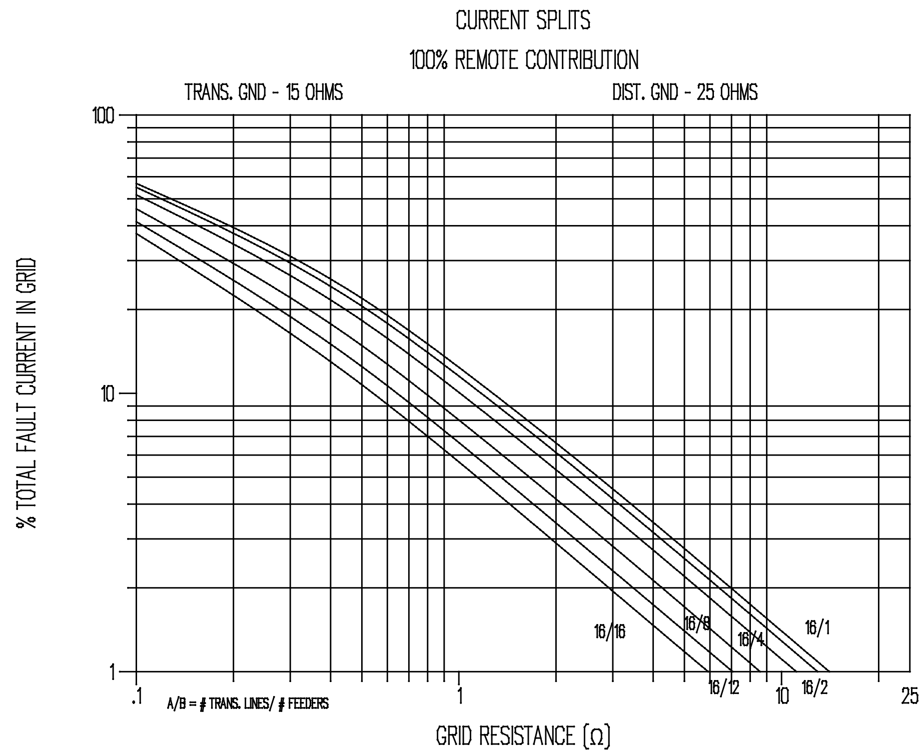


Figure C.11—Curves to approximate split factor S_f

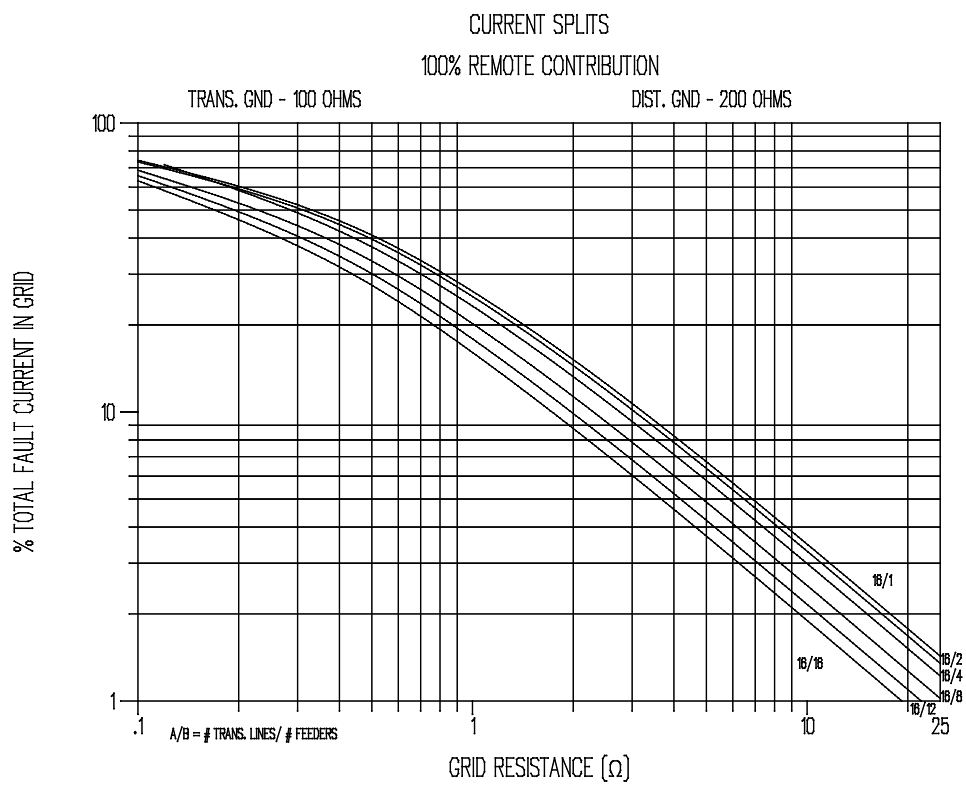


Figure C.12—Curves to approximate split factor S_f

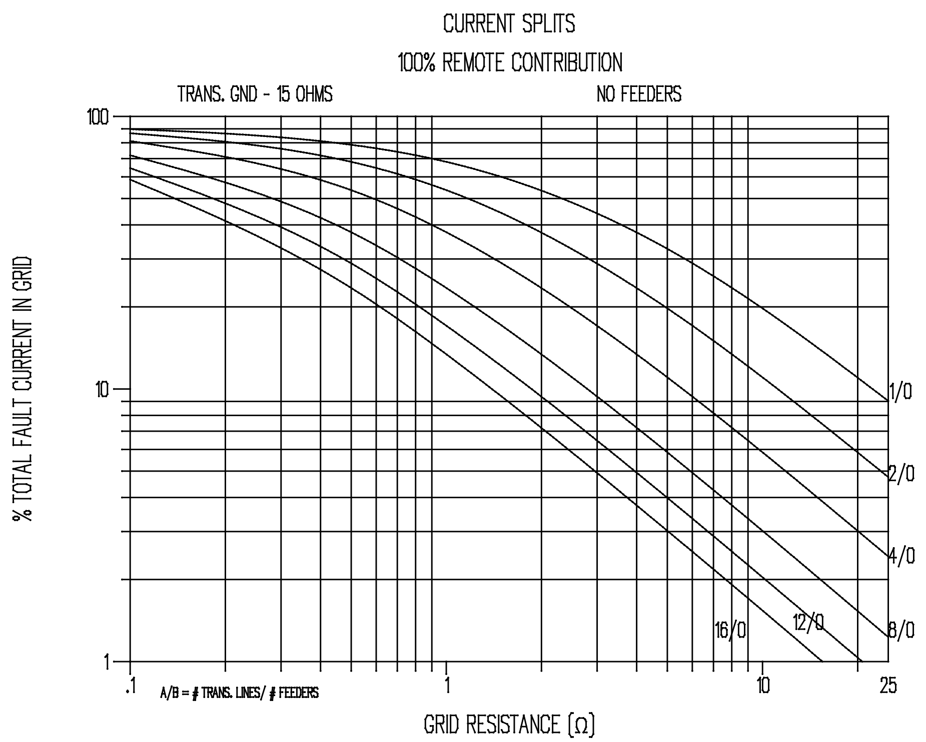


Figure C.13—Curves to approximate split factor S_f

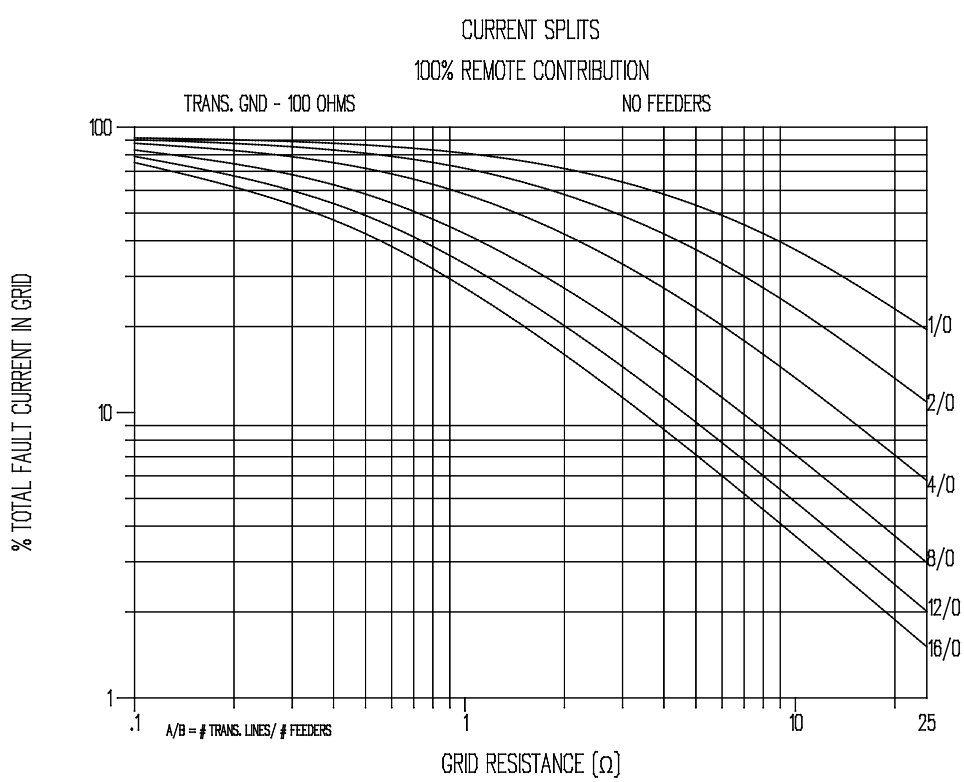


Figure C.14—Curves to approximate split factor S_f

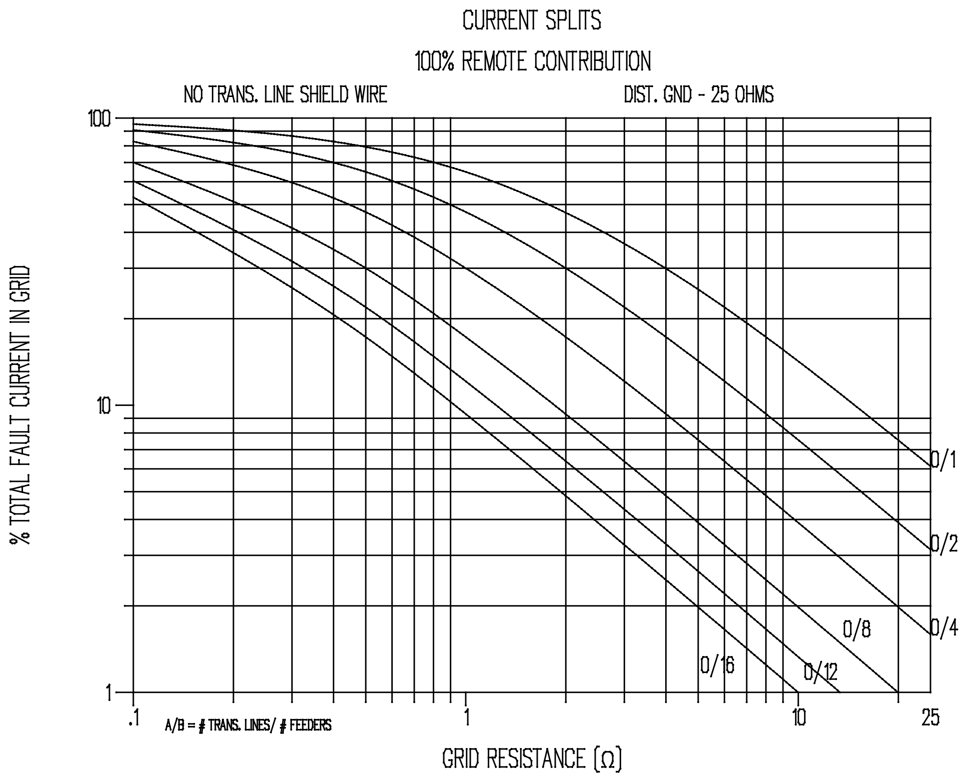


Figure C.15—Curves to approximate split factor S_f

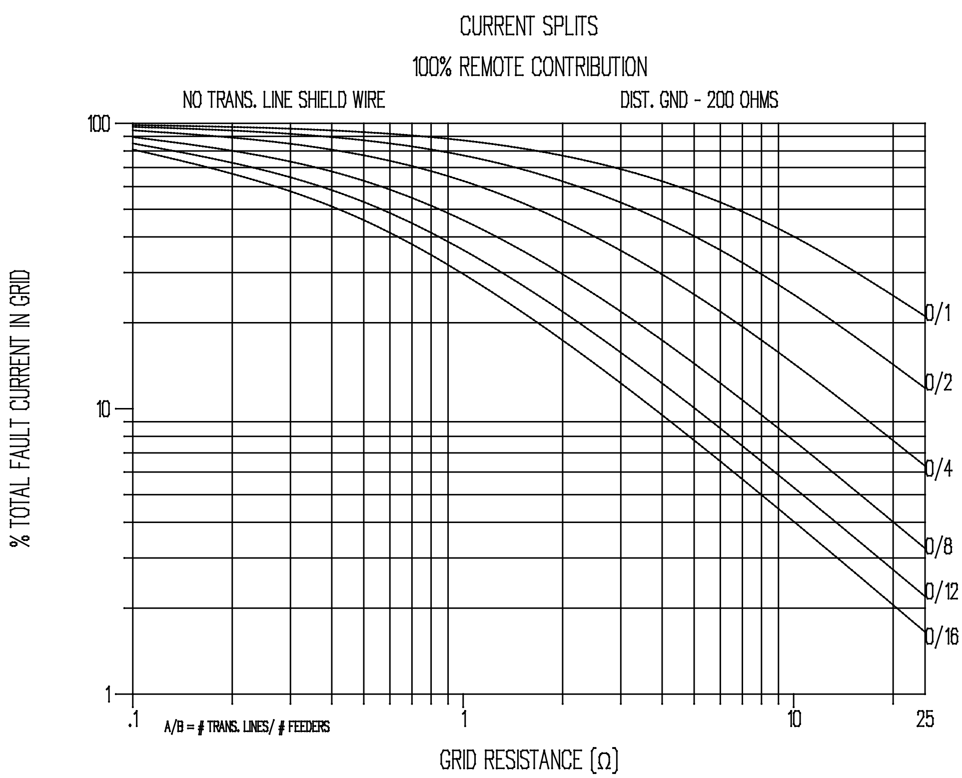


Figure C.16—Curves to approximate split factor S_f

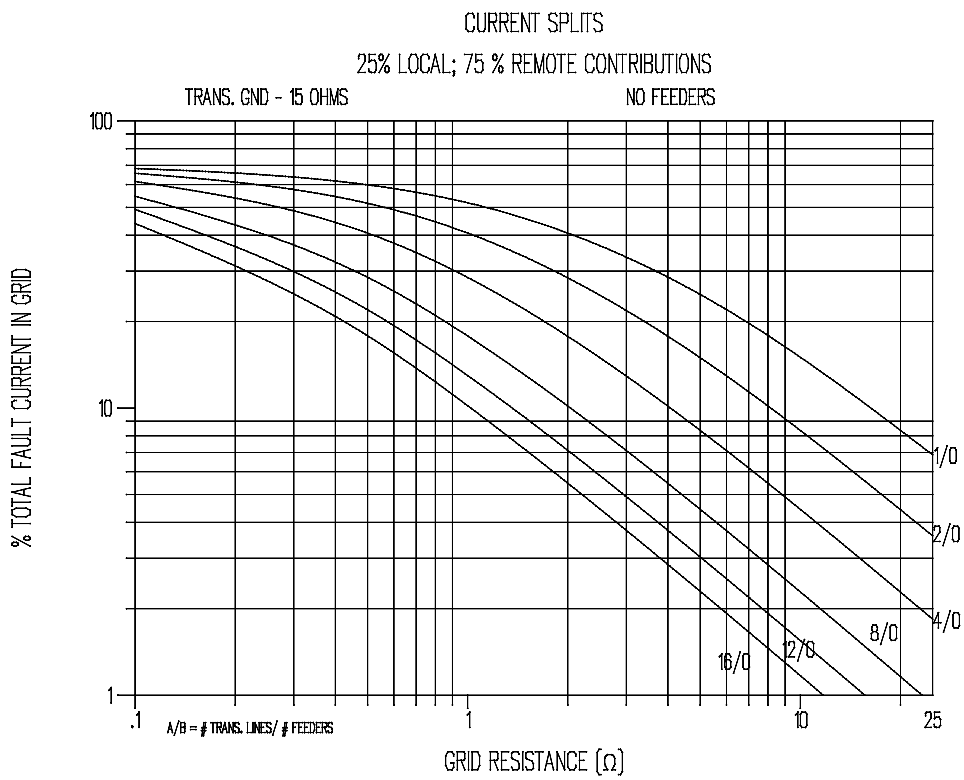


Figure C.17—Curves to approximate split factor S_f

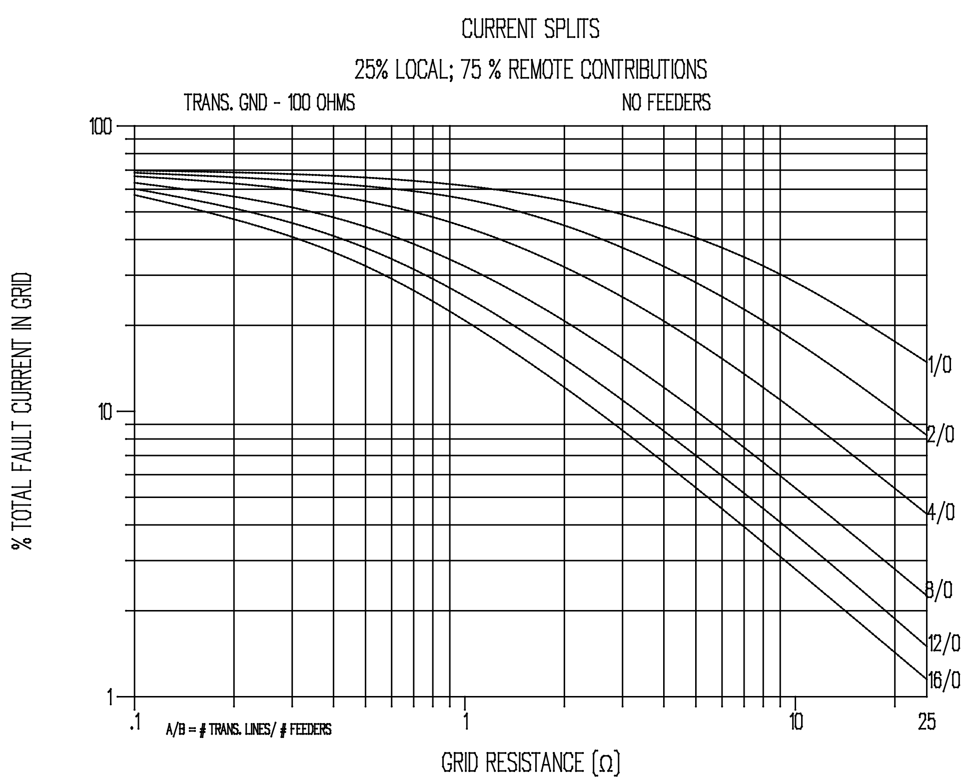


Figure C.18—Curves to approximate split factor S_f

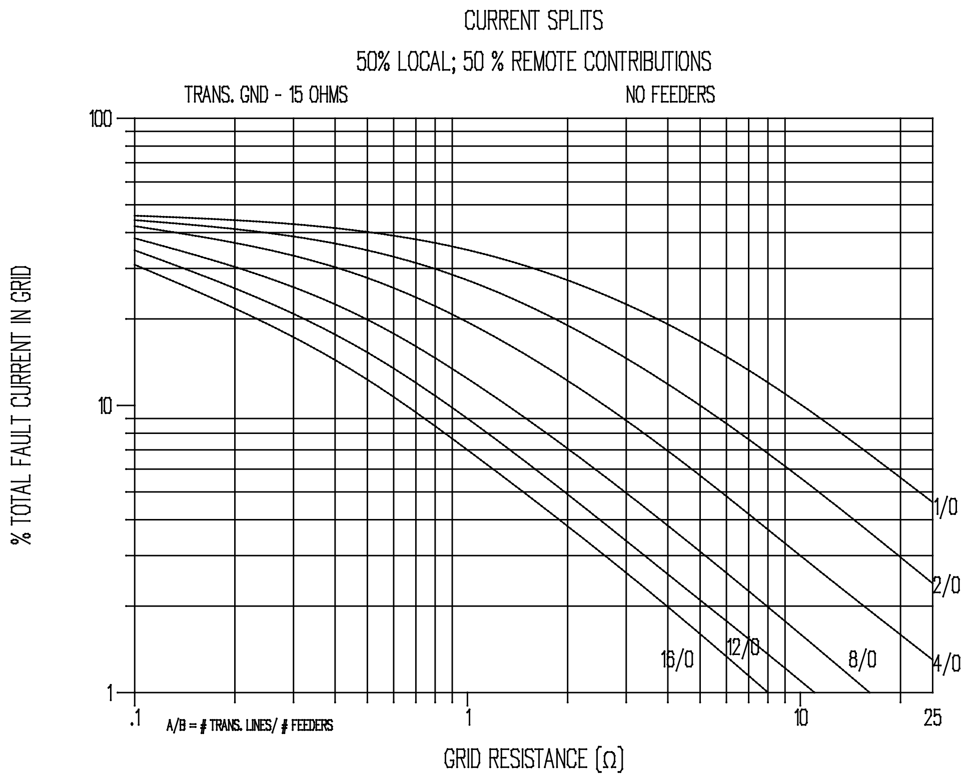


Figure C.19—Curves to approximate split factor S_f

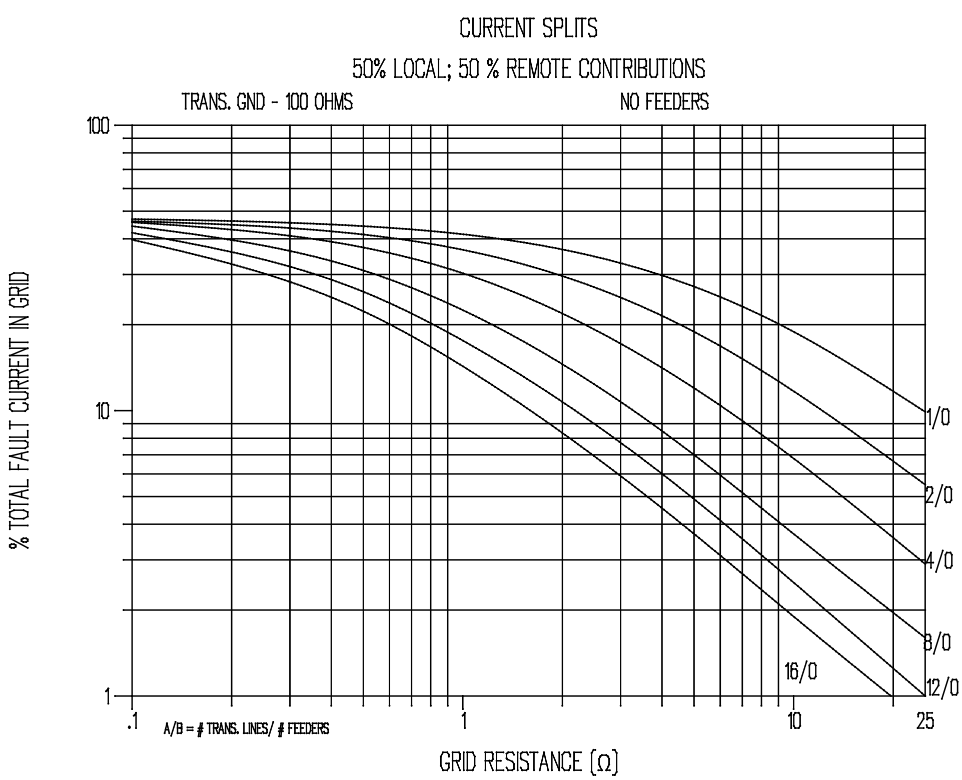


Figure C.20—Curves to approximate split factor S_f

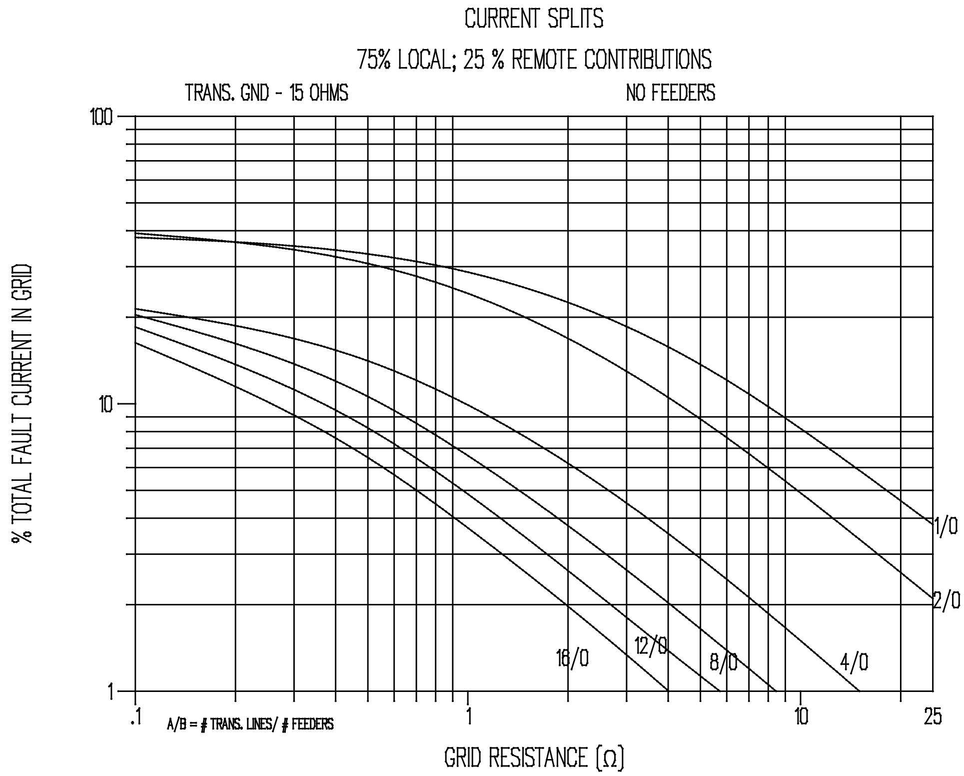


Figure C.21—Curves to approximate split factor S_f

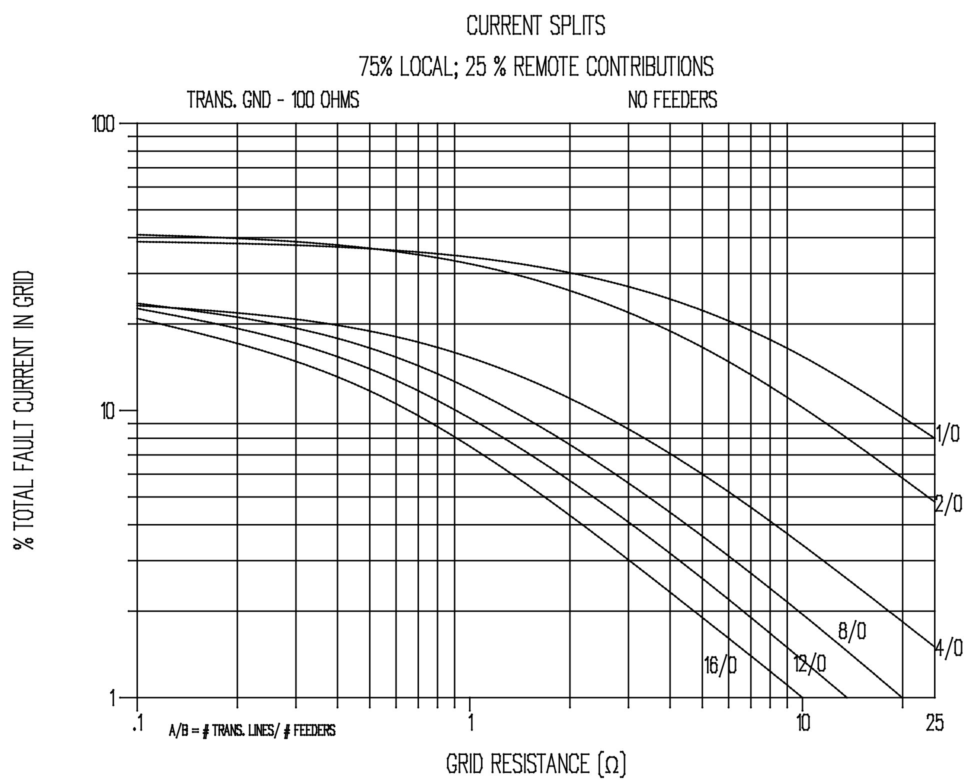


Figure C.22—Curves to approximate split factor S_f

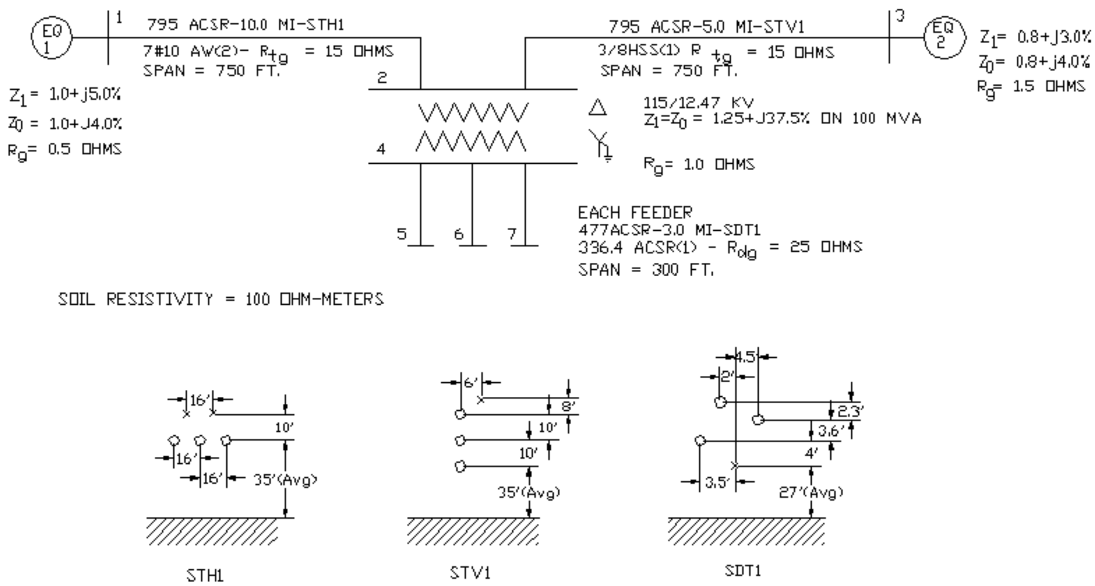


Figure C.23—System and configuration data for example 1 of C.3

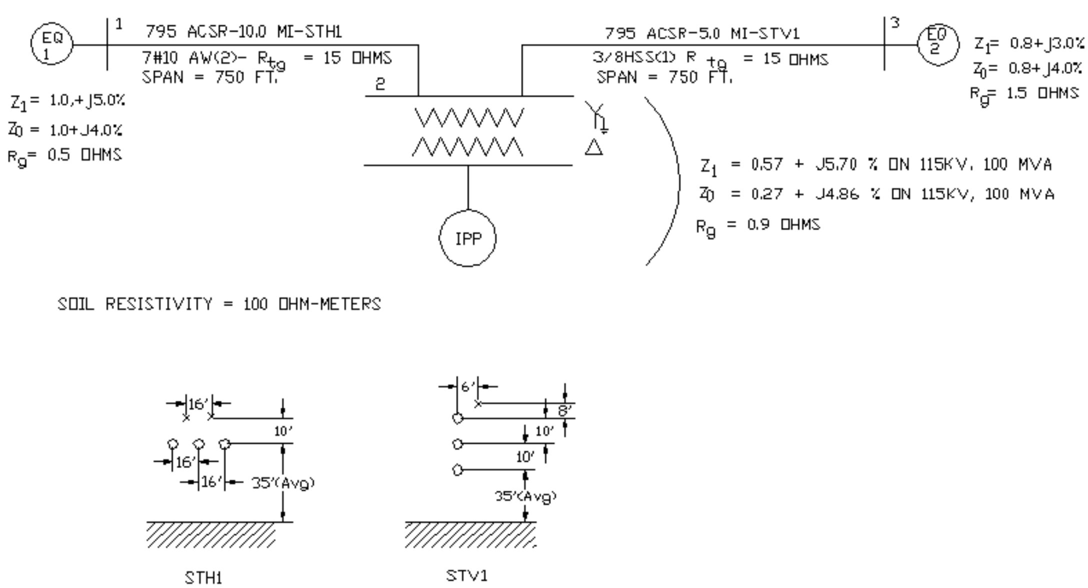


Figure C.24—System and configuration data for example 2 of C.3

Annex D

(informative)

Simplified step and mesh equations

In the previous editions of this guide, the following equation was provided for determining the value of a mesh voltage (in volts) on the earth's surface above the center of a corner mesh (assuming an equally spaced rectangular grid, which is buried at depth *h* in a homogeneous soil of uniform resistivity). This grid may consist of *n* parallel conductors spaced *D* apart, and of an undetermined number of cross connections. All grid wires are assumed to be of diameter *d*. The spacing of parallel conductors *D*, as well as *d* and *h*, are in meters.

$$E_m = \frac{\rho \cdot K_m \cdot K_i \cdot I_G}{L_M} \tag{D.1}$$

where

E_m is the mesh voltage in V
ρ is the average soil resistivity in Ω·m
I_G is the maximum rms current flowing between ground grid and earth in A
L_M is the total length of buried conductors, including cross connections, and (optionally) the combined length of ground rods in m
K_i is the corrective factor for current irregularity
K_m is the mesh factor defined for n parallel conductors

The AIEE Working Group on Substation Grounding Practices [B3] derived the factors K_m and K_i to account for the geometry of the grounding system. The relationship between K_m and E_m depends largely on the current density in the perimeter conductors versus the current density in the inner conductors. To reflect this effect of current density and to correct some of the deficiencies in the equation for K_m, Sverak [B132] added the weighting terms, K_{ii} and K_h into the equation for K_m. The resulting equation for K_m was more accurate and versatile than previous forms of the equation

$$K_m = \frac{1}{2 \cdot \pi} \cdot \left[\ln\left[\frac{D^2}{16 \cdot h \cdot d} + \frac{(D + 2 \cdot h)^2}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right] + \frac{K_{ii}}{K_h} \cdot \ln\left[\frac{8}{\pi(2 \cdot n - 1)}\right]\right] \tag{D.2}$$

For grids with ground rods along the perimeter, or for grids with ground rods in the grid corners, as well as both along the perimeter and throughout the grid area

$$K_{ii} = 1$$

For grids with no ground rods or grids with only a few ground rods, none located in the corners or on the perimeter.

$$K_{ii} = \frac{1}{(2 \cdot n)^{\frac{2}{n}}} \tag{D.3}$$

$$K_h = \sqrt{1 + \frac{h}{h_o}} \quad h_o = 1 \text{ m (grid reference depth)} \tag{D.4}$$

Because of assumptions made in the derivation of K_m, a corrective factor K_i is needed to compensate for the fact that the subject mathematical model of n parallel conductors cannot fully account for the effects of a grid geometry; that is, for two sets of parallel conductors that are perpendicular to each other and interconnected at the cross connection points. For a large number of square and rectangular grids, the mesh voltage was obtained using a computer. From this computer generated data, a new expression for K_i was found to better fit in the mesh voltage equation (Thapar, Gerez, Balakrishnan, and Blank [B144]). This factor is

$$K_i = 0.644 + 0.148 \cdot n \tag{D.5}$$

The simplified E_m equation used in the previous edition of the guide has been limited to square and rectangular grids with square meshes. In practice, a large number of grounding grids have shapes other than square or rectangular. While the specific formula for K_m has remained the same as the 1986 edition of the guide, a new value of n based on the geometry of the grid and the geometry of the meshes was developed in Thapar, Gerez, Balakrishnan, and Blank [B144] to allow Equation (D.2), Equation (D.3), and Equation (D5) to be effective for a variety of grid shapes, including symmetrical T-shaped, triangular, and L-shaped grids.

$$n = n_a \cdot n_b \cdot n_c \cdot n_d \tag{D.6}$$

where

$$n_a = \frac{2 \cdot L_C}{L_p} \tag{D.7}$$

$n_b = 1$ for square grids

$n_c = 1$ for square and rectangular grids

$n_d = 1$ for square, rectangular, and L-shaped grids

Otherwise

$$n_b = \sqrt{\frac{L_p}{4 \cdot \sqrt{A}}} \tag{D.8}$$

$$n_c = \left[\frac{L_x \cdot L_y}{A}\right]^{\frac{0.7 \cdot A}{L_x \cdot L_y}} \tag{D.9}$$

$$n_d = \frac{D_m}{\sqrt{L_x^2 + L_y^2}} \tag{D.10}$$

where

L_c is the total length of the conductor in the horizontal grid in m
L_p is the peripheral length of the grid in m
A is the area of the grid in m^2
L_x is the maximum length of the grid in the x direction in m
L_y is the maximum length of the grid in the y direction in m
D_m is the maximum distance between any two points on the grid in m

While these changes to the equations did expand their use to include a variety of practical ground grid shapes, they did not include the use of ground rods. An attempt was made to expand these equation to include the use of ground rods. If L_C represents the total grid conductor length, L_R represents the total length of all ground rods, and L_r represents the average length of each ground rod, then for grids with ground rods in the corners, as well as along the perimeter and throughout the grid.

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + \left[1.55 + 1.22 \cdot \left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] \cdot L_R} \tag{D.11}$$

The multiplier for L_R is an empirical function that reflects the fact that the current density is higher in the ground rods than in the horizontal grid conductors for uniform soil.

In the previous editions of this guide, the following equation was provided for determining the value of the worst case step voltage (in volts):

$$E_s = \frac{\rho \cdot I_G \cdot K_s \cdot K_i}{L_s} \tag{D.12}$$

where

- E_s is the step voltage in V
- ρ is the average soil resistivity in Ω·m
- I_G is the maximum rms current flowing between ground grid and earth in A
- L_S is the total length of buried conductors, including cross connections, and (optionally) the total effective length of ground rods in m
- K_i is the corrective factor for current irregularity
- K_s is the mesh factor defined for n parallel conductors

Sverak [B132] derived a factor K_s, based on the geometry of a ground grid with no ground rods. As with the mesh voltage, this K_s is proportional to the step voltage E_s. Again, computer simulations were used to derive empirical factors to improve the accuracy of previous versions of E_S, specifically the factor *n*. (Thapar, Gerez, Balakrishnan, and Blank [B144])

$$K_s = \frac{1}{\pi}\left[\frac{1}{2 \cdot h} + \frac{1}{D + h} + \frac{1}{D}(1 - 0.5^{n-2})\right] \tag{D.13}$$

where *n*, *D*, and *h* are defined above.

While these changes to the equations did expand their use to include a variety of practical ground grid shapes, they did not include the use of ground rods. An attempt was made to expand these equations to include the use of ground rods. If L_C represents the total grid conductor length and L_R represents the total length of all ground rods, then for grids with or without ground rods

$$E_s = \frac{\rho \cdot I_G \cdot K_s \cdot K_i}{0.75 \cdot L_C + 0.85 \cdot L_R} \tag{D.14}$$

These new simplified equations were compared to computer solutions for hundreds of different ground grids and the results compared favorably.

Annex E

(informative)

Equivalent uniform soil model for nonuniform soils

In the interest of simplicity, several assumptions have been made in developing the ground grid design equations of this guide. One such assumption is that these equations are only valid for a uniform soil resistivity model regardless of the soil under consideration. A survey indicated the need to provide a guideline for representing a soil regardless of its type by a uniform equivalent and, thus, remove this limitation in the use of the design equations.

A typical soil has several layers, each having a different resistivity. Most often lateral changes also occur, but in comparison to the vertical layers, these changes usually are more gradual. Station sites where the soil may possess uniform resistivity throughout the area and to a considerable depth are seldom found. A uniform soil interpretation of apparent resistivities obtained in the field, under these circumstances, is the most difficult task to perform even with the help of computers. Accordingly, it must be recognized that the soil model is only an approximation of the actual soil conditions and that a perfect match is unlikely. However, it has been recognized that the two-layer representation of a soil is closer to the actual soil conditions compared to its uniform equivalent.

Sometimes, in a multilayer soil, the variation in apparent soil resistivity ρ_a with respect to depth or pin spacing is not too great. Such a soil can be represented as a uniform soil with a single soil resistivity value. Although it is difficult to draw a clear line to indicate whether the soil is uniform or not, the approach taken here consisted of defining the uniform soil based on the two-layer equivalents of several field measured resistivity profiles. The computer program of EPRI TR-100622 [B63] was used to compute an equivalent two-layer soil model. The computer values indicated that a soil can be represented as a uniform soil if the difference between two extreme values of apparent resistivity is moderate. After it is determined that the soil can be approximated as uniform, the average apparent resistivity value computed from Equation (E.1) represents that soil in the design equations.

$$\rho_{a(av1)} = \frac{\rho_{a(1)} + \rho_{a(2)} + \rho_{a(3)} \dots + \rho_{a(n)}}{n} \tag{E.1}$$

Where $\rho_{a(1)}$, $\rho_{a(2)}$, $\rho_{a(3)}$... $\rho_{a(n)}$ are the apparent resistivity measurements obtained at n different spacings in four-pin method or at n different depths in driven ground rod method in Ω·m.

A majority of the soils will not meet the above criteria for the uniform soil. To determine uniform soil models to represent nonuniform soils, a similar approach was taken. The measured apparent resistivity data from several sites were used to obtain three different soil models: a two-layer soil model computed with EPRI TR-100622 [B63], and two different uniform soil models using Equation (E.1) and Equation (E.2).

$$\rho_{a(av2)} = \frac{\rho_{a(max)} + \rho_{a(min)}}{2} \tag{E.2}$$

where

$\rho_{a(max)}$ is the maximum apparent resistivity value (from measured data), Ω·m.
$\rho_{a(min)}$ is the minimum apparent resistivity value (from measured data), Ω·m.

The next step was to compute the ground grid resistance R_g, the corner mesh voltage E_{mesh}, and the corner step voltage E_{step} for a typical ground grid using EPRI TR-100622 [B63]. A 76.2 m × 76.2 m ground grid with 64 meshes and uniformly distributed ground rods was selected for this investigation. The length of the ground rods varied with the soil model. For a given soil model, this length was determined so as to reach the depth (or pin spacing) where $\rho_{a(av1)}$ or $\rho_{a(av2)}$ occurred in the measured apparent resistivity profile. Figure E.1 illustrates the modeled ground grid including the locations for computed step and touch voltages.

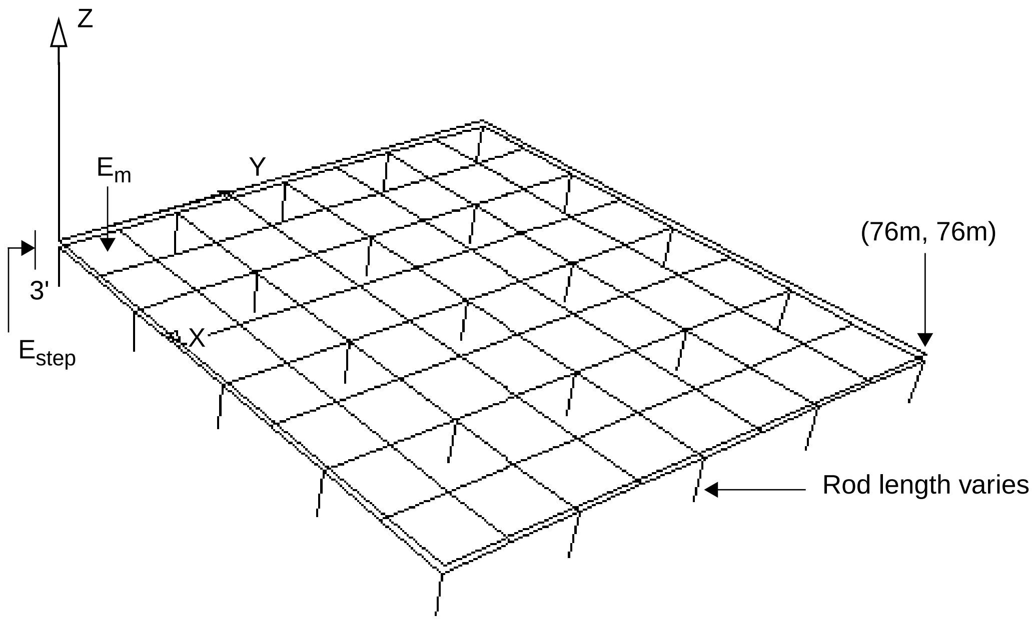


Figure E.1—The ground grid modeled for computing grounding parameters

Following the computations, the grounding parameters computed with the two layer model were compared with those computed using the uniform soil models. This comparison indicated that the mesh and step voltages computed with the soil model represented by $\rho_{a(av2)}$ yielded values comparable to those computed with the two-layer model for the soils investigated.

Table E.1 presents the comparison of grounding parameters computed using the two-layer soil model with those computed using the uniform soil model represented by $\rho_{a(av2)}$ for two typical soils. The soil resistivity values shown in Table E.2 were mathematically derived from assumed two-layer soil models.

Table E.1—Ground parameters computed with two-layer soil compared with those computed with equivalent uniform soil model

Soil type	Computed grounding parameters with two-layer soil model				Computed grounding parameters with uniform soil model			
	ρ_1, ρ_2, h Ω·m, Ω·m	R_g Ω·m	E_m (V)	E_s (V)	$\rho_{(av2)}$ Ω·m	R_g Ω	E_m (V)	E_s (V)
1	100, 300, 6.1	1.28	126	85	158	0.89	151	86
2	300, 100, 6.1	0.72	187	92	193	1.09	185	106

Table E.2—Calculated resistance and apparent resistivity data for soil type 1 and type 2 of Table E.1, based on the four-pin method

Probe separation		Soil type 1		Soil type 2	
(ft)	(m)	Resistance Ω	Apparent resistivity ρ_a Ω·m	Resistance Ω	Apparent resistivity ρ_a Ω·m
1	0.305	29.73	56.94	89.13	170.74
3	0.915	15.33	88.07	45.85	263.46
5	1.524	9.97	95.48	29.55	283.06
15	4.573	3.85	110.71	9.39	269.67
20	6.098	3.15	120.76	6.46	247.57
30	9.146	2.49	143.10	3.52	202.12
50	15.244	1.90	181.70	1.50	144.05
70	21.341	1.56	208.78	0.90	120.28
90	27.439	1.32	227.75	0.64	110.68
110	33.537	1.15	241.48	0.51	106.41
130	39.634	1.01	251.77	0.42	104.34
150	45.731	0.90	259.76	0.36	103.16

Annex F

(informative)

Parametric analysis of grounding systems

(This Annex is taken from Dawalibi, F., and Mukhedkar, D., "Parametric analysis of grounding systems," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, no. 5, pp. 1659–1668, Sept./Oct. 1979; and Dawalibi, F., and Mukhedkar, D., "Influence of ground rods on grounding systems," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, no. 6, pp. 2089–2098, Nov./ Dec. 1979.)

To efficiently design a safe grounding system it is necessary to have knowledge of how various parameters affect the performance of the grounding system. Some of these parameters include grid conductor spacing and arrangement, number of ground rods, location and length, and soil resistivity parameters (that is, homogeneous or multilayered with various surface layer thickness and values of K, the reflection factor coefficient).

This annex gives a brief discussion of how the above parameters affect the behavior of grounding systems for uniform soil resistivity and for two-layer soil resistivity. There are many other parameters that may affect the performance of the grounding system, but it is not within the scope of this annex to discuss these parameters.

F.1 Uniform soil

F.1.1 Current density—grid only

For a grounding system consisting only of grid conductors, the current along any one of the conductors is discharged into the earth in a fairly uniform manner. However, a larger portion of the current is discharged into the soil from the outer grid conductors rather than from the conductors at or near the center of the grid (refer to Figure F.1 and Figure F.2). An effective way of making the current density more uniform between the inside and periphery conductors is to employ a nonuniform conductor spacing, with the conductor spacing larger at the center of the grid and smaller toward the perimeter. However, analysis of grids with this type of spacing cannot be accomplished using the simplified methods of this guide, but must be done using techniques similar to those described in the references.

F.1.2 Resistance—grid only

For a given area to be grounded, the effect on resistance of increasing the number of meshes in a grid-only system becomes minimal. That is, as the number of meshes increases from one, the resistance of the grid decreases. However, this decrease quickly becomes negligible for large numbers of meshes (or small parallel conductor spacing). See Figure F.3 and Figure F.4.

As shown in Figure F.5, the resistance also shows a gradual decrease with burial depth, until it approaches one half its resistance value at the surface as the depth increases to infinity. But for typical variations of burial depth found within the industry (that is, approximately 0.5–1.5 m), this change in resistance with depth is negligible for uniform soil.

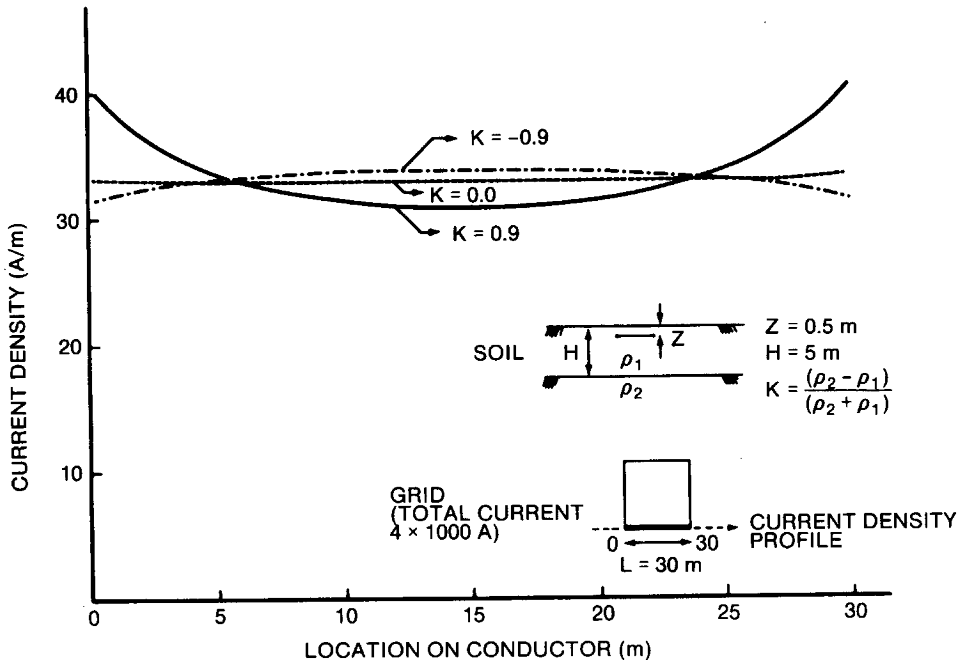


Figure F.1—One mesh grid current density

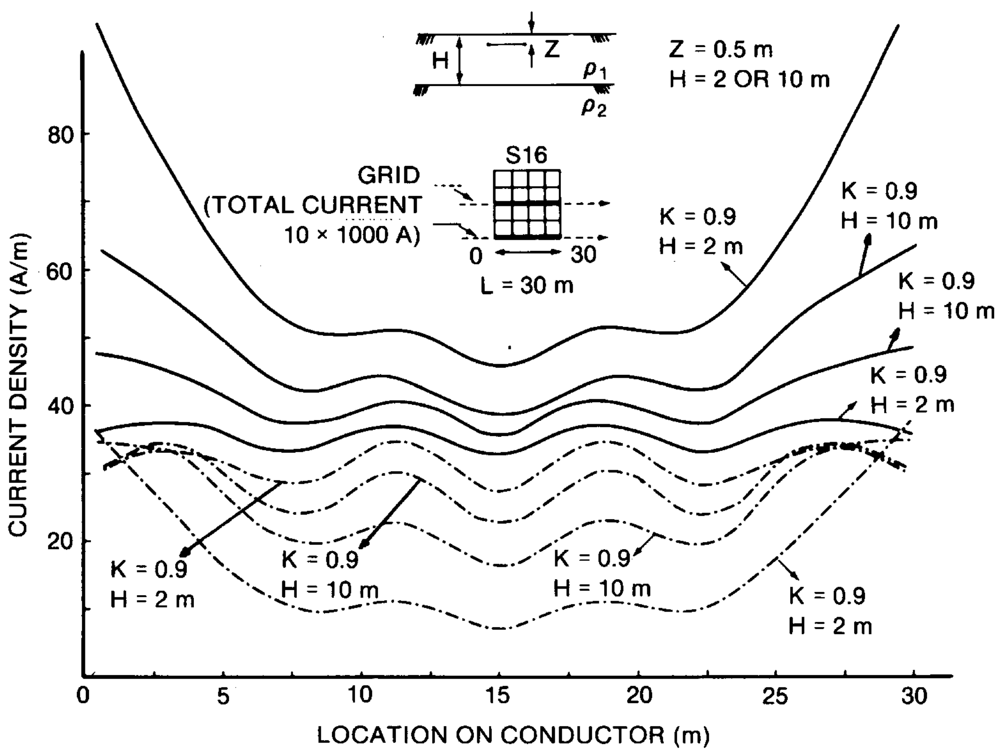


Figure F.2—Sixteen mesh grid current density

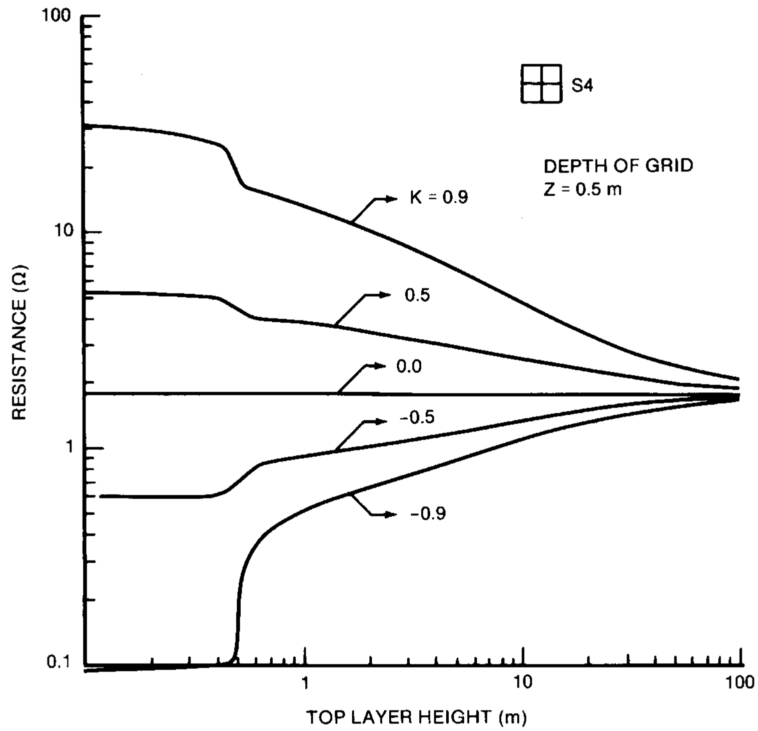


Figure F.3—Four mesh grid resistance

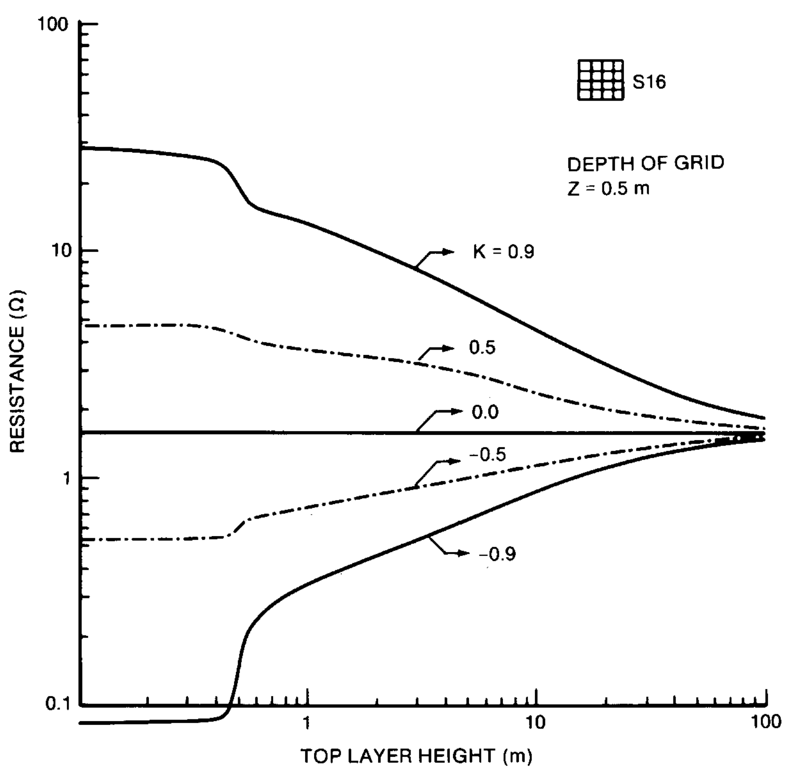


Figure F.4—Sixteen mesh grid resistance

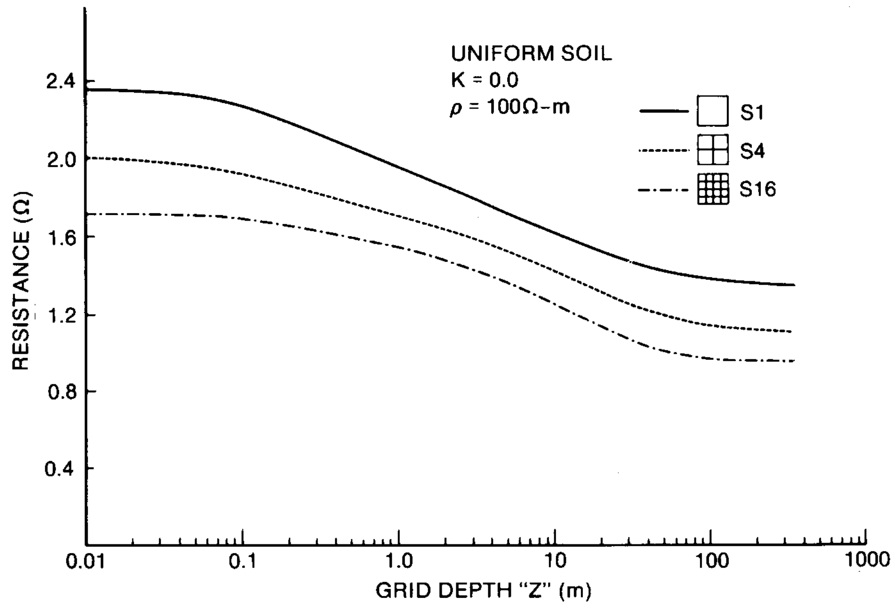


Figure F.5—Grid resistance versus grid depth

F.1.3 Step and touch voltages—grid only

Since most of the current in a uniformly spaced grid is discharged into the earth from the outer conductors, the worst touch and step voltages occur in the outer meshes, especially in the corner meshes. Increasing the number of meshes (decreasing the conductor spacing) tends to reduce the touch and step voltages until a saturation limit is reached. Beyond this number of meshes, reducing the conductor spacing has minimal effect on reducing the voltages (refer to Figure F.6 through Figure F.9). This saturation limit is the vertical component of voltage caused by the depth of burial of the grid, and is changed only with a change in depth of the grid.

The grid burial depth also influences the step and touch voltages significantly as shown in Figure F.10 and Figure F.11. For moderate increases in depth, the touch voltage decreases, due mainly to the reduced grid resistance and corresponding reduction in the grid potential rise. However, for very large increases in depth, the touch voltage may actually increase. The reduction in grid potential rise reduces to a limit of approximately half its value at the surface as the depth of the grid approaches infinity, while the earth surface potential approaches zero at infinite depths. Therefore, depending on the initial depth, an increase in grid burial depth may either increase or decrease the touch voltage, while the step voltage is always reduced for increased depths.

F.1.4 Ground rods only

For systems consisting only of ground rods, the current has been found to discharge into the earth at a fairly uniform rate along the length of the rod with a gradual increase with depth and with slightly higher increases in current density near the ends (refer to Figure F.12). As in the case of the grid conductors, the current density is greater in the rods near the periphery of the grounding system than for those in the center (refer to Figure F.13 and Figure F.14). Thus, the step and touch voltages are higher near the outer ground rods.

Increasing the length of the rods is effective in reducing the resistance of the system, and therefore, reducing the step and touch voltages. Increasing the number of rods also reduces the resistance until the grounded area is saturated, and is even more effective in reducing the step and touch voltages as shown in Table F.1. This is true because in addition to the lower resistance and lower ground potential rise, the spacing between the rods is reduced, which tends to make the earth surface potential more uniform. The comments above on the effects of grid burial depth also apply to the effects of the top-of-the-rod depths.

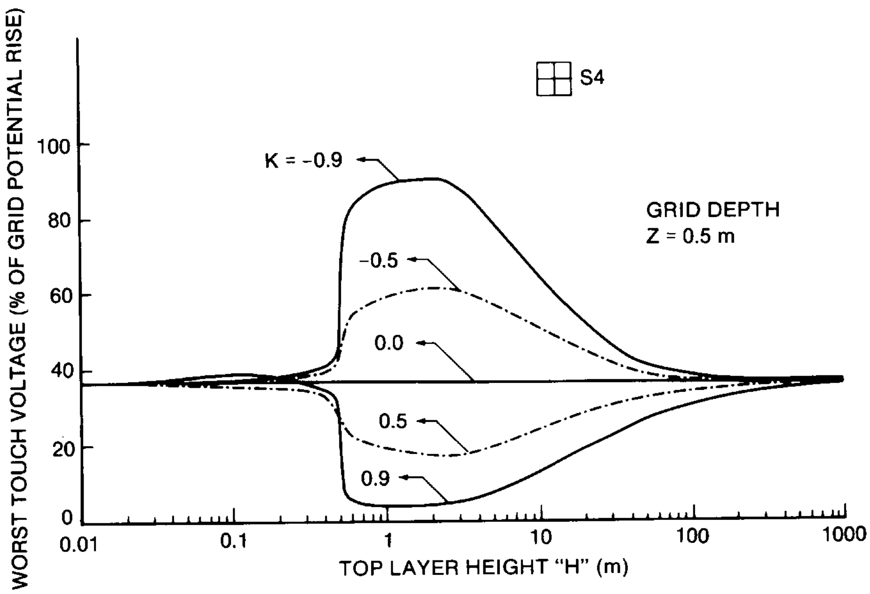


Figure F.6—Four mesh grid touch voltages

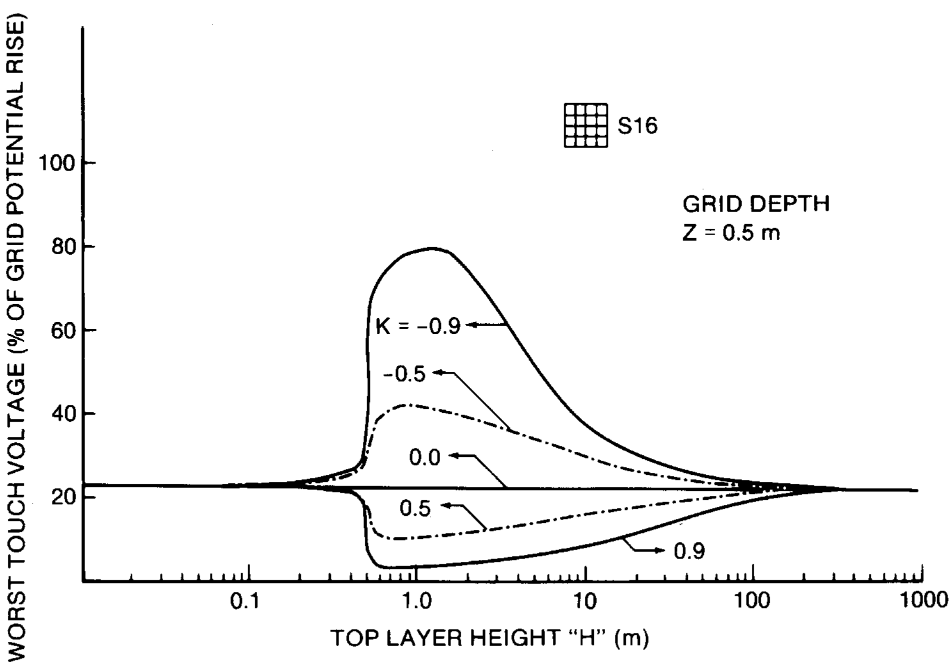


Figure F.7—Sixteen mesh grid touch voltages

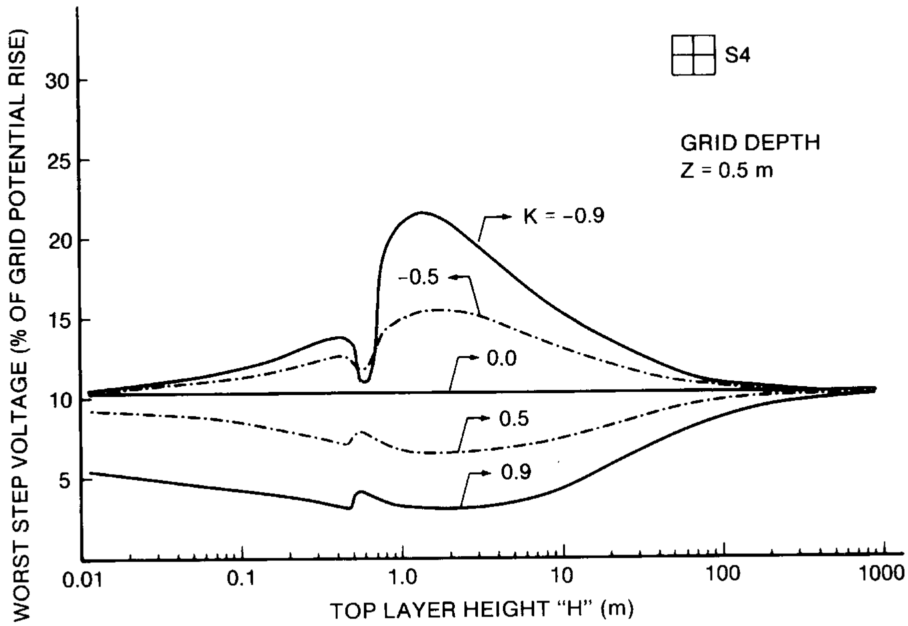


Figure F.8—Four mesh grid step voltages

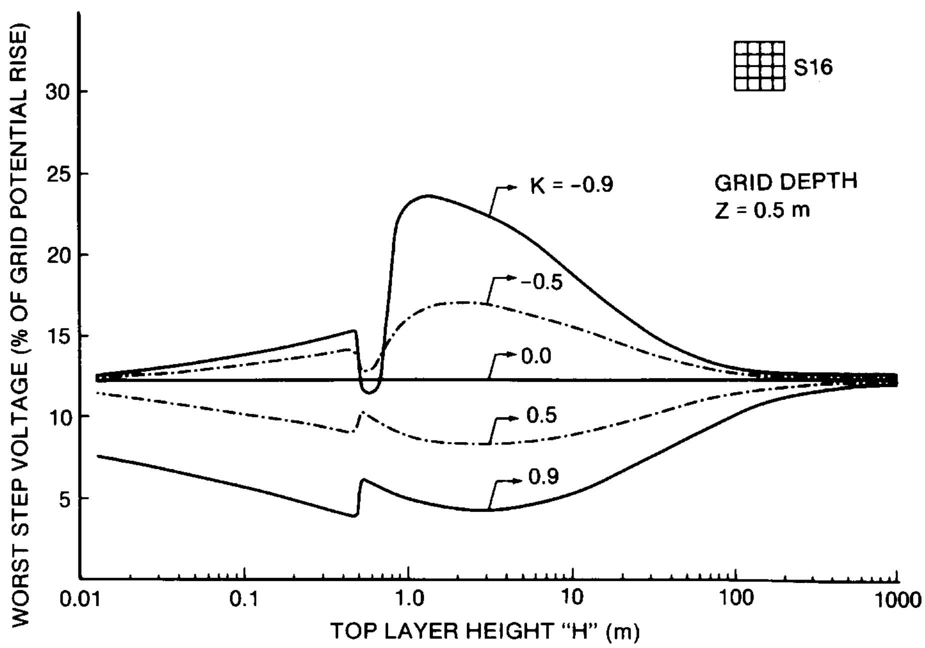


Figure F.9—Sixteen mesh grid step voltages

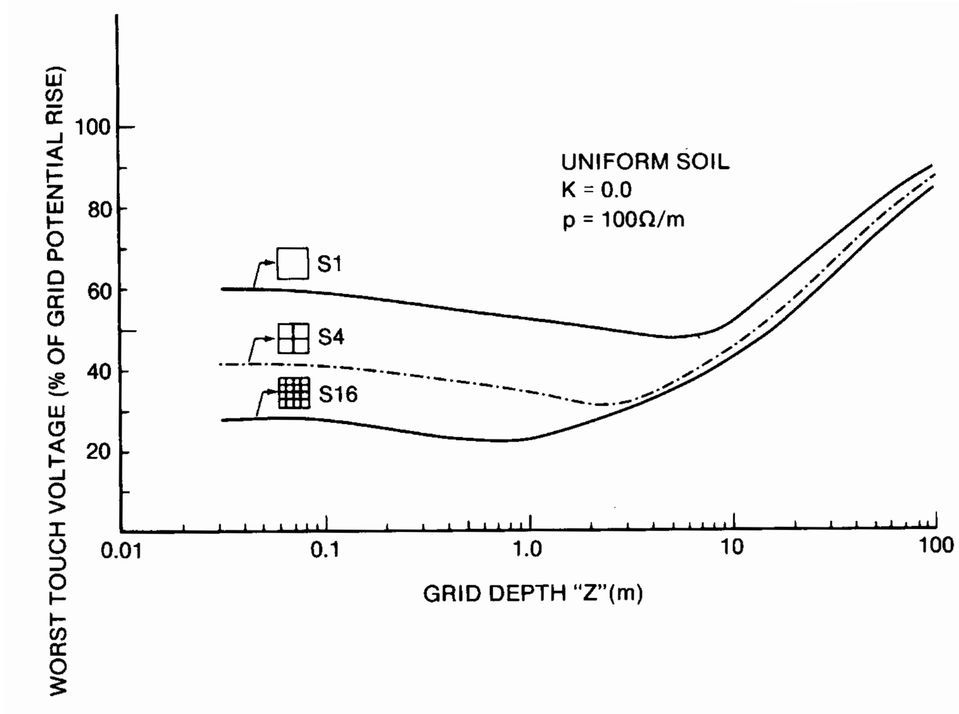


Figure F.10—Touch voltage versus grid depth

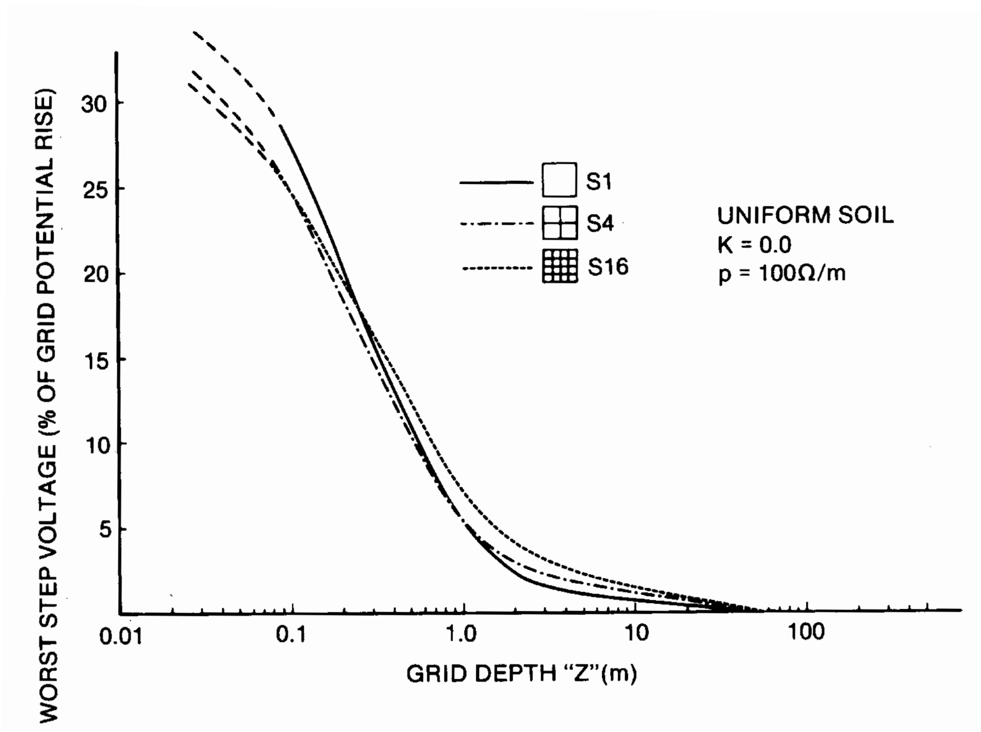


Figure F.11—Step voltage versus grid depth

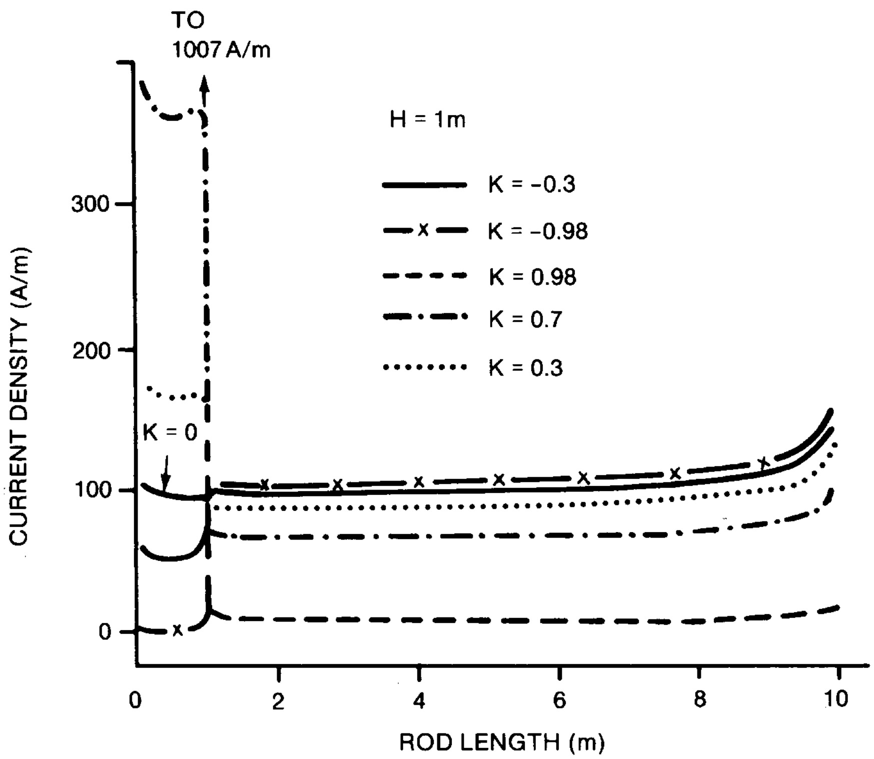


Figure F.12—Single rod current density

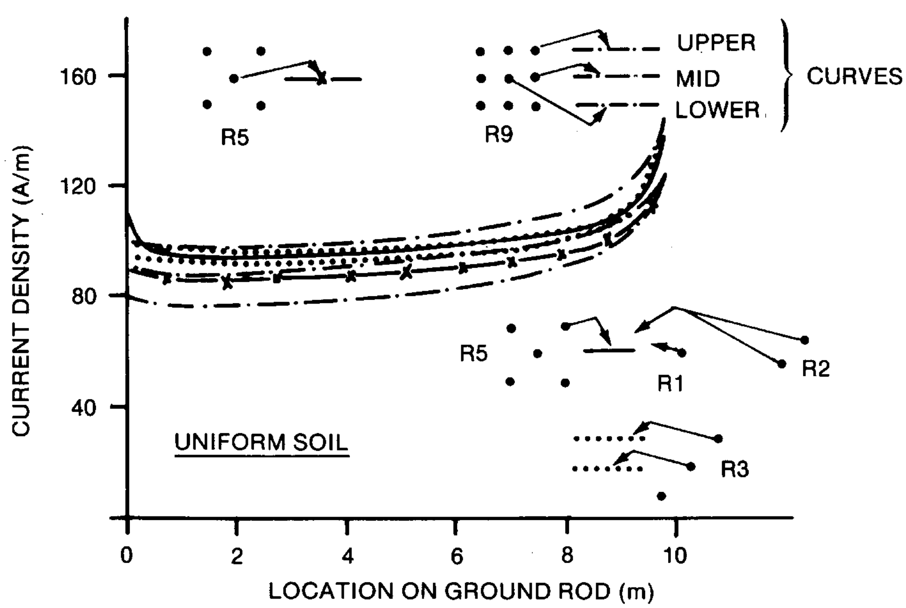


Figure F.13—Multiple driven rod current density in uniform soil

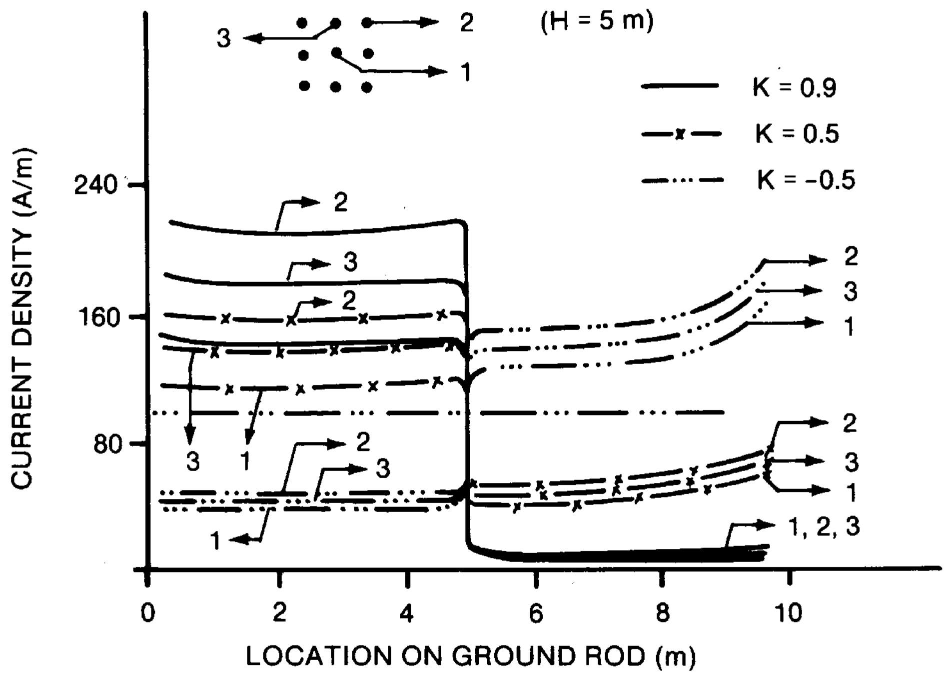


Figure F.14—Current density in multiple driven rods in two-layer soil

F.1.5 Grid and ground rod combinations

When a combination of grid conductors and ground rods are used in a grounding system, the number and length of ground rods may have a great influence on the performance of the grounding system. For a given length of grid conductor or ground rod, the ground rod discharges much more current into the earth than does the grid conductor, as shown in Figure F.15 through Figure F.18. This current in the ground rod is also discharged mainly in the lower portion of the rod. Therefore, the touch and step voltages are reduced significantly compared to that of grid alone.

F.1.6 Conclusions

In general, a uniformly spaced grounding system consisting of a grid and ground rods is superior to a uniformly spaced grounding system consisting only of a grid with the same total conductor length. The variable spacing technique discussed earlier might be used to design a grounding system consisting of a grid only, with lower step and touch voltages than a uniformly spaced grid and ground rod design of equal length. However, this variable spacing technique might also be used to design a better grounding system using nonuniformly spaced grid conductors and ground rods. It shall be emphasized that this type of design shall be analyzed using the detailed analysis techniques in the references.

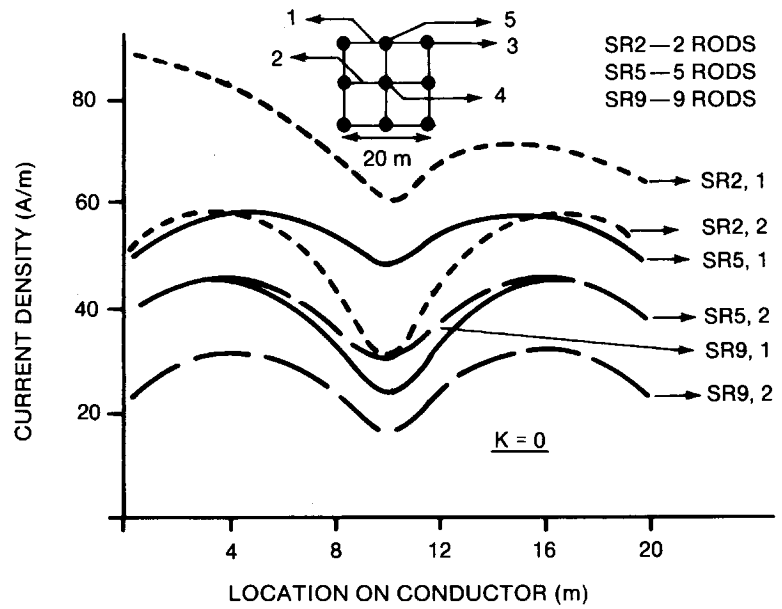


Figure F.15—Grid current density—rods and grid in uniform soil

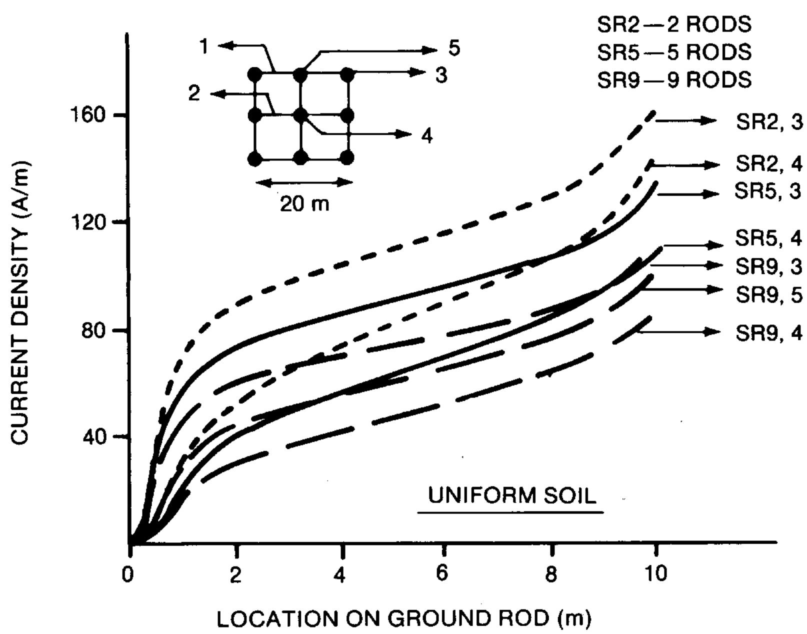


Figure F.16—Rod current density—rods and grids in uniform soil

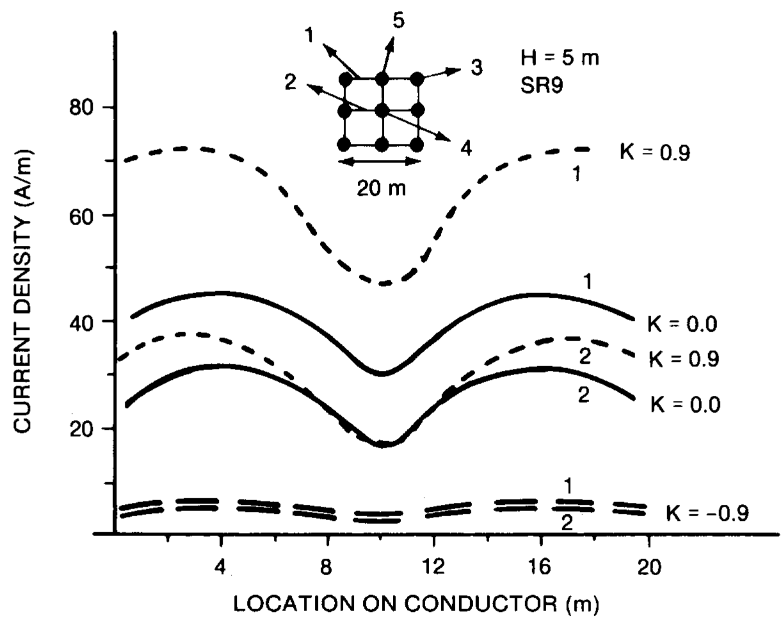


Figure F.17—Rod and grid current density—nine rodsand grid in two-layer soil

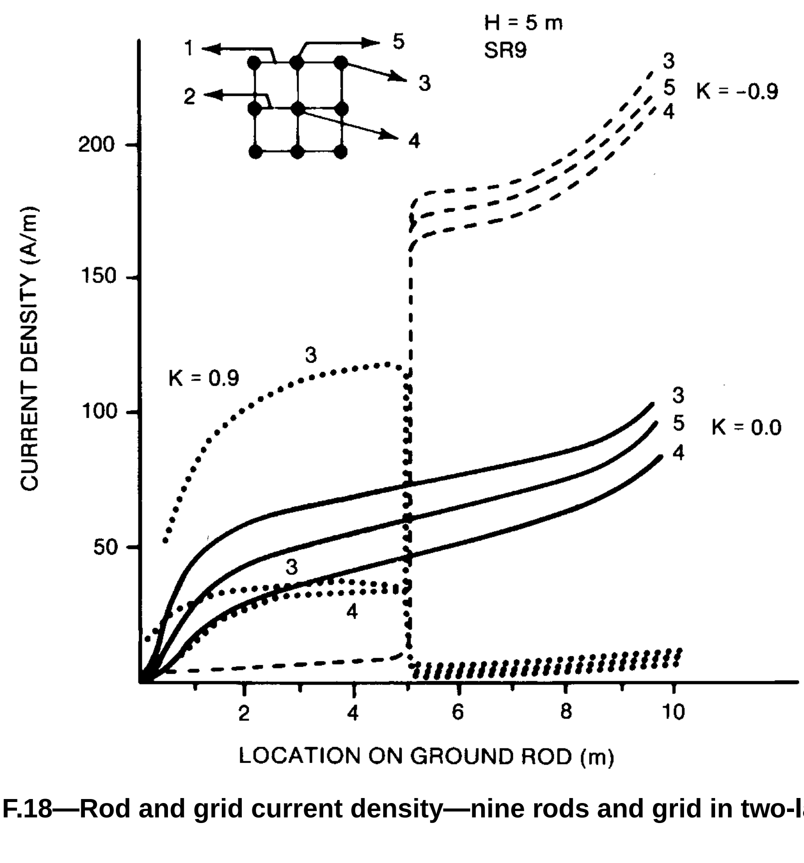


Figure F.18—Rod and grid current density—nine rods and grid in two-layer soil

F.2 Two-layer soil

The performance of a grounding system in multilayered earth can differ greatly from the same system in uniform soil. In addition to other parameters, the performance is affected by the resistivity and thicknesses of the soil layers and the burial depth of the grounding system. The following discussion will consider only two-layer earth models, due to the complexity and numerous combinations possible for additional layers. For an explanation of two-layer earth analysis of grounding systems, refer to 13.4.2 of this guide.

For brevity of the discussion, the following variables are defined:

ρ_1 = resistivity of upper layer of soil
ρ_2 = resistivity of lower layer of soil
K = reflection factor coefficient $\frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}$
h = height of upper layer of soil

F.2.1 Current density—grid only

For grounding systems consisting only of grid conductors, the current density is highly dependent on both K and h, as shown in Figure F.1 and Figure F.2. For negative values of K ($\rho_1 > \rho_2$), the current density is fairly uniform over the entire grid with slightly higher densities in the conductor between intersection points on the grid, and is slightly higher for outer conductors than for conductors near the center of the grid. As the height of the top layer increases, this higher current density in the outer conductors becomes more dominant. This can be explained as follows. For small values of h, most of the current discharged from the grid goes downward into the low resistivity soil, while for large values of h most of the current remains in the high resistivity layer of soil, assuming that the grid is in this upper layer. As h increases, the model approaches that of uniform soil with a resistivity equal to that of the upper layer. Therefore, as in the case of the uniform soil model discussed in F.1, the outer grid conductors discharge a larger portion of the current into the earth than do the center conductors.

For positive values of K ($\rho_1 < \rho_2$), the current has a much higher tendency to remain in the low resistivity soil, even for moderately small values of h. As h increases, the current density rapidly approaches that of a uniform soil, with higher current densities in the periphery conductors.

F.2.2 Resistance—grid only

The resistance of a grid-only system may vary greatly as a function of K and h and, thus, may be higher or lower than the same grid in a uniform soil, as shown in Figure F.3 and Figure F.4. In general, the resistance of a grid is lowest if it is in the most conductive layer of soil. As h increases the resistance of the grid approaches that of a grid in uniform soil of the same resistivity as the upper layer. Assuming that the grid is located in the upper soil layer with resistivity equal to ρ_1, the following can be generalized:

a) For negative values of K ($\rho_1 > \rho_2$), the resistance of the grid will be higher than that of an identical grid in uniform soil with resistivity ρ_1.
b) For positive values of K ($\rho_1 < \rho_2$), the resistance grid will be lower than that of an identical grid in uniform soil resistivity ρ_2.

F.2.3 Step and touch voltages—grid only

The step, touch voltages, and mesh voltages may also vary significantly with K, h, and grid depth. They may be very much higher or lower than a corresponding uniform soil model. See Figure F.6 through Figure F.9.

For grids buried near the surface of the earth, increasing the number of meshes is an effective means of reducing the mesh voltages. However, as the grid depth increases, the effectiveness of this method of reducing the mesh voltages decreases until at some characteristic grid depth, the mesh voltages begin to increase. The reasons for this phenomenon are identical to those described previously for uniform soil. For a very large number of meshes (that is, small spacing between parallel conductors), the touch voltages are relatively unaffected by *h* and *K*.

For negative values of *K* ($\rho_1 > \rho_2$), the highest touch potential occurs when h is slightly greater than the grid depth. For positive values of *K* ($\rho_1 < \rho_2$), the highest touch potentials occur when h is less than the grid depth, or when *h* is much greater than the grid depth.

One way of reducing the touch voltage without increasing the total amount of conductor is to omit the cross-connecting conductors (except at the ends) and reduce the spacing between the remaining parallel conductors. It must be noted, however, that while the touch voltage is reduced, the step voltage is increased when this design is used.

F.2.4 Ground rods only

The behavior of a grounding system consisting only of ground rods may vary greatly from that in uniform soil. The major differences are because the current density in each rod can be much higher in the portion of the rod located in the lower resistivity layer, depending on the value of *K*. As the absolute value of *K* increases, so does the percentage of the current discharged from the portion of the rod located in the lower resistivity layer of soil, as shown in Figure F.12.

Assuming that the rod extends through the top layer into the bottom layer of soil, the current density in the portion of the rod in either layer is essentially uniform with a slight increase near the boundary of that layer. There is an abrupt change in current density, however, at the surface layer depth *h*. For rods that are mainly in the low resistivity layer, there is an appreciably higher current density in the outer rods as compared to rods near the center of the design, but for rods mainly in the high resistivity layer the difference in the current density of the outside and inside rods is much less (see Figure F.14).

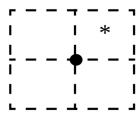
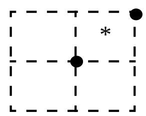
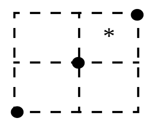
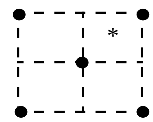
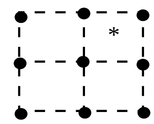
As in the case of the grid, positive values of *K*($\rho_1 < \rho_2$) generally give a higher resistance and negative values of *K*($\rho_1 > \rho_2$) give a lower resistance for a system of ground rods as compared to the identical grounding system in uniform soil with a resistivity of ρ_1. However, as the surface layer height increases, the resistance of the rods for all values of *K* approaches that of the uniform model (see Table F.1).

F.2.5 Grid and ground rod combinations

Depending on the values of *K* and *h*, adding ground rods to a system of grid conductors can have a tremendous effect on the performance of the grounding system. For negative values of *K*($\rho_1 > \rho_2$) and for values of *h* limited so that the rods extend into more conductive soil, the majority of the current is discharged through the rods into the lower layer of soil. Even for large values of h where none of the rod extends into the more conductive soil, the current density is higher in the ground rods than in the grid conductors, as shown in Figure F.17 and Figure F.18.

If *K* is positive($\rho_1 < \rho_2$), the current density for the portion of the ground rods in the upper layer is still higher than that of the grid conductors. For positive values of *K*, the effects of the ground rods become largely dependent on *h*, or on the length of the rods in the more conductive layer. Depending on the magnitude of *K* and *h*, the lengths of the rods are effectively shortened so that they may not contribute significantly to the control of step and touch voltages. However, for moderate positive *K* values and large *h* values, the ground rods can be used to effectively improve the step and touch voltages.

Table F.1—Touch voltages for multiple driven rods

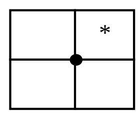
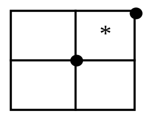
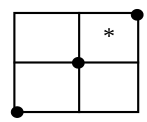
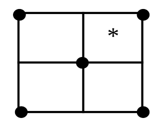
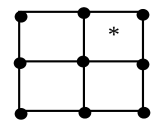
(A) Uniform soil					
	R1	R2	R3	R4	R5
Electrode type					
Resistance (Ω)	11.85	6.43	4.52	3.01	2.16
Touch* Voltage (%)	84.7	72.0	68.2	59.1	40.8
(B) R9 in two-layer soil (*H* = 5 m)					
Reflection factor K	–0.9	–0.5	Uniform soil (0.0)	0.5	0.9
Resistance (Ω)	0.169	0.926	2.16	4.21	8.69
Touch* Voltage (%)	51.1	47.4	40.8	31.8	19.3

If *K* is negative($\rho_1 > \rho_2$), the step and touch voltages are reduced significantly with the addition of ground rods to a system of grid conductors. For small to medium values of *h*, relatively all of the current is discharged into the lower soil layer, thereby reducing the step and touch potentials. As *h* increases, the performance of the grounding system approaches that of an identical system in uniform soil of resistivity ρ_1.

F.3 Summary

The two-layer parameters *h* and *K* discussed above can have considerable influence on the performance of the grounding system. A system designed using the uniform soil techniques can give results for step and touch potentials and station resistance ranging from highly pessimistic to highly optimistic, depending on the specific values of various parameters. Table F.2 summarizes the effects of a two-layer soil environment on touch voltage of adding a ground rod to a grid, and on the touch voltage for a grid-rod combination.

Table F.2—Touch voltages for grid and ground rod combinations in two-layer soil

(A) Uniform soil					
	S4	SR1	SR2	SR3	SR4
Electrode type					
Resistance (Ω)	2.58	—	2.28	2.00	1.81
Touch* Voltage (%)	35.0	—	31.0	25.0	21.0
(B) SR9 in two-layer soil (*H* = 5 m)					
Reflection factor K	–0.9	–0.5	Uniform soil (0.0)	0.5	0.9
Resistance (Ω)	0.164	—	1.81	3.50	7.78
Touch* Voltage (%)	35.0	—	21.0	13.4	6.6

Annex G

(informative)

Grounding methods for high-voltage stations with grounded neutrals

(Erdungsmassnahmen fur Hochstspannungsanlagen mit Geerdetem Sternpunkt)

Walter Koch,[18] *Electrotechnische Zeitschrift,* vol. 71, no. 4, pp. 89-91, Feb. 1950.

It is not economically feasible to provide grounding in high-voltage stations with grounded neutral, which will limit contact potentials to ground electrodes and the connected apparatus to less than 125 V. One has to deal with a multiplicity of potentials which may be established between the plant and the surroundings under short-circuit conditions.

Experiments with models show that by making the ground system in the form of a grid, areas within the system can be produced which will be safe. Means for safe entry into the grounding area will be given.

With a directly grounded neutral point there flows into the system at the fault point the so-called ground-fault current instead of the total single-phase short-circuit ground current (ungrounded system). This ground-fault current depends upon the generating capacity of the power plants in the area and on the impedance of the ground circuit. The grounding systems of a solidly grounded network will carry a portion of the ground-fault current which may be a minimum for faults a great distance from the station and may be a maximum, namely the total ground-fault current, for a fault in the station.

While the grounding systems may be adjusted to eliminate dangerous contact potentials by suppression of ground short-circuit currents, this is not usually demanded of solidly grounded neutral systems because it does not appear to be practicable. For ground-fault currents above 1000 A, grounding systems of vast dimensions must be installed in order to meet the usual 125 V contact potential requirement. A numerical example will show this. The surface area of an outdoor substation may be 250 m × 250 m. Here one has the possibility of placing a ground plate of 62 500 m^2 under the station. With an average ground resistivity of 100 Ω·m and the equivalent circular plate diameter of 280 m the ground resistance is

$$R = \frac{\rho}{2D}$$

or

$$R = \frac{10\ 000}{2 \cdot 28\ 000} = 0.18\Omega$$

With such a ground, a ground-fault current of 5000 A will produce a 900 V potential above the more-distant surroundings which is many times the potential allowed by VDE. In spite of this, it has the indisputable advantage that the entire station on this metal plate will have no potentials between parts within itself that are worth mentioning. For persons inside the station there will not be the slightest danger from undue contact potentials at such a high current. There would be danger only if at the moment of fault one were to enter or leave the plant or touch it from the outside. It is not practical to construct such a ground plate. However, in order not to endanger the personnel of an electrical plant, ways must be sought to fulfill this requirement.

[18]English translation by T. W. Stringfield. Some portions on Petersen coil systems and German (VDE) regulations omitted.

Besides the dangers to personnel, there will be some to the material of the control and communications equipment if it is not provided against. The sheaths of the control cables provide a connection between the controlled apparatus in the high-voltage bays and the control point. Thereby, a fault to ground in the station can cause a very large current to flow through the sheath and melt it. Communication cables which leave the plant will also conduct ground currents away since intentionally or unintentionally they come into contact with building construction parts. Thereby, the sheaths acquire the high potential of the station in their vicinity while the conductors approximate the potential of the more-distant surroundings, so that insulation failures may occur. So likewise the cables of the low-voltage plant and the windings of control motors among others may be endangered by large potential differences. Indeed, for these reasons it is not permissible to rely only on a sufficient interconnection of all apparatus such as circuit breakers, transformer cases, frame parts, etc. To this all cable sheaths within the plant must also be connected; so likewise the control mechanisms in the switching station to which the control cables are connected. Basically the entire plant should be provided with a built-up ground mat for the ground-fault current, to which all equipment parts in the plant are connected. So likewise, the existing neutral conductors of independent low-voltage systems should be tied to the ground mat. By this method there will be the least worry that significant potential differences will arise between the accessible metallic parts of the plant and the plant equipment so protected will be safe from failure.

Now, it is certain that considerable and therefore dangerous potentials can arise between the soil, the floors of buildings on one side, and the metallic parts of the plant during the time of faults. Therefore one must also consider the safety of operating personnel who in the course of their work must touch such metal parts. For this purpose the operating position may be provided either with an insulated floor capable of withstanding the high potential or with a metallic grid in the floor and tied to the ground mat or provided with both. Such metallic foot grids have been previously used for protection in Siemens-Schuckert plants with ungrounded star neutral. They consisted of small meshed wire netting cemented into the floor and tied to the grounding system, and provided absolute protection to persons standing thereon and grasping operating controls in that a highly conducting shunt path was provided between hands and feet.

As mentioned in the introduction, a large metallic plate is a suitable protection against all step potentials and contact potentials within the plant. Since such a metallic plate installation is not realizable, the question arises on how far one can go in substituting a network of ground straps and the necessary mesh spacing in order to obtain tolerable potential differences.

The investigation of the potential distribution of complicated ground electrode arrangements, which such a ground mat is, is not possible by computation, since one can derive formulae only for simple electrode shapes and even simple combinations of these electrode shapes are not amenable to calculation. For mesh-type electrode arrangements with irregular depth of burial which is the way they are used for the purpose of potential control and other complicated grounding structures, one is led to the use of models. For this purpose such model measurements using an electrolytic tank were undertaken. A metal container filled with a conducting solution served as the semi-infinite space for the current diffusion. Figure G.1 shows the circuit of the test arrangement. The potential distribution for model M can be obtained by a null method using the electrode S, the calibrated potentiometer P and telephone receiver T. In order to reduce the electrolytic effect of the chopped direct current supply on the model, a slowly rotating switch U was placed in the direct current supply leads.

The model of the ground mat consisted of a copper wire 0.2 mm in diameter arranged in a square with 120 mm sides and set on the surface. For the usual ground straps with a cross-section of 30 mm × 3 mm corresponding to an equivalent diameter of 23 mm this model represented a replica of a ground system with a length of

$$\frac{20}{0.2} \cdot 120 = 13\ 800\ \text{mm}$$

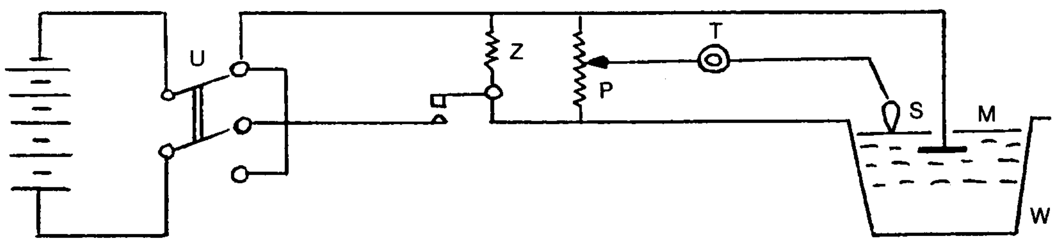


Figure G.1—Circuit for obtaining potential distribution

or 13.8 m on a side. After obtaining the potential distribution, the square was subdivided to contain four squares by the addition of a wire cross, the four subsquares were similarly subdivided until 64 subsquares were attained and in each case the potential inside the square was measured. As the mesh becomes finer the effect approaches a plate electrode. In Figure G.2 through Figure G.5, the potential at the center point of each square is given in percent of the potential of the ground mat. The potential differences which characterize the step potentials and thereby the hazard are according to these figures for fine-mesh electrodes 11–20% of the total potential. The mesh spacing of the mat with 64 meshes is, according to the above-mentioned model scale, 13.8/8 = 1.7 m. The potential distributions in cross-sections through the mats at A-B, C-D, E-F and G-H of Figure G.2 through Figure G.5 are shown in Figure G.6. To determine the effect of only a partial fine mesh inside the outer edge, the arrangement shown in Figure G.7 was investigated and as shown in Figure G.8 with further subdivision of a single mesh. From this it follows that in the area of a fine mesh the same relations (proportions) hold as in the complete meshing of the total grounding area. The still finer subdivision of a single mesh results in a further raising of the potential inside the mesh, that is, a corresponding decrease of the potential differences and thereby the step potential.

The measurements show, as might be expected, that by using a fine mesh a considerable reduction in potential differences within the mat area can be obtained. Further, it is apparent that small protected areas can be produced by partial matting without completely matting the entire grounding area. Practical application of such finer meshing can be found principally in outdoor stations in the neighborhood of accessible equipment where the hazard is greatest.

A reduction of the effect, which will not completely eliminate potential differences, can be arrived at by a fill of coarse grit (gravel) to a depth of about 1 cm over such a ground grid. With this, everything practical has been done in order to minimize the hazard, if not to eliminate it entirely.

To be sure, there remain the locations of the passageways to the protected areas which remain a hazard when traveling over them during the time of a fault. Figure G.6 shows the high potential drops at the edges of the wide meshed areas, where step potentials of about 45% of the total potential to the ground electrode can be encountered. If one must obtain absolute safety, then on the passageways one must resort to the so-called potential ramps in order to obtain a small, and as far as possible, uniform potential drop. Wooden passageways have likewise already been used in the Siemens-Schuckert works in 200 kV stations.

The means of potential control through grounding straps buried at progressively deeper depths is shown in principle in Figure G.9, the effectiveness of which was proved by the leveling off of the potential surface in a model. Figure G.10 shows the application of potential control around the footing of a tower when one does not desire to, or is not able to, employ a fence.

The magnitude of the expected step potential for a ground mat depends upon the ground resistance, the short-circuit current and the mesh density. If one takes the area of an outdoor substation 250 m square, then a ground strap around the periphery will be 1000 m long. Without regard to the cross connections and matted grounds, the ground resistance of this strap is $R = \rho/\pi L \ln(2L/d)$; where ρ is the ground resistivity (generally 100 Ω·m), L is the length of the strap in centimeters, and d is the equivalent diameter of the strap as a conductor with a semicircular cross-section (for the usual ground-strap d = 2.3 cm). With these figures R = 0.36 Ω. The resistance is thus only twice as great as for a solid plate 250 × 250 m. The reactance will be reduced by the cross-connections which are required for tying in the apparatus to be grounded.

With a short-circuit current of, for example, 5000 A, the voltage to the ground system will be about 1800 V. With a ground rating as shown in Figure G.5, the greatest step potential to be expected will be about 11–12% of this value, or 200 V, the effect of which on persons can be reduced effectively by using gravel fill. According to Figure G.8, with a mesh spacing of 0.85 m the potential inside the mesh is 7% of the ground mat potential and for a ground mat potential of 1800 V the step potential can thereby be reduced below 125 V if necessary.

The systematic application of the protective measures described makes the separation of the operating ground from the protective ground superfluous. The separation of operating and protective grounds gives no protection for faults inside the station and from experience these must be considered. The installation of a separated star neutral ground system requires a tremendous amount of land outside the station. There is no advantage worth mentioning for this since a protective ground is still required inside the station. It therefore can only be recommended that the star-neutral point be connected to a suitable ground system as described in the foregoing or otherwise for a separate grounding system to employ the requisite materials for an ample development of the protective ground system.

Tying together both systems (protective and operating) has the noteworthy advantage that for a ground fault within the station the ground-fault current component of the faulted station need not be carried by the ground mat but is conducted directly over the grounding conductors which are tied to the star neutral point. Also, one has only to reckon with the difference between the total ground-fault current and the station component, whereby there is a considerable reduction in ground mat potential and step potential.

The overhead ground wire of the outgoing station transmission lines may be advantageously connected to the station ground, and effectively reduce the total ground resistance; this is especially so where the ground wire which appears to be necessary for star neutral grounded systems with high ground-fault currents is of ample design.

Summary

Large contact and step potentials under fault conditions must be considered in high-voltage stations using grounded star neutral point. Potential differences which may endanger cable insulation and low-voltage apparatus and facilities (for example, windings of control motors) may be eliminated by metallic interconnection of equipment housing, sheaths of control and service cables and their neutral conductors, and the construction parts in the control house. For protection of personnel at the danger points, narrow meshed ground mats with mesh spacing of about 1 m will serve. The potential distribution of such ground mats may be investigated by means of electrolytic tanks. A separate operating ground for the star neutral point is not recommended, since connection of the latter to a general ground system designed according to the viewpoint outlined herein, has advantages over separation. Approaches to parts of the ground system which have potential control can be made safe by the so-called potential ramps.

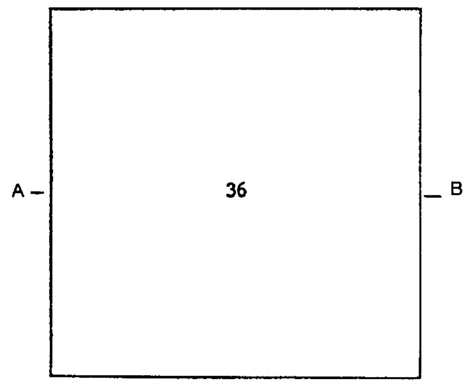


Figure G.2—Measured potential distribution for various ground mats

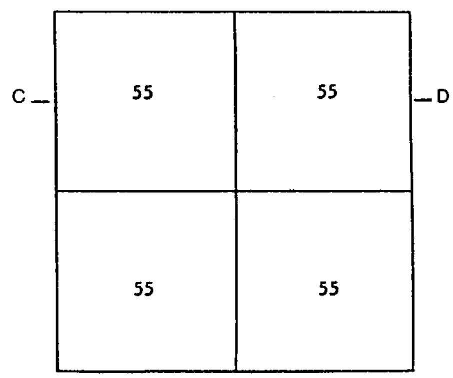


Figure G.3—Measured potential distribution for various ground mats

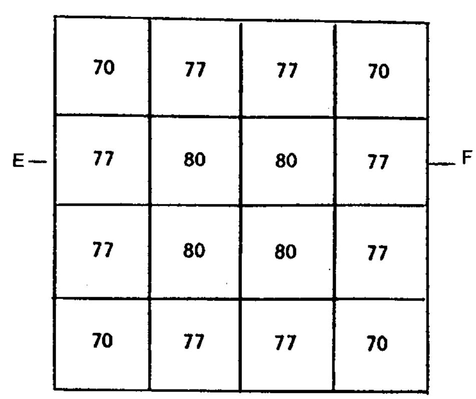


Figure G.4—Measured potential distribution for various ground mats

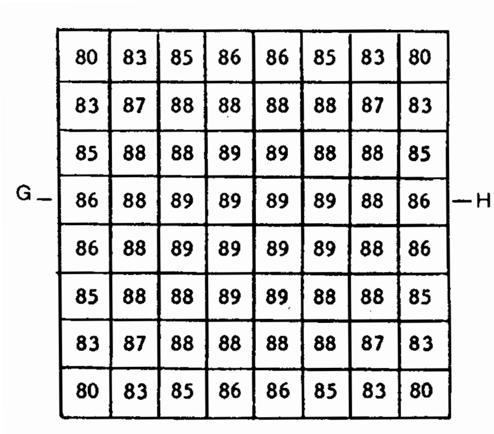


Figure G.5—Measured potential distribution for various ground mats

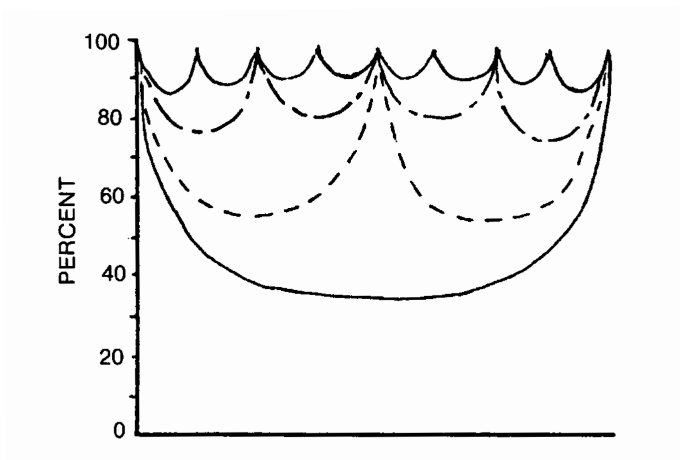


Figure G.6—Potential distribution for a ground mat with various mesh densities; ground mat potential = 100%

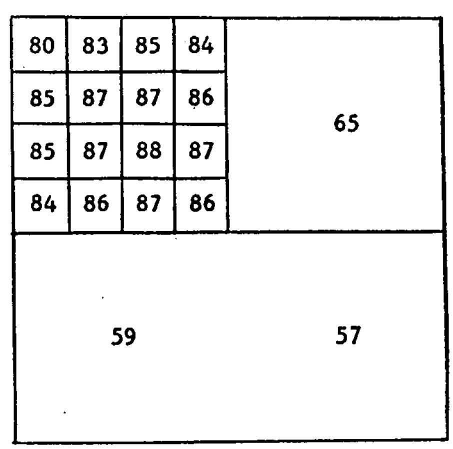


Figure G.7—Potential distribution for ground mats with fine meshes in portions

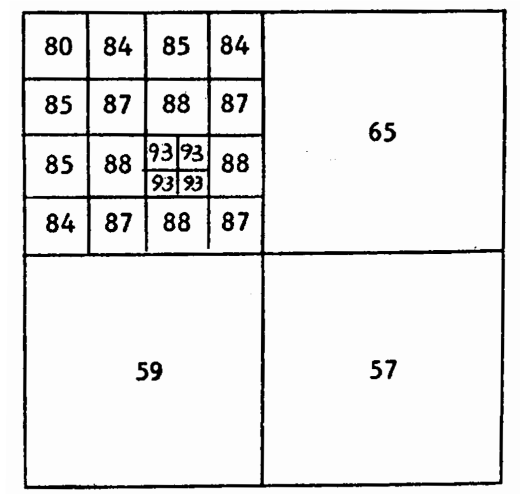


Figure G.8—Potential distribution for ground mats with fine meshes in portions

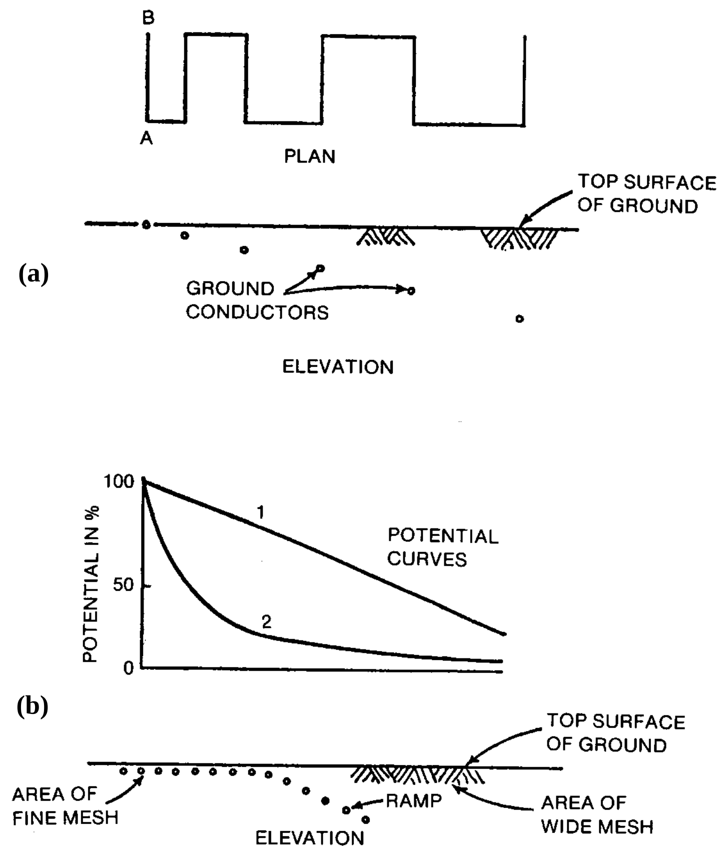


Figure G.9—Potential distribution in a ground mat with ramp (Curve 1) and without ramp (Curve 2)

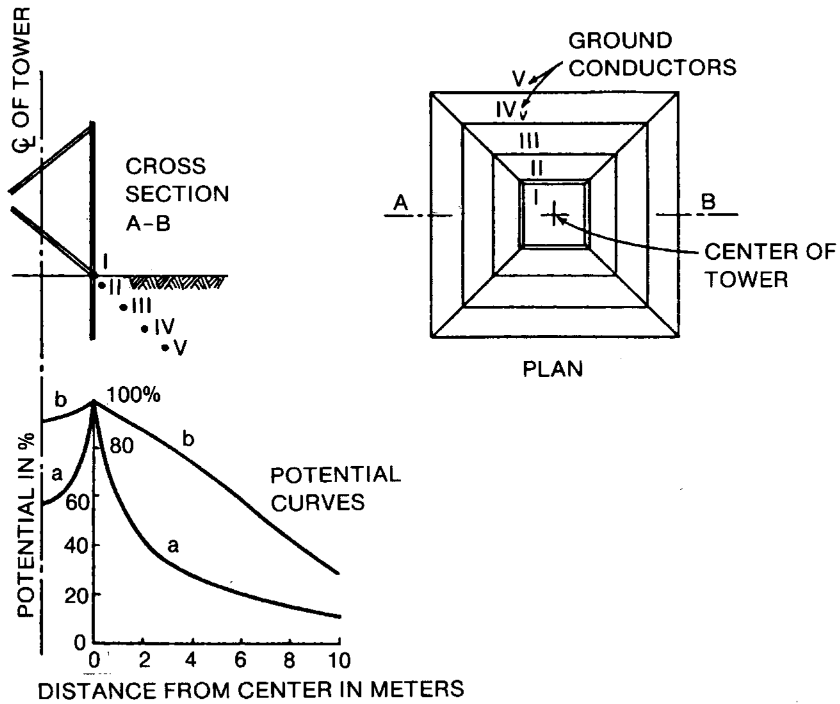


Figure G.10—Potential distribution around a mast footing in the direction A-B for a mast with ramp (Curve b) and without ramp (Curve a)

DIRECTIVA 2006/95/CE DO PARLAMENTO EUROPEU E DO CONSELHO

de 12 de Dezembro de 2006

relativa à harmonização das legislações dos Estados-Membros no domínio do material eléctrico destinado a ser utilizado dentro de certos limites de tensão

(versão codificada)

(Texto relevante para efeitos do EEE)

O PARLAMENTO EUROPEU E O CONSELHO DA UNIÃO EUROPEIA,

Tendo em conta o Tratado que institui a Comunidade Europeia, nomeadamente o artigo 95.º,

Tendo em conta a proposta da Comissão,

Tendo em conta o parecer do Comité Económico e Social Europeu [1],

Deliberando nos termos do artigo 251.º do Tratado [2],

Considerando o seguinte:

(1) A Directiva 73/23/CEE do Conselho, de 19 de Fevereiro de 1973, relativa à harmonização das legislações dos Estados-Membros no domínio do material eléctrico destinado a ser utilizado dentro de certos limites de tensão [3], foi substancialmente alterada [4]. Por uma questão de clareza e racionalidade, é necessário proceder à sua codificação.

(2) As disposições que se encontram em vigor nos Estados-Membros com vista a garantir a segurança de utilização do material eléctrico destinado a ser usado dentro de certos limites de tensão obedecem a concepções diferentes, o que cria entraves ao comércio.

(3) Em certos Estados-Membros, e para certos materiais eléctricos, o legislador recorreu, para atingir esse objectivo de segurança, a medidas preventivas e repressivas por meio de disposições de natureza imperativa.

(4) Noutros Estados-Membros, o legislador, para atingir esse mesmo objectivo, recorre a normas técnicas elaboradas por institutos de normalização. Este sistema apresenta a vantagem de uma adaptação rápida ao progresso técnico, sem que por isso sejam negligenciados os imperativos de segurança.

(5) Certos Estados-Membros procedem a operações de carácter administrativo para aprovação das normas. A aprovação não afecta em nada o conteúdo técnico das normas nem limita as suas condições de utilização. Tal aprovação não pode pois alterar, do ponto de vista comunitário, os efeitos de uma norma harmonizada e homologada.

(6) No plano comunitário, deverá ser permitida a livre circulação do material eléctrico, sempre que este respeite certas exigências em matéria de segurança reconhecidas por todos os Estados-Membros. Sem prejuízo de qualquer outro processo de verificação, o respeito pelo cumprimento dessas exigências pode ser estabelecido por recurso a normas harmonizadas que as concretizem. Essas normas deverão ser elaboradas de comum acordo por organismos que são objecto de notificação por cada Estado-Membro aos outros Estados-Membros e à Comissão e deverão ser objecto de uma ampla publicidade. Uma tal harmonização deverá permitir eliminar, no plano comercial, os inconvenientes resultantes das divergências entre as normas nacionais.

(7) Sem prejuízo de qualquer outro processo de verificação, pode presumir-se existir conformidade do material eléctrico com essas normas harmonizadas pela fixação ou emissão de marcas ou de certificados sob a responsabilidade de organismos competentes, ou, na sua falta, pela declaração de conformidade feita pelo fabricante. No entanto, os Estados-Membros deverão aceitar, como elementos de prova, essas marcas ou certificados, ou a referida declaração, a fim de facilitar a eliminação dos entraves ao comércio. Para tal efeito, essas marcas ou certificados deverão ser publicitados, nomeadamente, pela publicação no *Jornal Oficial da União Europeia*.

(8) No que respeita ao material eléctrico para o qual não existem ainda normas harmonizadas, pode assegurar-se, transitoriamente, a sua livre circulação recorrendo a normas ou disposições em matéria de segurança já elaboradas por outros organismos internacionais ou por um dos organismos que elabore normas harmonizadas.

(9) O material eléctrico pode ser posto em livre circulação sem responder ao exigido em matéria de segurança e é necessário, portanto, prever disposições adequadas para eliminar esse perigo.

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(1) JO C 10 de 14.1.2004, p. 6.

(2) Parecer do Parlamento Europeu de 21 de Outubro de 2003 (JO C 82 E de 1.4.2004, p. 68) e decisão do Conselho de 14 de Novembro de 2006.

(3) JO L 77 de 26.3.1973, p. 29. Directiva com a redacção que lhe foi dada pela Directiva 93/68/CEE (JO L 220 de 30.8.1993, p. 1).

(4) Ver Parte A do Anexo V.

(10) A Decisão 93/465/CEE do Conselho [1] determina os módulos referentes às diversas fases dos procedimentos de avaliação da conformidade destinados a ser utilizados nas directivas de harmonização técnica.

(11) A escolha dos procedimentos não deverá conduzir à redução do nível da segurança do material eléctrico já estabelecido na Comunidade.

(12) A presente directiva não deverá afectar as obrigações dos Estados-Membros relativas aos prazos de transposição para o direito interno e de aplicação das directivas constantes da Parte B do Anexo V,

APROVARAM A PRESENTE DIRECTIVA:

Artigo 1.º

Para efeitos da presente directiva, entende-se por «material eléctrico» todo o material eléctrico destinado a ser utilizado sob uma tensão nominal compreendida entre 50 e 1 000 V para a corrente alterna, e entre 75 e 1 500 V para a corrente contínua, com excepção dos materiais e fenómenos referidos no Anexo II.

Artigo 2.º

1. Os Estados-Membros devem tomar todas as medidas necessárias para que o material eléctrico não possa ser colocado no mercado senão quando construído de acordo com as regras da arte em matéria de segurança válidas na Comunidade, de modo a não comprometer, no caso de instalação e manutenção adequadas e de utilização de acordo com a sua finalidade, a segurança de pessoas, animais domésticos e bens.

2. O Anexo I resume os principais elementos dos objectivos de segurança a que se refere o n.º 1.

Artigo 3.º

Os Estados-Membros devem assegurar que as empresas não levantem obstáculos, por razões de segurança, à livre circulação, na Comunidade, do material eléctrico que respeite o disposto no artigo 2.º, de acordo com as condições previstas nos artigos 5.º, 6.º, 7.º ou 8.º.

Artigo 4.º

Os Estados-Membros devem assegurar que as empresas distribuidoras de electricidade não subordinem a ligação à rede e a alimentação de electricidade aos consumidores, no que disser respeito a material eléctrico, a exigências em matéria de segurança mais rigorosas que as previstas no artigo 2.º.

Artigo 5.º

Tendo em vista a colocação no mercado referida no artigo 2.º ou a livre circulação referida no artigo 3.º, os Estados-Membros devem tomar todas as medidas necessárias para que as respectivas entidades administrativas competentes considerem que o material eléctrico que satisfaça as prescrições em matéria de segurança definidas nas normas harmonizadas está de acordo com o disposto no artigo 2.º.

As normas são consideradas harmonizadas quando, tendo sido elaboradas de comum acordo pelos organismos notificados pelos Estados-Membros nos termos da alínea a) do primeiro parágrafo do artigo 11.º, forem publicadas de acordo com as legislações nacionais. As normas devem ser actualizadas em função do progresso tecnológico e da evolução das regras da arte em matéria de segurança.

A lista das normas harmonizadas e as respectivas referências serão publicadas, a título informativo, no *Jornal Oficial da União Europeia*.

Artigo 6.º

1. Sempre que não existam, elaboradas e publicadas, normas harmonizadas nos termos do artigo 5.º, e tendo em vista a colocação no mercado referida no artigo 2.º ou a livre circulação referida no artigo 3.º, os Estados-Membros devem tomar todas as medidas necessárias para que as respectivas entidades administrativas competentes considerem que um material eléctrico está de acordo com o disposto no artigo 2.º desde que satisfaça as regras de segurança da Comissão Internacional das Regulamentações para a Aprovação de Equipamento Eléctrico (CEE-el), ou da «International Electrotechnical Commission» (IEC — Comissão Electrotécnica Internacional) que respeitem o processo de publicação previsto nos n.ºs 2 e 3.

2. As disposições de segurança referidas no n.º 1 são notificadas aos Estados-Membros pela Comissão a partir da entrada em vigor da presente directiva e, seguidamente, a partir da respectiva publicação. A Comissão deve indicar, após consulta prévia dos Estados-Membros, as disposições de segurança e, em especial, as respectivas alterações para as quais é recomendada a publicação.

3. Os Estados-Membros devem comunicar à Comissão, no prazo de três meses, as eventuais objecções às disposições que lhe foram notificadas, com indicação dos motivos que, por razões de segurança, justificam a sua oposição à aceitação de qualquer dessas disposições.

As disposições que não tenham levantado objecções são publicadas, a título informativo, no *Jornal Oficial da União Europeia*.

Artigo 7.º

Sempre que não existam normas harmonizadas nos termos do artigo 5.º ou regras de segurança publicadas nos termos do artigo 6.º, e tendo em vista a colocação no mercado referida no artigo 2.º ou a livre circulação referida no artigo 3.º, os Estados-Membros devem tomar todas as medidas necessárias para que as respectivas entidades administrativas competentes considerem igualmente que o material eléctrico fabricado de acordo com as regras de segurança contidas nas normas aplicadas pelo Estado-Membro em que o material foi produzido respeita o disposto no artigo 2.º, desde que fique garantida uma segurança equivalente à que é requerida no seu próprio território.

[1] Decisão 93/465/CEE do Conselho, de 22 de Julho de 1993, relativa aos módulos referentes às diversas fases dos procedimentos de avaliação da conformidade e às regras de aposição e de utilização da marcação «CE» de conformidade, destinados a ser utilizados nas directivas de harmonização técnica (JO L 220 de 30.8.1993, p. 23).

Artigo 8.º

1. Antes da colocação no mercado, o material eléctrico deve ser munido da marcação «CE», tal como prevista no artigo 10.º, indicativa da respectiva conformidade com as disposições da presente directiva, incluindo o procedimento de avaliação de conformidade descrito no Anexo IV.

2. Em caso de divergência, o construtor ou o importador pode apresentar um relatório elaborado por um organismo notificado, nos termos da alínea b) do primeiro parágrafo do artigo 11.º para comprovação da conformidade do material eléctrico com o disposto no artigo 2.º.

3. Quando um material eléctrico for objecto de outras directivas relativas a outros aspectos e que prevejam a aposição da marcação «CE» de conformidade, esta deve indicar que se presume igualmente que esse material é conforme com as disposições dessas outras directivas.

Todavia, no caso de uma ou mais dessas directivas deixarem ao fabricante, durante um período transitório, a escolha do regime a aplicar, a marcação «CE» indica apenas a conformidade do material eléctrico com as disposições das directivas aplicadas pelo fabricante. Nesse caso, as referências dessas directivas tais como publicadas no *Jornal Oficial da União Europeia* devem ser inscritas nos documentos, manuais ou instruções exigidos por essas directivas e que acompanhem esse material.

Artigo 9.º

1. Se, por razões de segurança, um Estado-Membro proibir a colocação no mercado de um material eléctrico ou levantar obstáculos à sua livre circulação, deve informar imediatamente os outros Estados-Membros interessados, assim como a Comissão, indicando as razões da sua decisão e especificando, nomeadamente:

a) Se a não conformidade com o disposto no artigo 2.º resulta de lacuna nas normas harmonizadas a que se refere o artigo 5.º, das prescrições referidas no artigo 6.º ou das normas referidas no artigo 7.º;

b) Se a não conformidade com o disposto no artigo 2.º resulta de uma deficiente aplicação das referidas normas ou documentos, ou do não cumprimento das regras da arte a que se refere esse artigo.

2. Se outros Estados-Membros levantarem objecções a uma decisão tomada nos termos do n.º 1, a Comissão deve consultar imediatamente os Estados-Membros interessados.

3. Se não for possível obter um acordo dentro de um prazo de três meses, contados a partir da data do aviso referido no n.º 1, a Comissão deve obter o parecer de um dos organismos notificados nos termos da alínea b) do primeiro parágrafo do artigo 11.º sediado fora do território dos Estados-Membros interessados e que não tenha participado nas acções referidas no artigo 8.º. O parecer deve indicar quais os aspectos em que as disposições do artigo 2.º não foram respeitadas.

4. A Comissão deve comunicar o parecer do organismo referido no n.º 3 a todos os Estados-Membros, os quais podem apresentar as suas observações no prazo de um mês. Simultaneamente, a Comissão toma conhecimento das observações das partes interessadas relativamente ao referido parecer.

5. Após ter tomado conhecimento de todas as observações, a Comissão deve formular, se for caso disso, as recomendações ou pareceres apropriados.

Artigo 10.º

1. A marcação «CE» de conformidade referida no Anexo III deve ser aposta pelo fabricante ou o seu mandatário estabelecido na Comunidade nos materiais eléctricos ou, na sua falta, nas embalagens, nas instruções de utilização ou nos cartões de garantia, de modo visível, facilmente legível e indelével.

2. É proibido apor nos materiais eléctricos qualquer outra marcação, sinal ou indicação susceptível de induzir terceiros em erro quanto ao significado ou ao grafismo da marcação «CE». Pode ser aposta nos materiais eléctricos, nas suas embalagens, nas instruções de utilização ou nos cartões de garantia qualquer outra marcação, desde que não reduza a visibilidade e a legibilidade da marcação «CE».

3. Sem prejuízo do artigo 9.º:

a) A verificação por um Estado-Membro de que a aposição da marcação «CE» foi indevida implica a obrigação, por parte do fabricante ou do seu mandatário estabelecido na Comunidade, de repor o produto em conformidade no que diz respeito às disposições relativas à marcação «CE» e de fazer cessar a infracção nas condições fixadas por esse Estado-Membro;

b) No caso de a não conformidade persistir, o Estado-Membro deve tomar todas as medidas adequadas para restringir ou proibir a colocação no mercado do produto em questão, ou assegurar a sua retirada do mercado, nos termos do artigo 9.º.

Artigo 11.º

Cada Estado-Membro deve comunicar aos outros Estados-Membros e à Comissão:

a) A lista dos organismos referidos no segundo parágrafo do artigo 5.º;

b) A lista dos organismos que podem elaborar os relatórios referidos no n.º 2 do artigo 8.º ou dar pareceres de acordo com o artigo 9.º;

c) As referências de publicação referidas no segundo parágrafo do artigo 5.º.

Cada Estado-Membro deve comunicar aos outros Estados-Membros e à Comissão qualquer alteração às referidas informações.

Artigo 12.º

A presente directiva não se aplica ao material eléctrico destinado à exportação para países terceiros.

Artigo 13.º

Os Estados-Membros devem comunicar à Comissão o texto das disposições fundamentais de direito interno que forem adoptadas no âmbito da presente directiva.

Artigo 14.º

É revogada a Directiva 73/23/CEE, sem prejuízo das obrigações dos Estados-Membros relativas aos prazos de transposição para o direito interno e de aplicação das directivas constantes da Parte B do Anexo V.

As remissões para a directiva revogada devem entender-se como sendo feitas para a presente directiva e ler-se nos termos do quadro de correspondência constante do Anexo VI.

Artigo 15.º

A presente decisão entra em vigor no vigésimo dia seguinte ao da sua publicação no *Jornal Oficial da União Europeia*.

Artigo 16.º

Os Estados-Membros são os destinatários da presente decisão.

Feito em Estrasburgo, em 12 de Dezembro de 2006.

Pelo Parlamento Europeu	*Pelo Conselho*
O Presidente	*O Presidente*
J. BORRELL FONTAILLES	M. PEKKARINEN

ANEXO I

Principais Elementos dos Objectivos de Segurança para o Material Eléctrico Destinado a Ser utilizado dentro de Certos Limites de Tensão

1. Condições gerais

a) As características essenciais do material eléctrico cujo conhecimento e cumprimento sejam indispensáveis para uma utilização isenta de perigos e de acordo com o fim a que o material se destina serão afixadas no próprio material, ou, em caso de impossibilidade, num documento que o acompanhe;

b) A marca de fabrico ou a marca comercial será aposta de forma bem visível no material eléctrico ou, se isso não for possível, na embalagem;

c) Tanto o material eléctrico como as partes que o constituem serão fabricados de modo a poder ser montados de forma segura e adequada;

d) O material eléctrico será projectado e fabricado de tal modo que fique garantida a protecção contra os riscos mencionados nos pontos 2 e 3 do presente anexo, desde que seja utilizado de acordo com o fim a que se destina e que seja objecto de uma manutenção adequada.

2. Protecção contra os riscos resultantes do material eléctrico

Serão previstas medidas de ordem técnica de acordo com o ponto 1, a fim de que:

a) As pessoas e os animais domésticos fiquem protegidos de forma adequada contra os riscos de ferimentos ou de outros acidentes resultantes de contactos directos ou indirectos;

b) Não se produzam temperaturas, descargas ou radiações que possam provocar perigo;

c) As pessoas, os animais domésticos e os bens sejam protegidos de forma adequada contra os riscos de natureza não eléctrica provenientes do material eléctrico que a experiência venha a revelar;

d) O isolamento seja adequado aos condicionamentos previstos.

3. Protecção contra os riscos que possam ser provocados por influências exteriores sobre o material eléctrico

Serão previstas medidas de ordem técnica de acordo com o ponto 1, a fim de que:

a) O material eléctrico responda às exigências mecânicas previstas, de modo a não pôr em perigo as pessoas, os animais domésticos e os bens;

b) O material eléctrico resista às influências não mecânicas nas condições ambientes previstas, de modo a não pôr em risco as pessoas, os animais domésticos e os bens;

c) O material eléctrico não ponha em risco as pessoas, os animais domésticos e os bens nas condições de sobrecarga previstas.

ANEXO II

Material e Fenómenos excluídos do Campo de aplicação da presente Directiva

Equipamento eléctrico destinado a ser utilizado numa atmosfera explosiva.

Equipamento eléctrico para radiologia e para medicina.

Partes eléctricas dos elevadores e monta-cargas.

Contadores eléctricos.

Tomadas de corrente (bases e fichas) para uso doméstico.

Dispositivos de alimentação de vedações electrificadas.

Perturbações radioeléctricas.

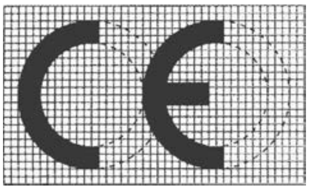
Material eléctrico especializado, para utilização em navios ou aviões e nos caminhos-de-ferro, que satisfaça as regras de segurança estabelecidas pelos organismos internacionais de que os Estados-Membros façam parte.

ANEXO III

Marcação «CE» de Conformidade e Declaração «CE» de Conformidade

A. Marcação «CE» de conformidade

A marcação «CE» de conformidade é constituída pelas iniciais «CE», de acordo com o seguinte grafismo:



— No caso de redução ou ampliação da marcação «CE», devem ser respeitadas as proporções resultantes do grafismo graduado acima indicado.

— Os diferentes elementos da marcação «CE» devem ter sensivelmente a mesma dimensão vertical, que não pode ser inferior a 5 milímetros.

B. Declaração «CE» de conformidade

A declaração «CE» de conformidade deve conter os seguintes elementos:

— nome e morada do fabricante ou do seu mandatário estabelecido na Comunidade,

— descrição do material eléctrico,

— referência às normas harmonizadas,

— se aplicável, referência às especificações em relação às quais a conformidade é declarada,

— identificação do signatário com competência para vincular o fabricante ou o seu mandatário estabelecido na Comunidade,

— os dois últimos algarismos do ano de aposição da marcação «CE».

ANEXO IV

Controlo Interno de Fabrico

1. O controlo interno de fabrico é o procedimento pelo qual o fabricante, ou o seu mandatário estabelecido na Comunidade, que satisfaça as obrigações previstas no ponto 2, assegura e declara que o material eléctrico satisfaz as exigências aplicáveis da presente directiva. O fabricante ou o seu mandatário estabelecido na Comunidade deve apor a marcação «CE» em cada produto e redigir uma declaração de conformidade.

2. O fabricante preparará a documentação técnica descrita no ponto 3. O fabricante, ou o seu mandatário estabelecido na Comunidade, manterá essa documentação no território da Comunidade à disposição das autoridades nacionais, para efeitos de inspecção, durante pelo menos dez anos a contar da última data de fabrico do produto.

   Quando nem o fabricante nem o seu mandatário estiverem estabelecidos na Comunidade, essa obrigação cabe à pessoa responsável pela colocação do material eléctrico no mercado comunitário.

3. A documentação técnica deve permitir a avaliação da conformidade do material eléctrico com os requisitos da presente directiva e abranger, na medida do necessário para essa avaliação, a concepção, o fabrico e o funcionamento desse material. Deve conter:

   — uma descrição geral do material eléctrico,

   — desenhos de projecto e de fabrico, bem como esquemas dos componentes, submontagens, circuitos, etc.,

   — as descrições e explicações necessárias à compreensão dos referidos desenhos e esquemas e do funcionamento do material eléctrico,

   — uma lista das normas aplicadas total ou parcialmente e uma descrição das soluções adoptadas para cumprir os requisitos de segurança da presente directiva quando não tiverem sido aplicadas normas,

   — os resultados dos cálculos de projecto, dos controlos efectuados, etc.,

   — os relatórios de ensaio.

4. O fabricante ou o seu mandatário devem conservar, com a documentação técnica, um exemplar da declaração de conformidade.

5. O fabricante tomará todas as medidas necessárias para que o processo de fabrico garanta a conformidade dos produtos fabricados com a documentação técnica mencionada no ponto 2 e com os requisitos aplicáveis da presente directiva.

ANEXO V

Parte A

Directiva revogada e sua alteração

Directiva 73/23/CEE do Conselho	(JO L 77 de 26.3.1973, p. 29)
Directiva 93/68/CEE do Conselho	(JO L 220 de 30.8.1993, p. 1)
Apenas artigo 1.º, ponto 12 e artigo 13.º	

Parte B

Prazos de transposição para o direito interno e de aplicação

(referidos no artigo 14.º)

Directiva	Termo do prazo de transposição	Data de início de aplicação
73/23/CEE	21 de Agosto de 1974 (1)	—
93/68/CEE	1 de Julho de 1994	1 de Janeiro de 1995 (2)

(1) No caso da Dinamarca, o prazo foi prorrogado por cinco anos, ou seja, tem termo em 21 de Fevereiro de 1978. Ver n.º 1 do artigo 13.º da Directiva 73/23/CEE.

(2) Os Estados-Membros tiveram que admitir, até 1 de Janeiro de 1997, a colocação no mercado e a entrada em serviço dos produtos conformes com os regimes de marcação em vigor antes de 1 de Janeiro de 1995. Ver ponto 2 do artigo 14.º da Directiva 93/68/CEE.

ANEXO VI

Quadro de Correspondência

Directiva 73/23/CEE	Presente Directiva
Artigos 1.º- 7.º	Artigos 1.º- 7.º
Artigo 8.º, n.º 1	Artigo 8.º, n.º 1
Artigo 8.º, n.º 2	Artigo 8.º, n.º 2
Artigo 8.º, n.º 3, alínea a)	Artigo 8.º, n.º 3, primeiro parágrafo
Artigo 8.º, n.º 3, alínea b)	Artigo 8.º, n.º 3, segundo parágrafo
Artigo 9.º, n.º 1, primeiro travessão	Artigo 9.º, n.º 1, alínea a)
Artigo 9.º, n.º 1, segundo travessão	Artigo 9.º, n.º 1, alínea b)
Artigo 9.º, n.ºs 2 a 5	Artigo 9.º, n.ºs 2 a 5
Artigo 10.º	Artigo 10.º
Artigo 11.º, primeiro travessão	Artigo 11.º, alínea a)
Artigo 11.º, segundo travessão	Artigo 11.º, alínea b)
Artigo 11.º, terceiro travessão	Artigo 11.º, alínea c)
Artigo 12.º	Artigo 12.º
Artigo 13.º, n.º 1	—
Artigo 13.º, n.º 2	Artigo 13.º
—	Artigo 14.º
—	Artigo 15.º
Artigo 14.º	Artigo 16.º
Anexos I — IV	Anexos I — IV
—	Anexo V
—	Anexo VI

ANEXO III

Documentos consultados

A Reply to Mr. Edison
Author(s): George Westinghouse, Jr.
Reviewed work(s):
Source: *The North American Review*, Vol. 149, No. 397 (Dec., 1889), pp. 653-664
Published by: University of Northern Iowa
Stable URL: http://www.jstor.org/stable/25101904
Accessed: 21/03/2012 17:21

A REPLY TO MR. EDISON.

BY GEORGE WESTINGHOUSE, JR., PRESIDENT OF THE WESTINGHOUSE ELECTRIC COMPANY.

No one will now question the great benefit of the electric light to the public. By the rays of the brilliant arc lamp our streets are better lighted than ever before, with a corresponding increase in security both to life and property, while the incandescent lamp supplies our homes with the most agreeable artificial illumination known to science, and one which, at the same time, is absolutely free from the deleterious products of combustion incident to the use of gas or oil.

The use of electricity for supplying light and power has now become as much a part of our every-day life as the railway, the steamship, the street-car, or the gas supply. In fact, we live in a time when power is made in every way subservient to the comfort of the people. It is employed in nearly every useful industry, with a full knowledge that such employment has been and always must be attended with an appreciable degree of danger. Electricity is one manifestation of power. It represents a form of mechanical energy capable of being utilized for innumerable purposes. Indeed, were it a question of prohibiting the use not merely of electricity, but of all other things dangerous to life, we would no longer have fires to warm us or light to enable us to see, and, in fact, would be deprived of most of the necessaries and comforts of existence. As has been the case with the utilization of all other forms of energy, the demand for the most economical methods will ultimately prevail, provided these can be made safe, as they most certainly can, by the exercise of proper precautions.

Electric lighting, unlike many other industries protected by patents, has been followed with keen interest at every step by the public at large, but among more immediately interested parties the struggle for the control of the electric light and power business has never been exceeded in bitterness by any of the historical commercial controversies of a former day. Thousands of persons have large pecuniary interests at stake, and, as might be expected, many of them view this great subject solely from the stand-point of self-interest. That the public may to some extent understand the mass of literature now being printed with reference to the use of electric currents of both high and low tension, it is necessary that something of the story of this business rivalry should be told.

The successful use of the Jablochkoff electric light in Paris, in 1878, was the beginning of a new era in a field which had not remained wholly uncultivated during the preceding thirty years, although with unimportant commercial results. In 1877 and 1878 we find William E. Sawyer, Charles F. Brush, Hiram S. Maxim, Edward Weston, Thomas A. Edison, and others entering this alluring field of invention. In 1877 Sawyer took out three patents of more than ordinary importance in view of what has since become the practice in electric lighting. Early in 1878 he associated with himself Albon Man, who became a joint inventor with him of several electric-lighting inventions, the promising results from which led to the formation, on July 8 of that year, of the Electro-Dynamic Light Company of New York. The objects for which this company was formed were stated as follows:

"The production of light and power by means of electricity; the lighting of streets, buildings, and other places; producing, conducting, and distributing electrical currents for lighting and other purposes, and the manufacture and sale of all machinery necessary for or adapted to accomplish the purposes named."

Charles F. Brush early invented and perfected a dynamo, an arc lamp, and a method of operation whereby a number of such arc lamps could be used on one circuit, principally for street-lighting purposes. To make and sell Mr. Brush's inventions, there was organized the Brush Electric-Light Company, of Cleveland, Ohio.

In September, 1878, appeared the first announcement of Mr. Edison's discoveries in electric lighting, and on October 17, three months after the formation of the Electro-Dynamic Company to operate Sawyer and Man's electric-light inventions, the Edison Electric-Light Company, of New York, was organized. To introduce the inventions of Maxim and Weston, there was formed the

United States Electric-Lighting Company, of New York, and thus four large corporations were started almost simultaneously upon a career of competitive business. The energy and money since expended by each of these corporations in efforts to thwart the progress of the others has mutually embittered the interested parties to a degree that can with difficulty be comprehended by those not immediately concerned in the strife.

Mr. Edison, already a well-known inventor in telegraphy, apparently had his attention drawn to this subject by a visit to Mr. William Wallace, of Ansonia, Conn., in September, 1878. There he saw Mr. Wallace's dynamos feeding eight electric lights at one time, and also witnessed the transmission of power by electricity from the Naugatuck River, a quarter of a mile distant. The spirit in which he entered the electric-light business would seem to be indicated in the following extract from the New York *Tribune* of September 28, 1878:

> "Mr. Wallace's machines produce electricity which can be made available for electric light." Mr. Edison continued: "I have let the other inventors get the start of me in this matter somewhat, because I have not given much attention to electric lights, but I believe I can catch up to them now." . . . "Now that I have a machine (Wallace's) to make the electricity, I can experiment as much as I please." "I think," he added, smiling, "there is where I can beat the other inventors, as I have so many facilities here for trying experiments." "If you can make the electric light supply the place of gas, you can easily make a great fortune," the reporter suggested. "I don't care so much for a fortune," Mr. Edison replied, "as I do for getting ahead of the other fellows."

Setting out with this determination, it is perhaps no wonder he has worked so energetically. Reviewing his inventions and utterances, it is evident that he believed from the beginning that the system of gas-distribution was the thing to be copied, and that electric conductors could be laid under the streets with branches or connections to each house, supplied by generators located in central stations; but this system necessitated the limitation of the electric pressure to that which the lamps could be made to endure—in practice about 110 volts. The formidable quantities of copper required to conduct the necessary volume of current at this low pressure soon led to the development of what is known as the Edison "three-wire" system of distribution, an improvement founded upon earlier patents of Sawyer and Brush. This system permits a pressure of 220 volts on a circuit equipped with 110-volt lamps, and requires for the whole installation only one-quarter of the weight of copper conductors necessary with the two-wire system.

It must be constantly borne in mind that the pressure of this direct-current system is necessarily limited to 220 volts by the conditions of the lamp, and also that the underground mains in all directions are interconnected, forming what is termed a mesh-work, analogous to the gas-distribution system, but with very important differences, hereafter explained at length. The cost of copper required for mains of sufficient conductivity to avoid a decrease in light by reason of large consumption, even at moderate distances, was found to be prohibitive, and this fact necessitated a system of "feeders," through which the electricity is forced against a very considerable resistance. These feeders are connected at various points to the mesh-work of mains so as to maintain at such points an approximately constant pressure. The generators at the central stations deliver their product collectively into common feeders and mains, and with a large plant an enormous energy is constantly exerted in these mains.

Any plan of distribution involving the meshing of the mains underneath the streets, with all house wires connected directly thereto, is regarded by the majority of competent electrical engineers as in many respects radically defective ; so defective, in fact, that, unless the use of alternating currents can be prohibited, it seems destined to be wholly supplanted by the more scientific and in all respects (so far as concerns the users or occupants of buildings) far safer inductive system. Apparently sensible of this, Mr. Edison does not hesitate to say : "My personal desire would be to prohibit entirely the use of alternating currents."

The fact that the shocking accident which has given rise to the present discussion was, in all probability, the result of a direct continuous current, and that the burning of the unfortunate victim may have resulted from a low-tension current used for telegraphic or power purposes, apparently does not deter Mr. Edison from his self-imposed task of proving the low-pressure system to be the only safe one. It is, nevertheless, a common practice of the Edison Company to use uninsulated overhead wires for its 220-volt current for the purpose of economizing first cost, although it is well known that such a current is capable of burning a body subjected to it as effectually as in the case of lineman Feeks, provided the skin be sufficiently abraded to diminish the electrical resistance of the subject.

Accepting Mr. Edison's classification of the currents used for electric lighting, let us discuss them as follows :

"*First*—The low-tension continuous current, with a pressure not exceeding 200 volts, used for incandescent lighting.

"*Second*—The high-tension continuous current, with a pressure of 2,000 volts and over.

"*Third*—The high-tension semi-continuous, or pulsatory, current, with a pressure of 2,000 volts and over.

"*Fourth*—The alternating current, with a pressure of from 1,000 to 3,000 volts and over."

The first is not dangerous when a person comes into momentary contact with one wire, but no one can endure its passage through the body when the contact is made "in the most effective manner." I have witnessed the roasting of a large piece of fresh beef by a direct continuous current of less than one hundred volts within two minutes. Any one having access to electric lights operated by the low-tension underground system in New York can easily prove to his own satisfaction how much credence ought to be given to the assertion that a current of 200 volts can be passed through the human body without producing uncomfortable sensations. Let him connect a tin pan to one of the electric wires, and place therein a thick piece of beef, and upon this a gridiron of metal connected to the other wire. The electrical energy exhibited in the steaming and cooking of this beef may possibly surprise the experimenter. If the current is from an underground main, the experiment may be varied by connecting the gridiron to a water-pipe with like results. With even less than one hundred volts it is painful beyond endurance to press firmly with the hands the brushes or any bright brass-work of the dynamo, or to grasp any metal connected with the wires.

That a continuous current of moderate tension may produce death when the connection is continued for even a short time is shown by the published record of experiments conducted by Mr. A. E. Kennelly at the Edison Laboratory. With a continuous current of 400 volts a dog weighing fifty-seven and a half pounds was killed in forty seconds ; and in another instance, with 1,000 volts of continuous current, a dog weighing thirteen and a half pounds was killed instantly. That an alternating current of one hundred volts, even when effectively applied, does not kill is shown by two experiments on another dog. A continuous current of 304 volts was applied for thirty seconds, and then an alternating current of one hundred volts for sixty-five seconds ; yet the dog was unhurt.

But mark this important fact: the so-called "alternating current" used for these experiments on animals was not the alternating current of commerce, but was an Edison direct continuous current made alternating by a "pole-changer," producing an effect incomparably more dangerous than the true alternating current under discussion, because of the exaggerated tension resulting from the partial discharge of the field-magnets of the dynamo, which act in this case like a Ruhmkorf coil of enormous dimensions.

The power of destruction residing in the low-tension current under certain conditions is best illustrated by quoting from Mr. Edison's own article, where he says:

> "Near the corner of William and Wall Streets, New York, the underground conductors of the Edison Illuminating Company became crossed, and the current which was passing through them at a pressure of only one hundred and ten volts melted not only the wires, but several feet of iron tubing in which they were incased, and reduced the paving-stones within a radius of three or four feet to a molten mass."

He adds: "This system is so arranged that consumers are not affected by such accidents as these." But it is, nevertheless, true that every consumer is directly connected to the mains, so that it is evident that the reverse of this statement would have more truly represented the actual possibilities of the case.

Concerning the three other conditions of current referred to by Mr. Edison, he classes them, and rightly so, as dangerous to life, although momentary contacts have repeatedly been made with wires carrying 1,000 and even 2,000 volts of each of these currents, without fatal results. In fact, there have been hundreds of cases in which momentary contact with an alternating current of 1,000 volts and over, as well as with pulsatory and continuous currents, has resulted only in painful shocks, unaccompanied by permanent injury.

The reader of Mr. Edison's article who is unfamiliar with the alternating system of distribution would naturally infer that in practice the same voltage is carried on the house wires as on the mains, as in the Edison system; but such is never the case under any circumstances. In this complete disconnection of the street and house wires is found the reason of the positive safety both to life and property enjoyed by the users of the alternating system. It is one of the great advantages of this system that it admits of the use of high voltages for the street mains, and of wholly separate and independent currents, with absolutely safe voltage, for all wires within buildings—a condition which is infallibly secured and maintained by converters, or transformers, located in or near each building. Each transformer of electric energy is composed of two separately-wound and insulated coils, one of thin wire connected to the street mains, and the other of thick wire connected to the wires of the building. One of the most beautiful features of the alternating system is that when currents of electricity are sent back and forth with almost inconceivable rapidity through the coil of thin wire, there is induced in a neighboring coil of thicker wire an equivalent amount of electrical energy, but at the same time so modified that the voltage, which may be 2,000 in the thin coil, need be only fifty in the thick coil, the volume of electricity being as many times increased as the pressure or voltage is diminished. A current of fifty volts is used in practice, as it is now well established that lamps of this capacity are far more durable and give a better light, with much greater economy, than the 100- or 110-volt lamps. The two coils being absolutely separated from each other by effective insulation through which the current in the primary wire cannot possibly penetrate, it follows that the alternating system has an enormous advantage over the direct system in respect of absolute safety to the consumer.

It seems possible that the time is not far distant when the regulations governing the distribution of electricity will rigidly prohibit direct electrical connection between the street wires and the local service-wires inside houses, thereby excluding from dwelling-places all the dangerous effects possible to ensue from accidental leakages in the underground system.

The forebodings of Mr. Edison concerning the results of the leakage of current from the underground mains have perhaps been in great part suggested by difficulties experienced in the working of his own system. The Edison underground lines are made up of a great number of short sections of iron pipe, each containing a copper rod, with a plastic insulating material forced between the copper and the iron. These sections are about sixteen feet long and are laid in trenches, and united at the joints like gas-pipes. These pipes are usually laid above the frost-line, and are necessarily affected by changes of temperature, which cause the iron pipes to move at the joints. It is, therefore, not unusual to find that after a short time the electrical leakage becomes sufficient to light a number of lamps when connection is made between a water-pipe and one of the mains—a fact well known to insurance inspectors. The Edison Company continues to use this system, although cables are now made capable of withstanding 2,500 volts of either alternating or direct current with even greater security than Mr. Edison has been able to provide for the 220 volts employed in his low-tension system.

One of the most perfect cables of to-day is a copper wire covered with a thick insulation, over which lead is pressed with very great force, thereby expelling air and gases, and solidifying the insulating material between the lead and copper. There is then woven upon the lead a textile envelope saturated with a water- and gas-proof compound. The continuous sections of this cable reach from one man-hole to another, a distance of several hundred feet, and can easily be drawn in and out of the ducts provided for them. Where one piece of cable is joined to another, an electric connection is made and well insulated, then encased in lead, which is afterward soldered to the ends of the respective cables. A cable of this character is uninfluenced by changes of temperature and is subject to little deterioration. To guard against its being pierced by a spark of static electricity, a very simple device is attached to it, offering an easier path for the electricity than through the insulation.

One of the differences alluded to, as existing between the low-tension, continuous-current underground system and a gas-pipe system, is that with reference to leakage. A gas leak is local and incapable of producing effects at a distance. With electricity, however, the aggregate effects of all the leakages from an underground system may be suddenly concentrated at any point within that system, as by one of the house wires coming in contact with a metal pipe, and such a contact may result even from the work of a mouse; whereupon the leakage of the entire net-work, which may amount to a large percentage of the total current, will be concentrated, and the surrounding material affected (although perhaps to a less degree) in the manner described by Mr. Edison in the reference to the currents at the corner of William and Wall Streets.

The interconnection of the conductors for the purpose of reducing the original investment has, in another important respect, a contrary effect from the meshing of gas-mains. In the case of the latter, the fracture of a pipe at one place, while it may cause a considerable leak, does not necessarily extinguish the lights of all the consumers. The grounding of one of the wires of an underground circuit, however, affects the entire mesh-work; and a cross between the wires may extinguish the lights of an entire district for a considerable time.

As to the accidents from electric currents, the records of deaths in the city of New York show that there were killed by street-cars during the year 1888, 64 persons; by omnibuses and wagons, 55; and by illuminating gas, 23; making the number killed by the electric current (5) insignificant compared with the deaths of individuals from any of the other causes named. The placing of the wires underground would eliminate many of the causes of accidents from electric currents, and they may all be prevented by the employment of reasonable and well-understood safeguards. Mr. Edison's statement that the putting of the wires underground will, instead of diminishing, increase the danger to life, is little less than amazing, at least when considered in connection with his advocacy of his own underground system. The repeated and violent explosions of gas in the man-holes of the Edison system, and in connection with the underground systems of the telephone and telegraph companies, have certainly shown that electricity from any source, either from low-tension electric-light, telephone, or telegraph currents, either of which is capable of producing a spark, may be the cause of a serious catastrophe, although there is no doubt that the accumulation of explosive mixtures within these chambers can be effectually prevented. Inasmuch as Mr. Edison's argnments against underground wires generally are equally applicable to his own system, it would seem, logically, that, if his views are to prevail, all electric wires must cease to serve the public. The experience of the cities of Chicago and Philadelphia in the use of underground cables for high-tension currents, to say nothing of the large number of cables laid underground in Rome, Berlin, Milan, and in other cities, indicates that the success of properly-constructed underground systems, whether for currents of high or low tension, has been established beyond question.

There is one radical difference between the alternating and the continuous low-tension system which should be fully understood. It has been shown that in the alternating system the street mains are absolutely disconnected and detached from the house mains, while the low-tension system necessitates the meshing of all underground mains into one net-work and the supply of the current to that system by a series of feeders. In fact, it necessitates at times the supply of an enormous electrical energy to supply the demand. With the alternating system the practice is not to mesh the wires, but to run independent pairs of wires connecting the switch-board in the station with the thin wires of the converters. These wires are designed to supply only about 1,500 to 2,000 lights per pair, and are made of such a size that there is no appreciable decrease in the lights at the farther end, even if there is a very large consumption of current. Each of these pairs of mains can, therefore, be provided at the station with safety devices which will instantly and automatically cut off the current in the event of a cross-connection taking an abnormal current from the dynamo. Such safety devices cannot be made available with the low-tension system.

Mr. Edison is, moreover, unfortunate in his reference to the use of electric currents abroad. Under the British Electric-Lighting Act of 1888 the Board of Trade has issued a set of regulations. Concerning high-pressure conductors it says:

"9. *High-Pressure Conductors to be Insulated.* Every high-pressure aërial conductor must be continuously insulated with a durable and efficient material, to be approved by the Board of Trade, to a thickness of not less than one-tenth part of an inch, and in cases where the extreme difference of potential in the circuit exceeds 2,000 volts, the thickness of insulation must not be less in inches or parts of an inch than the number obtained by dividing the number expressing the volts by 20,000."

It will be seen that these regulations provide not merely for 2,000 volts, which is double that used in the American alternating system, but for any voltage whatsoever which the electric companies may desire to carry.

In a recent authorized publication it is stated that the main characteristics of the Edison system are as follows:

First—Subdivision of generating units to secure reliability and economy of production.

Second —Meshing of distributing conductors in a common net-work throughout the entire area to be supplied, to secure uniform distribution.

Third—A system of special feeding conductors to apportion equally the supply of energy to the demand throughout the area covered by the system of conductors.

Fourth—A system of indicators to denote in the station variations of pressure at any point in the area of consumption.

Fifth—A system of regulation to compensate for any variation of pressure.

The main characteristics of the alternating system contrast with these in a marked manner. These characteristics may be stated as follows:

First—Large generators located in central stations at points convenient for coal and water supply, and away from residences.

Second—A series of mains running from the station, each set of mains having a capacity of not exceeding 1,500 lights, and each pair of mains extending to the station, so that the lines are only interconnected at the switch-board in the station.

Third—By reason of the limitation of the number of lights on each circuit, the leakage on any one circuit is reduced to a minimum.

Fourth—The interruption or burning-out of any one circuit can have no effect upon other circuits, the contrary being a most serious defect in a system wherein the wires are meshed.

Fifth—Absence of numerous and costly regulating contrivances.

Sixth—Ability to use within all houses a fifty-volt current, whereby the most efficient lamps can be utilized.

Seventh—Absolute separation of the street mains from the house mains, thereby preventing injury or danger from the leakage from the street mains.

Eighth—The use of a mechanical meter, which accurately records the entire electrical energy consumed in the house.

Ninth—The easy regulation of the current if required, so that the lights may be turned up and down without expensive and wasteful machinery.

There is not on record a solitary instance of a person having been injured or shocked from the consumers' current of an alternating system. This is wholly due to the fact that the converted current within the buildings supplied need not exceed fifty volts, and that the street mains and the house wires are absolutely detached from each other, so that there is no possibility of a shock being received from leakage or short-circuiting in the high-tension street mains.

The fire-risk from electricity is the one most to be feared. With the continuous current, whenever there is occasion to put out a number of lights by the movement of a switch, it not infrequently happens that a dazzling arc of blue flame is formed which has to be blown out. With the alternating system it is impossible to form any considerable arc, even if the switch controls a thousand lights, the rapid reversals of the current having the effect of preventing its establishment.

Mr. Edison's observations concerning the efforts of his competitors in the direction of saving in investment are no less applicable to the desires of the suppliers of his own system. At the annual convention of the Edison Illuminating Companies at Niagara, in August of this year, the following resolutions were offered by Mr. Gilbert, of the Detroit Edison Station:

"*Resolved*, That the Association respectfully call to the attention of the Edison General Electric Company the difficulties under which local companies are now laboring in consequence of the lack of

"1. An efficient and inexpensive arc-light system.

"2. An arc lamp which can be economically operated on the three-wire system.

"3. A flexible method of enlarging the territory which can be profitably covered

from their stations for domestic lighting *by higher pressures* and consequently *less outlay of copper* than that involved by the three-wire method.

" We earnestly appeal to the parent organization to supply these deficiencies."

The proceedings of the convention also contain the following:

"The address of Sir William Thomson, as president of the physical section of the British Association in 1882, contained this memorable passage: 'Nothing above 200 volts, on any account, ever should be admitted into a ship or house or other place where safeguards cannot be made absolutely and forever trustworthy against all possible accident.' This opinion accords with what Mr. Edison has always maintained—that in the long run every system will fail which does not (for domestic service) use a low-pressure current."

This is precisely what the alternating system supplies. The successful use of arc-lamps depends upon high voltages. Neither Mr. Edison nor any other person has yet been able to supply the requirements of the public by means of a low-tension arc-lighting system.

A careful consideration of the whole subject proves that it is possible to light all the buildings within a city by means of electricity distributed by an underground system, wherein there shall be no connection whatever between the underground system and the wires within the buildings. It has been demonstrated that an incandescent lamp operated by a fifty-volt current will give more light at a given cost than a 110-volt lamp ; and, these two things being admitted, it follows that, if there are to be any restrictive regulations with reference to electric lighting, they might more properly be: *First*—That the electro-motive force within any building shall never exceed one hundred volts; *Second*—That no underground system shall be placed in electrical connection with the wires in the buildings ; *Third*—That no underground system shall be permitted which does not provide for the renewal and repair of the mains without digging up the streets.

In conclusion it is worthy of note that for three years past the purchasers of apparatus for electric lighting, who are at perfect liberty to buy from any company, have, for the most part, preferred to use the alternating system, so that to-day the extension of that system for central-station incandescent lighting is at least five times as great as that of the direct current. If the opinion of these persons, who can have no interest except to purchase that which they believe to be the best, is of any value, then the alternating system has been demonstrated to be the one which can give to the public that which they so much desire—a safe, cheap, efficient, and universally-applicable system of incandescent electric lighting.

GEO. WESTINGHOUSE, JR.

ATMOSPHERIC ELECTRICITY.

AT the present time there is no satisfactory theory of the source of atmospheric electricity. Many believe, in the absence of positive evidence of the production of electricity by the operation of evaporation and condensation, that the earth has a definite charge, which resulted from the operations at its birth, and which it has kept undiminished in amount; and that thunder-storms are merely the expression of local accumulation due to currents of air.

Mr. G. Le Goarant de Tromelin, in a late number of the *Comptes rendus*, advances the opinion that atmospheric electricity is due to the friction of the air, humid or dry, upon the surface of land or water, and calls attention to Armstrong's hydro-electric machine, which produced electricity of high tension by the friction of jets of steam in issuing from narrow orifices. According to Tromelin, the wind, in skimming over the surface of water, carries water from the crests of the waves, which play the part of the comb of Armstrong's machine. The roughness of the soil does the same on land when a damp wind passes over it. The charge thus produced is collected upon the vesicles of clouds. The potential energy of a cloud depends upon its configuration and its temperature. If this configuration changes under the effect of condensation or congelation of the aqueous particles, the cloud absorbs a certain amount of energy, which must be found again under the form of an augmentation of potential energy: hence there is an electrical interchange constantly going on in the cloud region of the air; and when these changes are rapid, and great in amount, we have thunder-storms and other great electrical manifestations.

The advocates of Mr. Tromelin's views can point to the effect of the blasts of sand driven by the wind upon the pyramids, and to the extraordinary electrical manifestations upon high peaks in Colorado, where every *aiguille* seems to hiss, at times, with the escaping electrical charge.

We believe that the time has arrived when the scientific world no longer looks upon electrical phenomena as isolated and separate from the phenomena of heat and light, or chemical reactions. We cannot believe that any change can take place in the arrangement and mutual attractions of molecules without electrical manifestations. If we are to have a thermal chemistry, we must also have an electrical chemistry; and the history of the energy of a chemical reaction is not completely told when we sum up the heat of this reaction, unless we count also the heat-equivalent of the resulting electrical changes. If we were, therefore, to frame a theory of atmospheric electricity, we should begin it with the assertion that every change in the configuration or arrangement of particles of matter is accompanied by an electrical disturbance; and, as far as this assertion goes, all the present theories of atmospheric electricity would fall under it as special cases.

The object of this paper, however, is not to frame hypotheses, but to trace the recent work which has been done in systematic observation of atmospheric electricity. It is only to systematic observation that we can evidently look for information which will be of immediate practical value to our signal-service. Unfortunately, no systematic observations have been made for any length of time in any country.

The electrical conference at Paris, held last April, was adjourned from a meeting of the previous year; and committees were appointed to study the subject of atmospheric electricity and earth-currents in different countries. The time was evidently too short for such a stupendous undertaking; but the conference did valuable work in stimulating systematic observation, and creating a bureau at Berne, to which it was recommended that observations made in different countries should be sent. The agitation of the subject of such observations called forth several papers. Professor Ròiti of Florence presented to the conference the result of observations made through several months with a self-registering apparatus. He found that the zero of Mascart's electrometer changed from time to time, and traced this change to the mechanical effect of the sulphuric acid upon the platinum wire connected with the electrometer needle. He therefore dispensed with the Leyden jar of the Thomson and the Mascart electrometer, and suspended the needle by a very fine silver wire which was connected directly to the positive pole of a water-battery of many cells. This instrument was found to work well. Professor Ròiti believes that local disturbances have great effect, and that these local effects must be carefully taken into account in comparing simultaneous observations over large areas.

Athough the scientific world has generally accepted Thomson's quadrant electrometer, or some modification of it (like that of Mascart's or Clifton's), as the most suitable instrument for the observation of atmospheric electricity, and has also adopted Thomson's water-dropper (which consists merely of an insulated can of water connected with the quadrants of the electrometer, the water issuing from this can in small drops, reducing it to the potential of the air), still there are those who believe that this method does not give correct results. Professor Palmieri, who has been connected so long with the meteorological stations on Mount Vesuvius, rejects Thomson's electrometer, and the water-dropper also. He believes that the electricity of the air is not led to the water-dropper by conduction, and that the insulated water-can does not take the electricity of the air by any similar process. According to his views, the electrical state of the air can be ascertained by its inductive effect upon a disk of metal which is suddenly elevated or lowered in the air; and he has devised a special electrometer, strongly resembling Peltier's electrometer, and a special apparatus for elevating and lowering a disk. He, moreover, does not think that continuous photographic registrations are of much use, since electrical observations are only of value when accompanied by observations on the condition of the sky with respect to clouds, and upon the direction of the wind.

Professor Palmieri's methods and instruments do not impress us very favorably. There must be great difficulty in insuring good insulation by his method of suddenly elevating a disk in the air. Moreover, his theory of induction does not appear to us to be well founded. The Thomson method of observing atmospheric electricity seems to promise better results than any other; yet it is not by any means perfect, especially in its practical adaptation to the needs of a government signal-service. The experiments which are being conducted at the physical laboratory of Harvard college show that in the American climate it is extremely difficult to secure a regular flow of water from the water-dropper, and to obtain good insulation, on account of frost and snow. During the months which are free from snow and ice, heavy showers wet the insulating stand of the water-dropper, and thus destroy the insulation. The latter evil can be obviated to some degree by a well-constructed screen of wood. It has been found preferable to neglect the insulation of the can, and allow the drops of water to fall upon a metallic plate, thrust out from the side of the room in which the electrometer is situated, by means of a glass cylinder through the centre of which runs a wire which connects the metallic plate with the electrometer. The drops of water fall, in turn, from the metallic plate, and reduce this to the potential of the air, while the insulation of the metallic disk can be perfectly maintained in all weathers. Preliminary experiments have also been made upon an arrangement which promises to be of use in winter, when the weather would prevent the use of the water-dropper. This arrangement consists merely of a wheel provided with metallic brushes. The wheel is run rapidly by simple clock-work, and is insulated. The brushes touch one end of an insulated conductor exposed to the air, and then touch a conductor connected with the earth, in this way imitating the action of the water-dropper. An arrangement of this kind, which will work in all changes of weather, is essential in the climate of the United States.

The preliminary experiments at the laboratory of Harvard college have also shown that it is essential that the electrometer should not be very distant from the water-dropper or its equivalent. A naked iron wire connected the electrometer with a water-dropper which was about three hundred feet distant at the top of a building, and at least sixty feet from the ground. The photographic record of the excursions of the electrometer needle showed that it moved irregularly to and fro under the influence of the fluctuation of potential along the wire. There is evidently a certain relation between the size of the conductor, which is reduced to the potential of the air by the succession of water-drops, and the number of orifices from which the water must issue in order to reduce the conductor and connecting wire to the potential of the air.

The photographic records that have been made show unmistakably that north-west winds in the colder months are preceded by a rise in the electrical potential of the air, and that during an east wind the potential falls. These general indications seem to be independent of local effects, and lead us to believe that electrical signal-station observations will be useful in predicting changes of weather. Photographs of the varying electrical state of the air could be forwarded to Washington from different stations, and a map could be made on which stations at the same electrical potential could be connected; and thus any law connecting the electrical state of the atmosphere with other meteorological changes could probably be ascertained. Much remains to be done, however, in ascertaining the best position for such signal-stations, and in perfecting simple and practical apparatus for the use of comparatively unskilled observers.

John Trowbridge.

XXI.

ATMOSPHERIC ELECTRICITY.

By Alexander McAdie and Austin L. McRae.

Communicated May 13, 1885.

By direction of the Chief Signal Officer, observations on atmospheric electricity were begun at Harvard College, Cambridge, Mass., under the supervision of Professor John Trowbridge, June 1, 1884.

By permission of the Chief Signal Officer the following abstract is taken from a report upon the apparatus used, and upon the observations from June 1, 1884, to April 30, 1885.

Electrometers.

A Thomson quadrant electrometer No. 26, and a Clifton modification of the Thomson, were originally used. A full description of the former can be found in the British Association Report for 1867, and also among the reprinted papers of Sir Wm. Thomson on "Electrostatics and Magnetism," Paper No. XX. The Clifton instrument is a modified form of the Thomson, designed for greater sensitiveness and of less complicated construction. It is not very generally known, and a brief description of it may therefore be given. The essential parts are four large brass or brass gilded quadrants, supported on glass rods of about 10 cm. length. A bifilar suspension carries an aluminium needle, corrugated and shaped like the figure eight. The length of the suspension is about 15 cm. A platinum wire from the needle dips into a glass vessel containing pure sulphuric acid, and coated on the outside and bottom with tinfoil. In the bottom of the case of the instrument, a circular opening is cut, of diameter sufficient to allow the removal of the glass vessel and the metal base on which it rests. In the upper part of the case is placed a small Thomson replenisher. The air within the case is kept dry by small open glass cups containing sulphuric acid. The needle is charged by means of a platinum wire imbedded in a gutta-percha rod, passing through the side of the case, and dipping into the sulphuric acid.

The instrument, as thus constructed, was found to be extremely sensitive, and admirably adapted to detect the smallest difference of potential of any two bodies, but for a long and continued series of observations, or single experiments of long duration, it was found unserviceable. The electric field of the quadrants was not sufficiently protected from external electrical influences. Two sides of the case only were coated on their interior surfaces with tinfoil, but the theory of the instrument demands, as far as possible, a complete shielding from external electrical influences. The great delicacy of the suspension is possibly the cause of the most serious defect, viz. a shifting of the zero point. The needle would never return exactly to its initial position. The difference was often great enough to give on a scale distant a meter from the mirror, a deflection of a centimeter. In the course of an hour a change in the position of the zero, when all the quadrants were connected, of from two to five or more millimeters would occur. These changes were in part due, no doubt, to a loss in the charge of the needle. To remedy the first defect, new suspending fibres were inserted without effect. To remedy the change due to dissipation of the charge, the vessel jar was paraffined around the edge, and for a time better results were obtained, though still faulty. The glass rods supporting the quadrants were several times taken out, washed with alcohol, dried, paraffined around the edges, and replaced. Other parts of the instrument, in which it was thought the fault might lie, were also carefully cleaned, and where needed provided with better insulation.

To obviate the difficulties met with in using the Clifton, the instrument described in the following sections was designed by Professor Trowbridge, and made at Boston, Mass. It is essentially the Clifton, so modified as to retain its great sensitiveness without having the defects mentioned. It was also desired to have an electrometer of more convenient arrangement than any of the forms now in use, — one in which the different parts should be amply protected from external influences, and yet be easily accessible for examination. The instrument devised has two compartments. In the upper compartment are the quadrants, needle, and suspending apparatus. In the lower compartment is the glass jar, with the arrangement for charging the needle. The upper compartment consists of a wooden case, 25 cm. high and 20 cm. square. On the top and back of the case are tight-fitting brass doors, the one at the top being 12 cm. square, the door at the back being 16 cm. high and 12 cm. wide. When open, these doors allow easy access to the suspending frame, and when shut, form part of the metallic shield, covering and perfectly protecting the needle and quadrants from external electrical influences and also air currents. Circular brass windows 7 cm. in diameter, encased in brass and inserted in three sides of the case, allow inspection from without, of the needle, and also the passage of the beam of light to and from the mirror.

The bottom of the compartment consists of a brass plate of about 5 mm. thickness. From this plate rise, at alternate corners, two brass rods of 23 cm. height, supporting a cross-beam 20 cm. in length and 5 mm. in diameter. Fastened by a screw to this beam is a cross piece of 3.5 cm. length, supporting two suspending rollers. One roller has a screw movement to or from a central point exactly over the centre of suspension. The end of the roller is enlarged and grooved. One end of the suspending fibre is fastened to the roller by insertion through a small eye-hole in the shaft, and then made to pass in the enlarged groove. The other roller consists of a like brass shaft with an enlarged groove, in which the other end of the suspension fibre runs. This roller has not, however, a screw movement, and turning the screw head in this case simply raises or lowers the needle without change of position of the points of suspension. The whole suspension may be raised or lowered by movement of the screw-head attached to the supporting cross-beam. The plane of suspension may be altered by movement of the cross-bar, which is pivoted on the end of the screw passing through the cross-beam. This suspension is much simpler, equally sensitive with the best arrangements in other instruments, and in case of accident easily repaired. The length of the suspension is about 9 cm. Only one long fibre is employed. The platinum wire carrying the needle is hooked at its upper extremity, and by this means attached to the fibre. The weight of the needle is sufficient to insure a symmetrical suspension, without extra adjustment. If two separate fibres are used, and attached to a small cross-piece on the platinum wire, it will be necessary to test the symmetry of the suspension. The single fibre, however, allows a symmetrical suspension and with the arrangements employed allows easy and accurate adjustment. In the instrument constructed there is no error of position of the zero point. After the greatest deflection when short-circuited, the position of the spot of light on the ground-glass scale is exactly that of its initial position. Six months' constant use of the instrument has not necessitated the use of any correction for the position of the zero.

The needle is made of aluminium about 10 cm. in length, and at its broadest parts about 2 cm. in width. The supporting platinum rod terminates in a small half-loop, just below the quadrants. To this loop a very fine platinum wire is attached, supporting a light lead paddle in the sulphuric acid of the glass jar. The quadrants are made of polished brass, the circle of which they are sections having a diameter of 15 cm. They are mounted on glass tubes, made of the best white glass, 5 cm. in height, and 1 cm. in diameter, and mounted on gutta-percha. Through the inside of the tubes run insulated wires imbedded in rubber, connected at the upper end with the quadrants, and at the lower end passing through the brass base plate to binding-screws in the walls of the lower compartment.

One of the quadrants can be slid out, the supporting rod being inserted in a brass plate moving in a groove cut in the base plate. A spring plate with a small projecting knob, fitting into the notches of the base plate, keeps this quadrant perpendicular and firm wherever it may be placed.

The lower compartment is 23 cm. high and 20 cm. square. In it is placed a glass jar of 15 cm. diameter and 10 cm. depth. The vessel is tinfoiled on the outside and bottom, and rests on a circular brass plate which can be either elevated or lowered several inches. The back of the compartment is hinged, and when opened allows full inspection. A platinum wire imbedded in gutta-percha passes through the side of the glass vessel about a centimeter from its upper edge. This wire dips into the acid of the jar.

The instrument, thus constructed, has been in constant use during the past six months, and, requiring but little attention, has proved itself very well adapted for work of this nature.

Multiple Quadrant Electrometer.

With a view to the construction of a portable electrometer sufficiently sensitive and accurate, the following instrument was designed by Professor Trowbridge and Mr. McAdie, and built according to their plans by the Western Electric Company of Boston. An exterior wooden case 30 cm. high and 12 cm. square, contains four compounded quadrants, a compound needle, and the suspending and charging arrangements. The outer case rests on a brass plate with the proper levelling arrangements, and is divided into three compartments, lettered A, B, and C. Each of these has one side at least hinged, so as to open and allow easy access to the interior. At the bottom of the front side of compartment A, a semicircular glass case 2 cm. in height projects. The bottom inside surface of this is mirrored in order to eliminate errors of parallax in reading the position of a fine aluminium index playing over it. This uppermost compartment contains the suspension apparatus and the long light aluminium index arm. The suspension is as previously described. The aluminium pointer is carried by the platinum wire which supports the needle, but is insulated from it. A small concave mirror is also attached to the platinum wire, so that, if desired, the instrument can be employed with lamp and scale as a reflecting instrument. In the middle compartment B, four brass quadrants are mounted on flint-glass tubes of 4 cm. in length and 1 cm. in diameter. Each quadrant is compounded of four single quadrants. The dividing partitions fit into slots cut in the back plate, and are removable at pleasure. They are held in an exact horizontal position by means of small screws. The needle is made of aluminium, and is also of a compound type, being made of four or more single needles, connected and so arranged as to move between the quadrant sections. The interior surface of compartment B is completely tinfoiled. The third compartment contains a glass jar tinfoiled on the outer side and in connection with the ground. Through the side of the glass vessel is led a platinum wire encased in hard rubber. The deflection of the needle is recorded by the movement of the aluminium pointer. In the instrument constructed, when one set of quadrants is connected with the ground, the other to the positive pole of a Daniell cell, and the needle connected with the positive pole of a Beetz battery of 200 cells (described below), the movement of the index hand is perceptible to the unaided eye. On a scale distant 70 cm. from the mirror this deflection is nearly 2 cm. The length of the suspension is about 4 cm. Increasing the potential of the needle increases the sensibility of the instrument. If, instead of the method generally employed, we connect one set of quadrants with the positive pole of a battery of a number of cells connected in series, and the negative pole to the other set of quadrants and the needle connected with the body whose potential is to be determined, we obtain greater sensitiveness. The deflection obtained has then to be compared directly with the deflection given by a Daniell cell.

Connected in this manner, our electrometer gave a movement of the index hand, for a Daniell cell, of several degrees, or, with the mirror and scale, a deflection of about 4 cm.

For getting a continuous record, this form of electrometer is more easily adaptable than the others. It is also obvious that, aside from the difficulty and uncertainty of photography, an electrometer for successful use in meteorological work must be of such a nature that its indications may be read at any time or place, and without delay.

Self-recording Apparatus.

We propose to place the following attachment on the multiple quadrant electrometer in order to render it self-recording. A metal plate is placed just above, and a metal cylinder with its axis horizontal just below, the metal index-pointer of the instrument. One terminal of the secondary circuit of a small Ruhmkorff coil is connected to the plate and the other to the cylinder. A strip of co-ordinate paper passing through a solution of iodide of potassium to keep it moist is drawn over the cylinder by clock-work. At regular intervals the primary circuit of the Ruhmkorff coil is broken for an instant by an automatic circuit-breaker, and a spark passes from the plate to the cylinder through the pointer, and registers on the paper the position of the pointer at the instant. Since the induced current will be of short duration, the spark will register the position of the index before the electrifications of the plate and cylinder can influence the needle. In this manner a record of every five minutes, or of every single minute, can be obtained without photography. The instrument need not be placed in a dark room, but may be moved around at will. The cost of the necessary apparatus for this registration will be more, but the expense of running it will be less, than the photographic apparatus. The great advantage of this apparatus will be that single observations can be made at any time without disturbing the record.

The preliminary experiments tried were successful; but as we have been unable to obtain a mechanician who could do the necessary mechanical work properly, the attachment has not been placed on the electrometer.

The Galvanometer.

A galvanometer was used to measure the potential of the atmosphere in the following manner. A condenser was charged by connecting one plate with the collector and the other plate with the ground. The condenser was then discharged through a ballistic galvanometer. By comparing the deflection of the needle with the deflection produced when the condenser is charged by a known electromotive force, and then discharged through the galvanometer, the difference of potential between the collector and the ground was obtained in absolute measure.

The Battery.

The needle of the electrometer was charged and kept at a constant potential by being connected to the positive pole of a constant battery, while the negative pole was connected to the ground.

At first, a zinc and copper distilled water battery of two hundred cells was used. The number of cells was afterwards increased to four hundred. The battery was placed in a large covered box to keep out the dust. The zinc used was common commercial zinc, and became coated with an oxide which had to be scraped off every two weeks. The evaporation of the water in a warm room was very great, so that the battery required constant care.

At the suggestion of Professor Trowbridge, we made a Beetz solid battery.* The cells consisted of glass tubes 10 cm. long and 1.2 cm. in diameter. One half of the tube was filled with white alabaster plaster of Paris mixed with a solution of copper sulphate. A copper wire was placed in this, and the plaster allowed to harden. Then the other half of the tube was filled with plaster of Paris mixed with a solution of zinc sulphate. A zinc wire was placed in this, and the plaster allowed to harden. The cells were connected in series. In order to save the time and trouble required to solder the copper of each cell to the zinc of the next, sheets of copper 10 cm. wide were soldered to similar sheets of zinc. These were then cut into strips, which were bent in the shape of a U. The copper end was placed in the plaster of Paris containing copper sulphate, and the zinc end in the plaster of Paris and zinc sulphate of the next cell. Care was taken that the wires should not extend quite to the middle of the cell, to prevent their coming in contact with the opposite sulphate. The ends of the cells and the connecting wires were dipped in paraffine to prevent the zinc and copper sulphates creeping along the wires. A battery of two hundred cells was made and placed in a box 60 cm. long, 40 cm. wide, and 20 cm. deep, which could be moved around easily. Care should be taken not to connect the terminals, for the battery will polarize and soon destroy itself. Six cells were experimented upon in November, 1884, to determine their electromotive force and internal resistance. They worked perfectly until the latter part of February, 1885, when they gave out. Their average electromotive force was 1.06 volts; their average internal resistance, 1,600 ohms. The rest of the battery does not seem to

* Phil. Mag., March, 1884.

have deteriorated any, although it has been in constant use since November 15, 1884.

An extra cell was made whose electromotive force was 1.04 volts. It has been tested occasionally since, and found to remain constant.

A distilled water cell was completely covered with paraffine. Although it has remained nearly constant, some of the water has been lost, and the zinc is now coated with a thick deposit.

At the same time these cells were made, we made another in the following manner. A copper cylinder six centimeters long and one centimeter in diameter was filled with plaster of Paris mixed with a solution of zinc chloride containing a small per cent of sodium chloride. A zinc wire was placed in this, and the plaster allowed to dry. This cell has an electromotive force of .80 volt, and an internal resistance much less than a Beetz cell. It has remained constant up to date.

A Beetz battery can be made of compact size, and imbedded in paraffine or some solid insulating substance, and made portable so as to be used in connection with a portable electrometer.

This is decidedly the best kind of a battery to use in electrostatic measurements. It has the advantage over the water battery of being cheaper, of being smaller and more convenient to move, and it requires little attention after it is made.

THE COLLECTOR.

The water-dropping collector proposed and used by Sir William Thomson* was employed at first. It consists of an insulated metallic vessel filled with water and connected to the electrometer. Water drops from the nozzle of the vessel, and reduces it to the potential of the air at the point where the stream ceases to be continuous.

A more convenient arrangement of the same principle is to allow the water to drop first on an insulated metallic plate connected with the electrometer, and then to the ground. The vessel containing the water need not be metallic nor insulated. Water dropping from the plate reduces it to the potential of the air, in the same manner that the nozzle of the vessel was reduced. The metal plate used was of brass 10 cm. by 15 cm. It was placed from five to ten centimeters below the nozzle. Different-sized plates of copper and of brass were used without appreciably affecting the results. With zinc and other plates there was a slight contact electricity between the plate and the brass quadrants of the electrometer. The plate has the double

* Papers on Elect. and Mag., § 262.

advantage over the metallic vessel of being more convenient to arrange and more easily insulated when the humidity of the air is high. The electricity produced by the impact of the water upon the plate is too slight to be measured.

Mechanical Collector.

Continuous records cannot be obtained in this climate with the water-dropper, because in winter water will freeze before it has been dropping long. At the suggestion of Professor Trowbridge several mechanical collectors were tested to see if any could be found that would be superior to the water-dropper.

1. The first consisted of a wheel thirty centimeters in diameter, with strips of tinfoil fastened to its circumference in such a manner that when the wheel revolved on a horizontal axis the pieces of tinfoil touched successively two metal knobs, A and B. A was connected to the electrometer, and B to the ground. When the wheel revolved, each strip of tinfoil carried off a part of the charge of A, and discharged it to the ground through B. Now A, losing continuously a part of its original charge, would approximate nearer and nearer to the potential of the surrounding air.

2. The second consisted of a pendulum attached to a framework. A non-conducting fibre with a metal ball at its lower end passed up through a hole in the framework and was attached to the bob of the pendulum. A piece of metal, G, connected to the ground, was placed in such a position that, when the pendulum hung vertically, the ball rested lightly on G. Another piece of metal, E, connected to the electrometer, was so placed that, when the pendulum swung to either side, the ball touched E. When the pendulum was in motion, the action was the same as in the first experiment. The proper facilities were not at hand for carrying out these experiments to the best advantage, so that the results were not satisfactory. With the apparatus used, the electricity produced by friction was too great to be neglected.

3. Fine platinum wires were attached at equal intervals to the dial-plate of a minute clock, in such a manner that the seconds hand could strike them. The clockwork was of sufficient strength not to be stopped when the hand came against a wire. Each alternate wire was connected to the ground. The others were connected to a metallic plate in the air, and to the electrometer. The seconds hand was insulated from each set. The principle is the same as in the first and second examples.

4. We next made use of the principle, that, if a metallic sphere is carried out in the air and connected by a fine wire to the ground, and then insulated, it will have the potential of the air.* Two wires connected together were placed on the dial of the clock described above, and carefully insulated from the clockwork. They were connected to a metal plate in the air, and to the electrometer. The hands of the clock were connected to the ground. The clock was placed inside of a box lined with tinfoil and hung upon the wall of the room. The tinfoil was connected to the ground. In this way the clock was shielded from the influence of the electricity of the room, and also from the effects of the weather without. A rubber hose ending in a glass tube was placed near the plate, and air drawn in over the plate through the hose by an aspirator. By this means the air around the plate was continually renewed. When the clock was running, the plate was connected to the ground every half-minute for a moment, and then insulated, and therefore took the potential of the adjacent air. When the plate was connected to the ground, the needle would tend to swing toward the zero, but the plate being immediately insulated, the needle would return to the proper deflection. The needle used had sufficient inertia to prevent much swinging. There was only a slight oscillation. In using this collector, if the inertia of the needle is small, the clock can be stopped long enough to take an observation after it has once been in operation and connected the plate to the ground.

With all these collectors, including the water-dropper, we do not measure the difference of potential between the ground and the air, but between the ground and some combination of the ground and air. If the ground is zero, the results will be correct; but if the ground has a local charge, the results will be a combination. For instance, when the mechanical collector is grounded, it takes the potential of the ground. Being then insulated, it combines this potential with the potential of the air, and the electrometer measures the difference between the ground and this combination. In the case of the water-dropper, water is drawn from the pipes in contact with the ground, so that the electrometer measures the difference between the potential of the ground and the combination formed by the charge of the water and the charge of the air. It is probable that this effect is generally very small, and is soon neutralized; but under certain circumstances, (e. g. when an electrified cloud is near the place of observation,) it

* Maxwell's Elect. and Mag., sect. 221.

may be of sufficient magnitude to destroy the value of the observation. In a continuous record, we could not compare the results when this effect was acting with those when it was not acting, and deduce any valuable laws. It was thought that by connecting the positive pole of the battery to one set of quadrants, and the negative pole to the other set, and then connected first to the ground and then to the collector, (the deflection of the needle being noted in each case,) the effect of a local charge in the ground could be eliminated. This was tried with very good results, but it would not be accurate if rapid changes were taking place at the time of observation, nor could it be used to obtain a continuous record.

In order, therefore, to overcome the various difficulties of the collectors described, we made use of the following principle.

Maxwell * says: "Now let us suppose a firm insulated wire carried from the electrode of the electrometer to the place where the potential is to be measured. Let the sphere be first completely discharged. This may be done by putting it into the inside of a vessel of the same metal which nearly surrounds it, and making it touch the vessel. Now let the sphere thus discharged be carried to the end of the wire and made to touch it. Since the sphere is not electrified, it will be at the potential of the air at the place. If the electrode wire is at the same potential, it will not be affected by the contact; but if the electrode is at a different potential, it will by contact with the sphere be made nearer to that of the air than it was before. By a succession of such operations, the sphere being alternately discharged and made to touch the electrode, the potential of the electrode will continually approach that of the air at the given point."

We applied this principle to experiment 2 by making G a metal cup, but the height the ball was raised was so small that we abandoned that method, and constructed the following collector, which seems to be free from all the greater objections. It consists of a framework supporting a brass cup. A non-conducting string with a brass sphere at one end passes through a system of pulleys. A brass plate is attached to the framework just above the cup. It is insulated from the framework by a thick layer of paraffine. The cup is connected to the ground, and the plate to the electrometer. By means of the string the sphere can be made to touch the inside of the cup and the plate successively, and thus reduce the plate to the potential of the air.

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* Elect. and Mag., sect. 221.

The sphere can be raised and lowered by means of clockwork, an electric motor, or a water motor. The laboratory has a small water motor, which was used for this purpose by attaching an arm to the circumference of the wheel and fastening the end of the string to this arm. When the arm is in a certain position of its revolution, the sphere rests lightly on the bottom of the cup. When the arm has turned 180° from this position the sphere touches the plate.

The sphere, cup, and plate must be of the same metal. As the quadrants of the electrometer are of brass, we made these of brass to avoid all contact electricity.

Comparative observations have been made with this collector and the water-dropper for a month. The changes seem to be similar, but the deflections of the water-dropper are the larger.

It seems possible, with some mechanical improvements, to make this form of collector superior to any other.

Observations.

The observations show that—

The potential of the air was generally low and positive, seldom as high as 25 or 30 volts.

The potential usually fell before precipitation, storms, or when the relative humidity increased.

The potential during precipitation, with a very few exceptions, was always low and positive.

Almost all the negative electricity, except that which was followed by precipitation, occurred during west to northwest gales, or during cold waves.

Low clouds sometimes seemed to affect the observations, but high clouds seemed to have no influence.

There was very slight variation with altitude,—at least, between two and ten meters above the ground.

There was no appreciable variation between collectors placed on different sides of the building.

On Obtaining the Electric Potential of the Upper Air.

On the morning of May 6th, the potential of the air at a point ten feet above the ground and three feet from the walls of the laboratory, obtained by the usual water-dropping method, was, reduced to volts, 0.5. A paper kite covered with cloth and tinfoil, with its longest axis about four feet, was flown, the connecting string being heavy English twine, previously soaked in a mixture of glycerine and water. The end of this string was connected to a wire well insulated, which in turn was connected to one set of the quadrants of the Trowbridge electrometer, the other set of quadrants being connected with the ground. The needle was connected to the positive pole of a Beetz solid battery of 200 cells (200 volts). The needle was at once deflected to its limit, indicating a high positive potential for the air at an elevation of less than 300 feet. Remaining for a few seconds at this high positive, it would suddenly change to an equally high negative, sometimes without the least warning. It was, without doubt, extremely variable. The high positive indications seemed to be more prevalent. Connecting the kite-string with the multiple quadrant electrometer, described in this paper, the following results were obtained. The connection and charge of the needle were as in the other instrument. A fine index-pointer records the deflections in this instrument, and the mirror, scale, and dark room are dispensed with. A Daniell cell gives a deflection of half a degree. The deflection given by the kite was at times over 25 degrees in a positive direction, or equivalent to over 100 volts. The index-hand was seldom still, as in the previous case evidencing an extreme variableness of the electrical condition of the air at that place and time. The wind was from the east, steady and light, the pressure 30.061, the temperature 49° F., the relative humidity 77, and the sky covered with a low pallium of stratus clouds moving from the east slowly.

On the next day, May 7, the kite was again flown, this time reaching an altitude of about 500 feet. The potential of the air at a point ten feet from the ground, obtained by a water-dropper, reduced to volts, was 0.4.

The table on the following page shows the deflections for short intervals. These deflections were comparatively steady, and had not the variableness of those on the preceding day. The wind was east, and had now been blowing from that quarter for nearly thirty hours. The sky was covered with stratus clouds, having the unusual appearance of billows with the crests pointing to the earth. The pressure was 30.040, the temperature 45° F., the relative humidity 75.

The experiment demonstrates that it is comparatively easy to obtain some indication, even if it be only a relative one, of the potential of the air at high altitudes. The method is simple and direct, and with the exception of the original cost of electrometer and charging battery, quite inexpensive. A series of simultaneous observations of this character would doubtless be of value in meteorology.

TABLE OF DEFLECTIONS.

Time. May 7.	Deflection.	Deflection reduced to Volts.	Wind	Remarks.
h. m. s.				
12 0 0 M.	12.0	24.0	E.N.E.	
12 5 0 P. M	+12.5	25.0	E.N.E.	
12 5 30 "	+11.5	23.0	E.N.E.	
12 5 45 "	+12.0	24.0	E.	
12 6 0 "	+10.7	21.5	E.	
12 6 15 "	{ + 9.5 +11.5 }	{ 19.0 23.0 }	E.	Kite diving.
12 6 30 "	+11.5	23.0	E.	
12 6 45 "	+ 9.5	19.0	E.	
12 7 0 "	+ 9.5	19.0	E.	
12 7 15 "	+ 9.75	19.5	E.	
12 7 30 "	+10.0	20.0	E.	Gust of wind.
12 7 45 "	+ 9.5	19.0	E.	
12 8 0 "	+10.0	20.0	E.	
12 8 15 "	+10.5	21.0	E.	
12 8 30 "	+10.5	21.0	E.	
12 8 45 "	+10 5	21.0	E.	
12 9 0 "	+11.0	22.0	E.	
12 9 15 "	+11.5	23.0	E.	
12 9 30 "	+12.0	24.0	E.	
12 9 45 "	+11.75	23.5	E.	
12 10 0 "	+12.0	24.0	E.	
12 25 0 "	11.25	22.5	E.	
12 26 0 "	10.0	20.0	E.	
12 26 5 "	10.0	20.0	E.	
12 26 10 "	10.0	20.0	E.	
12 26 15 "	11.5	23.0	E.	
12 26 20 "	10.75	21.5	E.	
12 26 25 "	11.0	22.0	E.	
12 26 30 "	11.5	23.0	E.	
12 26 35 "	11.0	22.0	E.	
12 26 40 "	11.25	22.5	E.	
12 26 45 "	11.25	22.5	E.	
12 26 50 "	11.0	22.0	E.	
12 26 55 "	11.25	22.5	E.	
12 27 0 "	11.75	23.5	E.	

Jefferson Physical Laboratory.

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Electricity generation: options for reduction in carbon emissions

H. W. Whittington

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THE ROYAL SOCIETY

Electricity generation: options for reduction in carbon emissions

By H. W. Whittington†

Department of Electronics and Electrical Engineering, University of Edinburgh, Edinburgh EH9 3JL, UK

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Historically, the bulk production of electricity has been achieved by burning fossil fuels, with unavoidable gaseous emissions, including large quantities of carbon dioxide: an average-sized modern coal-burning power station is responsible for more than 10 Mt of CO_2 each year. This paper details typical emissions from present-day power stations and discusses the options for their reduction.

Acknowledging that the cuts achieved in the past decade in the UK CO_2 emissions have been achieved largely by fuel switching, the remaining possibilities offered by this method are discussed. Switching to less-polluting fossil fuels will achieve some measure of reduction, but the basic problem of CO_2 emissions continues. Of the alternatives to fossil fuels, only nuclear power represents a zero-carbon large-scale energy source. Unfortunately, public concerns over safety and radioactive waste have still to be assuaged.

Other approaches include the application of improved combustion technology, the removal of harmful gases from power-station flues and the use of waste heat to improve overall power-station efficiency. These all have a part to play, but many consider our best hope for emissions reduction to be the use of renewable energy. The main renewable energy contenders are assessed in this paper and realistic estimates of the contribution that each could provide are indicated. It appears that, in the time-scale envisaged by planners for reduction in CO_2 emission, in many countries renewable energy will be unlikely to deliver. At the same time, it is worth commenting that, again in many countries, the level of penetration of renewable energy will fall short of the present somewhat optimistic targets.

Of renewable options, wind energy could be used in the short to medium term to cover for thermal plant closures, but for wind energy to be successful, the network will have to be modified to cope with wind's intermittent nature.

Globally, hydroelectricity is currently the largest developed source of renewable electricity, but future large-scale projects will probably be limited to the less-developed world: the best schemes in the developed countries have already been exploited. Wave and tidal can be looked on as medium- to long-term generators of electricity, as their respective industries are not as mature as competing renewable resources. Municipal solid-waste combustion and landfill gas technologies can also be seen as short term, as can their rural equivalents, agriculture and forestry waste.

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† Deceased 11 March 2002.

Any widespread exploitation of renewable energy will depend on being able to transmit the energy from source to point of use, so the implications for the electrical network from the penetration of substantial levels of renewable energy are presented. Effective management of renewable energy installations will require technical assessment of the range of exploitation strategies, to compare local production of, say, hydrogen and the more traditional transmission of electricity. Such resources will have to compete with others in any national, or grid, system and detailed economic analysis will be necessary to determine the deployment that best fits the trading regime under which the energy will be sold. Consideration will also be necessary to determine how best to control the introduction of this radically new resource such that it does not attract punitive cost overheads until it is mature enough to cope.

Finally, it is inescapable that nuclear power is a proven technology that could take its place in any future generation portfolio. Unfortunately, suspicion and mistrust surround waste management and radioactivity release. Unless this is overcome, the lack of confidence engendered by this public mistrust may result in few, if any, new nuclear power stations being built. In the event of that decision, it is difficult to see how CO_2 levels can be significantly reduced: the irony is that nuclear energy may emerge as environmentally essential.

Keywords: electrical energy; gaseous emissions; fossil fuels; nuclear power; renewable energy

1. Background

Industrialization and economic development require an ample supply of electricity at an affordable price. The relationship between energy supply and economic well-being is well-established and, although the causality is a matter for debate, it is true that the most successful economies use the most electrical energy.

Originally, electricity was derived from the burning of fossil fuels: these were abundant, cheap and were available in most parts of the world. The technology to exploit these primary energy resources was widely available and operated reliably. The only significant input from a renewable resource was that from hydroelectricity, which presently accounts for around one-fifth of global electricity production. However, hydropower is available only to those countries with suitable hydrology and topology.

As evidence mounts for change in global climate, an assessment of ways in which to reduce the contribution to this effect from electricity production must be undertaken. The electricity supply industry is currently responsible for *ca.* 30% of the UK's total CO_2 emissions (the rest is divided approximately equally between transport and commercial/residential premises) (DEFRA 2002). Between 1990 and 1998, carbon dioxide emissions from power stations were reduced by 7.5%, mainly by closing old, inefficient, coal-burning plant and installing more-efficient gas-burning technology. However, recently the levels have been rising: in the last year (DEFRA 2002) there was a 2.5% increase on the base year of 1990. This has occurred as a result of the policy of decommissioning nuclear power stations (which emit no CO_2) and replacing them with fossil-fuelled, mainly gas-burning, plant. This trend is predicted to continue both in the UK and in continental Europe.

In addition to CO_2, power stations emit annually an estimated 2 534 000 t of SO_2 (71% of the national total) and 718 000 t of NO_x (26% of the national total).

Table 1. *How CO_2 emissions from UK power stations reduced in the early 1990s, but have begun to increase as nuclear plants are shut down and replaced by gas-fired generation (DEFRA 2002)*

	1990	1998	1999	2000
MtC	54.1	40.6	38.8	42.0
% reduction		−25.0	−4.4	+8.3

2. Options for reduction in gaseous emissions

With the global dominance of fossil fuels and the widespread availability of suitable technology to generate electricity, such fuels will be used for the foreseeable future. Several options present themselves for reducing gaseous emissions from fossil-fuelled power stations.

(*a*) *Switching to different fossil fuel for reduced emissions*

Low-sulphur coal, sourced from different parts of the world, reduces SO_2 production. Using gas instead of coal also reduces emissions: CO_2 output is halved and SO_2 falls to almost zero because of the superior efficiency of gas power stations, up to 53% as opposed to 35% for coal (IEE 1994). Gas is especially efficient when used in combined-cycle technology, where the hot exhaust gases from a gas turbine are used to produce steam, which then powers a steam turbine. A major proportion of the reduction in carbon emissions in UK since 1990 (DEFRA 2002) has been as a result of the switch from coal to gas for electricity generation (DTI 2001), as is shown in table 1.

(*b*) *Fuel switching to nuclear power*

Despite public concerns over waste disposal and uncertainties over economics, fuel switching to nuclear power currently remains the largest, proven, carbon-free generation option, accounting, in the USA and UK, for around one-fifth and one-quarter, respectively, of electricity produced annually.

Uranium is a far more effective fuel per kilogram than other fuel. One tonne of uranium produces the equivalent amount of electricity as 16 000 t of coal and 80 000 barrels of oil. Spent fuel is transferred to a storage facility next to the reactor to allow the radioactive level and heat to decrease. Waste fuel is stored in pools of water and the fuel is held there for about six months. The spent fuel from the reactor still contains ^{235}U, so it can be recycled. Reprocessing the spent fuel produces uranium, plutonium and waste.

Safe disposal/storage of waste from the nuclear fuel cycle presents a challenge. Three categories exist, depending on the level of radioactivity. Low-level waste is created at all stages of the nuclear fuel cycle: intermediate waste is produced by the reactor operation and recycling of materials; high-level waste is spent fuel containing fission products from the recycling process.

There appear to be three alternative routes for nuclear power in the future.

(i) A complete phase-out of nuclear power. For this to be successful, alternative plans must be made for electricity generation in the short term.

(ii) A continued growth of nuclear power for the foreseeable future, at its present rate. This is unlikely for the reasons of public concern, stated above.

(iii) A progressive reduction followed by return to current levels if alternative generating methods have not been successful. This allows alternative methods of power generation to be introduced in the short term, to be abandoned if they fail. However, there is a danger that the capability to design and build nuclear plant may have been lost in the interim.

Even if the decision to build new nuclear plant were to be taken, in order to create a level playing field, it is argued that the environmental costs of generating electricity from fossil fuels would have to be reflected in the prices consumers were charged. Electricity supply companies might be obliged to enter long-term contracts to purchase a set proportion of their power from different sources, so that generators, whether gas or nuclear, have the incentive to build base-load stations.

The existing planning procedures and regulatory approvals system are viewed by many as cumbersome and overly lengthy. Some streamlining would be necessary to ensure new nuclear reactors could be built effectively and efficiently. However, overarching all these considerations is the question of the radioactive waste disposal—arguably the thorniest problem the nuclear industry has to overcome. It is necessary for the Government to set an overall policy before there is any realistic chance of future nuclear expansion.

(*c*) *Remove harmful emissions from flue gases*

In flue-gas desulphurization, SO_2 is washed out of the flue gas using limestone slurry, producing gypsum as a byproduct (IEE 1994). This technique can reduce the SO_2 content of flue gas by up to 90%, but, since it results in an efficiency reduction of the plant, CO_2 output is increased.

(*d*) *Improve technology of combustion processes to reduce emissions*

A typical process is gasification, where the hot coal reacts with oxygen and steam to form a gas made up mainly of hydrogen and carbon monoxide, which can then be burnt to drive a gas turbine coupled to a generator. To improve the overall efficiency, the heat from the gasification process and from the gas-turbine exhaust is used to produce steam to drive a steam turbine. The combined process is called an 'integrated gasification combined cycle'.

(*e*) *Make use of waste heat to improve efficiency*

The exhaust heat can also be used to heat water that can be used to heat homes or offices in a combined heat and power (CHP) plant. Efficiencies of up to 80% are possible (IEE 1994) if there is a need for the heat. Ideal locations for CHP tend to be hospitals and schools, where there is a large demand for electricity and heat. CHP is the most cost-effective option to generate and reduce emissions. The UK Government has set a target of 10 GW of CHP by 2010, which, it is claimed, at 15% of the current electricity market, would secure £ 3 billion of new investment into the UK economy, £ 600 million in annual energy savings for UK businesses and one-fifth of the Government's 20% carbon reduction target (EA 2002) by 2010.

Table 2. *A comparison of typical cost (or estimates, where there are no costs available) and the annual potential for* CO_2 *reduction of different methods of electricity generation*

technology	cost (pence kWh^{-1})	carbon abatement potential in 2050 (MtC yr^{-1})
end-use efficiency	low	65
photovoltaic	10–16	N/A
onshore wind	1.5–2.5	5
offshore wind	2.0–3.0	>20
energy crops	2.5–4.0	10
wave	3.0–6.0	>20
nuclear	3.0–4.0	>20
gas turbine[a]	2.0–2.3	—
coal[b]	3.0–3.5	—

[a] Combined-cycle gas turbine: combination of gas turbine and steam turbine.
[b] Integrated-gasification combined cycle: combination of gasification of coal and combined-cycle gas turbine.

(*f*) *Exploitation of renewable energy*

Around 23% of global electricity production is presently renewable in nature: it is large-scale hydroelectric development. Other sources of renewable energy include wind (both onshore and offshore), solar panels, biomass and wave and tidal energy.

Biomass includes energy from waste, landfill gas, sewage gas, agricultural or forestry residues and fast growing energy crops. Solar energy can also be used in both passive and active heating systems in addition to the direct generation of electricity. Cost estimates and potential for carbon reduction for some renewables compared with the best fossil-fuelled plant are given in table 2. An impression of the potential for reduction in carbon dioxide offered by the different technologies is given below (PIU 2002).

(*g*) *Declared net capacity (DNC)*

DNC is a scaling factor given to renewable sources of electricity generation to account for the fact that the machine nameplate output cannot be guaranteed. The DNC represents that proportion of generation capacity which can be regarded as always available. Table 3 shows values of DNC for the most abundant renewables.

(*h*) *Wind energy*

The Earth's winds are created as a result of the heating of the planet's surface by the Sun, setting up pressure gradients balanced by the Coriolis force set up by the Earth's rotation. These winds are modified by thermodynamic and frictional forces at the Earth's surface.

Environmental impact can be gauged by considering a typical large wind-energy installation of, say, 300 MW. This would save *ca.* 20 Mt of CO_2 over its 20-year lifetime (IEE 1994) but the 300 or so wind turbines, especially in such a large group, cause a visual impact on the surrounding environment.

Table 3. *DNC capacity of a renewable sources (House of Lords 1999)*

energy source	declared net capacity
hydroelectricity	1.0
waste	1.0
biomass	1.0
wind	0.43
tidal	0.33
wave	0.33
solar	0.17

As a result, the planning authority and developer must work together to decide how best to install the turbines in an area. Of particular importance are size, colour and number of turbines. In practice, the total raw wind-energy potential must be reduced to a feasible level:

(i) by excluding areas which are environmentally sensitive (this means excluding building wind-energy farms in areas of landscape importance, e.g. in national scenic areas, green belt and areas of archaeological interest and in areas of nature conservancy importance, including special protection areas and national and local nature reserves); and

(ii) by allowing for 'accessibility', defined by three factors: clustering and proximity, build rate and restrictions of the electricity network.

Some idea of just how this affects the raw potential can be obtained using an example, namely, the potential Scottish on-shore wind resource, which is 11.5 GW (Scottish Executive 2001*a*, *b*). In practice, allowances have to be made that reduce this figure considerably. Features such as national environmental and cultural designations and local environmental regulation remove around two-thirds of the land area available for wind turbines (Scottish Executive 2001*a*, *b*). Recently, the Ministry of Defence has indicated that it would not generally favour wind farms in certain low-flying areas and this accounts for a further quarter of the country. Local transmission-system limitations which could cause bottlenecks reduce the resource still further, as do public acceptability of the turbines. All of these translate the 11.5 GW resource to 3 GW (Scottish Executive 2001*a*, *b*) of practical resource (this may be compared with the total of all generation plant in Scotland, which presently stands at *ca.* 10 GW (EA 2002)).

(i) *Practical build rate*

Build rate is defined as the generation capacity installed per year. Currently, the maximum historical build rate in the UK is 105 MW per annum in 1992/1993. Two years later the European wind industry managed 400 MW per annum. The prediction is that the European build rate will double to 800 MW per annum but a realistic UK build rate would be a doubling of the present rate to 210 MW per annum because of the complex nature of the UK terrain compared with that in Europe. Network issues may also limited wind energy development.

A modern aerogenerator is rated *ca.* 1 MW: this suggests 3000 new aerogenerators in Scotland. As a visual-amenity comparison, there are *ca.* 12 000 large steel transmission towers (pylons) in the entire UK. Currently, a typical wind farm is *ca.* 35 units, so *ca.* 85 new sites would have to be developed.

(ii) *Typical installation characteristics*

For a 1 MW unit-size of wind turbine, typical capital costs would be *ca.* £ 800 kW^{-1} and annual operation and maintenance costs of *ca.* £ 300 kW^{-1}. The farm would have, on average, a turbine density of 15 turbines per square kilometre and would be designed to operate on an average mean wind speed of greater than 7 $m\,s^{-1}$. Buffer zones would be included: 100 m around woodland, 400 m around settlements and 6 km around airports.

(*i*) *Municipal solid-waste combustion*

(i) *Technology*

Currently, in the UK, 80% of household waste is dumped in landfill sites (EA 2002). This is regarded as a short-term solution as suitable sites become full and costs increase. There is much controversy over the categorization of waste-to-energy plants, with some planners feeling that the technology should not fall into the category of renewable. Such plants are fed from local waste, which is reduced to small amounts of disposable sterile waste for integration with combined heat and power schemes and recycling policies.

(ii) *Installation characteristics*

The capital costs (Carlin 1996) for a combustion plant are just over £ 4000 kW^{-1}, with annual costs of £ 325 kW^{-1}. For example, a 25 MW plant would require an initial outlay of around £ 100M with annual running costs of £ 12.25M. One tonne of waste generates 475 kWh, so a 25 MW plant would consume *ca.* 350 000 t of waste each year, which, at the current landfill tax of £ 7 t^{-1} for waste, would cost £ 2.45M.

Using energy from waste combustion to provide both electricity and heat is possible through the use of CHP plants, where most of the energy released through combustion is captured. This leads to an increase in the efficiency of the plant and therefore reduces pollution. In order to make full use of its heat output, any plant must be situated close to the area where the heat will be required. This means that the use of heat in towns requires a CHP plant near to the residential area, to reduce heat losses and the cost of distribution systems. If the area using the heat also supplies the waste for combustion (such as in hospitals or farms) then the entire system is much more self supporting. Many different types of waste can be used for combustion, such as waste from domestic and commercial properties. Municipal solid waste includes

(i) scrap tyres, burnt whole or as pellets;

(ii) straw, burnt as bales or chopped up and blown into a furnace;

(iii) poultry litter; and

(iv) industrial wood waste.

Regulations for waste combustion depend entirely on the type of fuel used. Local authority air-pollution-control authorization and a waste-management licence may be required or, in the case of plants where wastes are discharged into sewers or controlled waters, the local sewerage authority or River Purification Authority must also be consulted. A plant can meet all requirements for air pollution but still emit odours and as a result, close proximity to housing may not be welcomed by the residents. Emission levels are regulated on a local scale by the Local Authority Air Pollution Control authorization.

(j) *Anaerobic digestion*

Anaerobic digestion produces biogas, a gaseous mixture with high methane content. Using biogas for heating and/or electricity generation displaces fossil fuels and thus is beneficial to the environment. However, methane is a strong greenhouse gas (GHG) and only through combustion can it be converted to the less harmful carbon dioxide. Although carbon dioxide and methane are both damaging to the environment, the production of methane is already present at most sewage treatment works, so it can be argued that the introduction of anaerobic digestion as a means of electricity generation would not have an adverse effect on the environment, as it would merely capture an untapped resource. Sewage treatment authorities have tightened the controls on disposal of sludge such as pumping into the sea, which increases the waste available for energy production. This indicated that there should be a logical push for anaerobic-digestion-based electricity generation. The visual impact of a digestion plant is not likely to be large, as most installations will be at municipal sewage works. The digesters can be as much as 15 m high but can be partly buried to reduce the visual impact and also reduce the energy demand for the digestion process due to the heat insulation benefits. A gas flare is required to dispose of excess gas.

An anaerobic-digestion plant requires a waste-management licence under the Environmental Protection Act 1990, covering areas such as acceptance, handling and storage of wastes, operation and monitoring of flare stacks and gas-cleaning equipment, odour control, handling, storage and use or disposal of digestate and monitoring of pathogens.

(k) *Landfill gas*

Landfill gas, a mixture of CO_2 and CH_4, is formed under anaerobic conditions where organic waste is broken down by micro-organisms (Ewall 2000). With a calorific value half that of natural gas, landfill gas is collected in gas wells when a small pressure is applied. Once a scheme is commissioned, gas production starts within two years of when the anaerobic conditions have been placed on a landfill site. Production reaches its maximum around five years after commissioning and starts to decline after 15 years.

The methane is used in gas turbines (with a typical efficiency of 26%) and dual-fuel engines (with a typical efficiency of 42%) (Ewall 2000). Landfill gas is an established and proven technology, with over 165 schemes in England and Wales with a DNC of 340 MW.

The regulations for landfill gas generation require planning permission for use of the land and a waste management licence. This licence covers the operational aspects of the site during its active life but also may include the decommissioning of the site for restoration to its original condition after the landfilling has stopped. The waste regulation authority is responsible for monitoring a site once it has closed.

(*l*) *Hydroelectric power*

(i) *Technology*

Hydroelectric power uses precipitation (rain and snow) to drive a generator, producing electricity. Hydroelectric-power plants are categorized into three basic groups.

High head: the most common type, where water is stored behind a dam to provide a flow of water which is set according to the needs of the network.

Low head: uses head heights from a few metres to the natural flow rate of the river controlled by low dams, weirs and channels. Low-head plants (sometimes termed 'run-of-river') have no capacity for storing water, so power is controlled by the seasonal flow of the river.

Pumped storage: operates both as a conventional high-head plant and as an energy store, by absorbing electricity by pumping water to an upper reservoir. Depending on the ratio of pumped-storage energy to natural catchment run-off, this type of station may be a net energy producer, an energy-neutral store or an absorber of energy. However, even as a net absorber of energy, it represents a valuable resource to the system planner and to the system operator. Because of the ability to change from pumping to generating, a pumped storage station appears, to the system operator, the same as a conventional power station of roughly twice the pumped storage installed capacity. For example, if a 100 MW station switches from pumping to generating, it appears to the system operator as a generator of 200 MW (100 MW from generation plus 100 MW from the pumping load, which has now disappeared), neglecting inefficiencies in pumping and generation. The planner also benefits, since the ability to switch the mode of operation means that a new power station of slightly less than twice the rating of the pumped storage station does not have to be built.

(ii) *Resource*

Hydroelectricity accounts for at least 50% of national electricity production in 63 countries and at least 90% in 23 countries (Baird 1993*a*). About 10 countries obtain essentially all their commercial electricity from hydro, including Norway, several African nations, Bhutan and Paraguay. There is *ca.* 700 GW of hydro capacity in operation worldwide, generating 2600 TWh per annum (*ca.* 19% of the world's electricity production). About half of this capacity and generation is in Europe and North America, but the proportion is declining as Asia and Latin America commission large amounts of new hydro capacity. Hydropower also plays an important role in reducing emissions of GHGs, by an estimated 10%, through displacement of thermal generation. Small, mini- and micro-hydro plants (usually defined as plants less than 10 MW, 2 MW and 100 kW, respectively) play a key role in many countries, often being the mainstay of rural electrification. An estimated 300 million people in China, for example, depend on small hydro. Only *ca.* 18% of the world's technically feasible hydro potential and 28% of the economic potential have been developed so far. Around 6400 TWh per annum economic potential therefore remains to be exploited (equivalent to *ca.* 1800 GW). Only 7% of the economic potential has been developed in Africa, 19% in South America, 19% in the Russian Federation, 20% in Asia, and 40% in Oceania. However, 61% have been developed in North and Central America and 65% in Europe (excluding the Russian Federation).

It is estimated that development of half of the world's remaining economically feasible hydro potential could reduce GHG emissions (1990 estimates) by 13%, with an even greater impact on SO_2 emissions. There has, however, recently been growing organized opposition to large-scale water-resources development projects, some of which incorporate hydro schemes. Hydropower's positive benefits are well known and have to be set against the negative impacts. Most of the UK's resource is located in Scotland, where *ca.* 1.1 GW is presently installed (Scottish Executive 2001*a*, *b*). An estimated further 1 GW is technically feasible, mainly as small-scale schemes but the economics case is often difficult to make.

(*m*) *Tidal energy*

(i) *Technology*

Tidal energy (Baird 1993*b*) makes use of the bulk movement of the oceans, twice per day. Two generic types of tidal energy device exist.

Barrage: a barrier, constructed across the path of the tide when flowing, holds the tide back to create a hydraulic head between the two sides. When the tide ebbs, the same technique is used, giving four generating periods per day. Barriers are expensive and projects usually need an additional use for the barrier to be successful, e.g. as a causeway for road transport.

Tidal mills: these are similar to an underwater wind turbine; as with wind, both axial flow and the cross flow rotor are available. Power cables are run back to the mainland to connect back to the grid. Tidal mills are still relatively small generators, in the 10 kW range. Several countries are active in tidal technology, including the UK, Japan, Russia and Australia; currently the UK has only conducted trials on tidal mills and has no installed capacity. The Department of Trade and Industry has predicted that, between 2005 and 2010, 322 MW will be installed in the UK.

Over the past three decades the feasibility of using ocean tides to generate electric power has been investigated at many sites throughout the world. Results suggest that the potential for economic development is small.

(ii) *Resource*

Of the *ca.* 22 000 TWh per year dissipated by the tides, 200 TWh is now considered economically recoverable and less than 0.6 TWh is produced by existing plants. By far the largest tidal plant in service is Rance (France), with a capacity of 240 MW and an annual output exceeding 500 GWh. Others include the 20 MW Annapolis plant in Canada, several small units in China with total capacity of *ca.* 5 MW and a 400 kW experimental unit near Murmansk in Russia. In the UK, the maximum practical rated capacity is 16 GW at *ca.* 5% load factor, which translates to *ca.* 40 TWh annual production: 25% of this is in the Pentland Firth (Scotland).

Worldwide, the following five areas account for well over half of the potentially developable energy (Baird 1993*b*);

(i) the headwaters of the Bay of Fundy (Canada);

(ii) the Severn estuary (United Kingdom);

(iii) the Gulf of St Malo (France);

(iv) the Southeast coast of China; and

(v) Russian coasts bordering the White Sea and Sea of Okhotsk.

Other potentially feasible sites include the Mersey estuary and smaller sites bordering the Irish Sea and Bristol Channel (United Kingdom), the Gulf of Kachch (India), the west coast of Korea, the northwest coast of Australia, Cook Inlet (Alaska) and the Gulf of San José (Argentina).

At the moment the tidal industry is not yet an established renewable energy source, but it will grow rapidly if the interested countries produce positive trial reports. Scotland has two promising areas for tidal stream: the Pentland Firth in northeast Scotland and the Mull of Galloway in southwest Scotland.

An alternative to building a barrage is to install tidal mills in the tidal flow. These are similar to windmills and have the advantage that they do not require the damming of an estuary. Around the UK, the resource is estimated to be 0.4 GW with an annual output of *ca.* 2 TWh (Scottish Executive 2001*a*, *b*).

(*n*) *Wave energy*

Energy from incident waves, especially in the North Atlantic approaches, offers a considerable renewable resource (Whittington & Jordan 1983). Devices to extract this energy can be split into the following three categories.

Shoreline devices: typical examples are the oscillating water column (OWC), tapered channel device (TAPCHAN) and the Pendular. The OWC is a vertical column positioned in the water, which uses the wave height to change the air pressure in the column to drive a gas turbine to generate electricity. The TAPCHAN uses a tapered channel to increase wave height to overflow and flood a raised lagoon, which stores water to release through a water turbine, generating electricity. The Pendular is a box open to the sea with one end hinged to hydraulic pumps, generating electricity when the front flap flips back and forth with the waves.

Nearshore devices: these are designed to operate in moderate depths of *ca.* 20 m located around the ends of harbour walls; a typical example is the OSPREY, which combines wave and wind for its generating resources.

Offshore devices: used in waters more than 40 m in depth; typical examples are the Swedish Hosepump, McCabe Wave Pump, the Danish Wave Piston Floating Pump, and the Edinburgh Duck (to be replaced by the Sloped IPS Buoy).

The UK has a practicable resource (Scottish Executive 2001*a*, *b*) of *ca.* 3 GW, which could deliver 8 TWh each year.

(o) *Geothermal energy*

Geothermal energy (Boyle 1998) is renewable heat energy from deep in the Earth: different variants exist, namely, hot dry rock, magma and geopressured geothermal energy.

Heat is brought to the near-surface by thermal conduction and by intrusion into the Earth's crust of molten magma originating from great depth. Ground water is heated to form hydrothermal resources—naturally occurring hot water and steam. The use of hydrothermal energy is economic today at a number of high-grade sites. Hydrothermal resources are tapped by existing well-drilling and energy-conversion technology to generate electricity or to produce hot water for direct use. Earth's energy is used by geothermal heat pumps.

For generation of electricity, hot water, at temperatures ranging from *ca.* 150 °C to more than 400 °C, is brought from the underground reservoir to the surface through production wells, and is flashed to steam in special vessels by release of pressure. The steam is separated from the liquid and fed to a turbine engine, which drives a generator.

If the reservoir is to be used for direct-heat application, the geothermal water is usually fed to a heat exchanger before being injected back into the Earth. Heated domestic water from the output side of the heat exchanger is used for home heating, greenhouse heating, vegetable drying and a wide variety of other uses.

Development of geothermal energy has a net positive impact on the environment compared with development of fossil-fuelled plant. Geothermal power has sulphur-emissions rates that average only a few per cent of those from fossil-fuel alternatives. The newest generation of geothermal power plants emits only 0.2% of carbon (as carbon dioxide) per MWh of electricity generated compared with the cleanest fossil-fuel plant (Boyle 1998).

(p) *Solar energy*

(i) *Solar water heating*

In Britain, each square metre of a south-facing roof can receive up to 1000 kWh of solar radiation during a year. Roofs represent an energy source for both space heating and hot water by using solar collectors to capture some of this solar radiation. As a consequence, there is a reduction in the consumption of fossil fuels.

In Britain it is possible to use the Sun to provide most of an average family's hot water requirements from about May to September and to obtain some 'pre-heating' of the cold water supply during the other months. In principle it is possible to scale-up the size of a solar water heater to provide central heating, in general it is not cost effective. However, a solar water heater can be used in a preheating arrangement if the hot water produced is not used elsewhere. Hot water is normally produced by heating the cold mains water to the required temperature with a gas- or oil-fired boiler or an immersion heater. By slightly modifying the conventional heating system, solar collectors may be introduced.

(ii) *Photovoltaics*

Solar cells convert energy from the Sun directly into electricity by what is known as the photovoltaic effect. Conversion efficiencies are over 24% and power levels from a few milliwatts to tens of kilowatts (Archer 2001). Photovoltaics is a growing industry, serving a wide range of terrestrial applications.

(iii) *Passive solar architecture*

The Sun can meet the entire annual space-heating needs of buildings in sunnier parts of the world. However, in much cloudier and colder climates, the Sun can still make a very useful contribution. It may seem surprising, but solar energy can actually save more units of energy needed for space-heating the further a building is away from the Equator. This is partly because ordinary windows can capture more solar energy from low-angle sun-rays, and partly because ambient temperatures tend to drop relatively more rapidly than the solar supply available. Low temperatures generate a demand for heat, even in July if you live in some northern parts of Europe. Thus, a house in Shetland, if appropriately designed, can save more fuel than the same house located in Cornwall; or one in Norway more than one in the south of France.

(*q*) *Biomass*

Photosynthesis by green plants converts large amounts of sunlight into energy-rich biological material called biomass, for example, trees, crop and forest residues. Products derived from biomass, such as grains, wood, sugar and alcohol, may be used as fuel. Coal, oil and gas are products of photosynthesis from millions of years ago. Firewood is also widely used: this is the product of more recent and present day photosynthesis (Ewall 2000).

The world's total energy use is *ca.* 10% of the biomass stored annually. The world's stored biomass energy (90% of this in trees) is as large as the proven fossil-fuel reserves. The total fossil-fuel store equals *ca.* 100 years of photosynthesis. The amount of carbon stored in biomass is equal to the amount of atmospheric carbon in the form of carbon dioxide and to the amount of CO_2 in the oceans' surface layer; this is important for the cycling of extra CO_2 produced from burning fossil fuels.

About 13% of the world's primary energy comes from biomass (equivalent to 25 million barrels of oil per day) and is used in the rural areas of less-developed countries.

(*r*) *Wood fuel*

Wood-fuel-fired power stations (Ewall 2000) are likely to become increasingly popular as the Government's emphasis on the development of renewable energy sources increases. Wood is not perceived to be an environmentally friendly fuel, as its burning produces carbon dioxide. However, this fuel is regarded as 'CO_2 neutral' because the carbon released during burning is only that which was absorbed during tree growth; thus, the gas is simply recycled. The scale of a wood-fuel-fired power plant depends on a number of factors:

(i) location with regards to inhabited areas;

(ii) size of available area;

(iii) capacities of the local area electricity-supply network;

(iv) size of the available wood resource; and

(v) extent of local transport infrastructure.

Wood fuel is less dense than coal, so the storage space required will be greater. The efficiency of electricity generation from wood can be increased through gasification, where the solid fuel is converted into a combustible gas by thermal processing. For example, in Scotland there are over 920 000 ha of woodland and forest, accounting for *ca.* 12% of the land area. The Government promotes the management of these woodlands for multipurpose forestry, including environmental conservation, access and wood production. Estimations of the amounts of wood required to produce 1 MW of power generation run at between 350 ha for the 'high-efficiency gasification' technique and 630 ha for the standard approach, running at 20% efficiency. It is estimated that a 6 MW power station will generate up to 50 traffic movements per day in total, through delivery lorries and staff. This means that local road access must already be well established or will require improvement.

(*s*) *Network issues*

If there is no change in current trends, the replacement of coal and nuclear power stations seems likely to be with gas-fired plant in the short term. It is to be hoped that a more sustainable solution will emerge in the longer term.

The majority of renewable resources is located in isolated areas of the country where demand is low and, at present, the electricity network could not transmit this energy to high demand areas (Scottish Executive 2001*a*, *b*).

In addition, the statistical nature of renewable resource availability means that new operation and control algorithms will have to be researched. Presently, the penetration of stochastic renewable energy into the grid will probably be limited to *ca.* 20% (House of Commons 2002) for operational reasons, independent of the size of the resource or the prevailing economics. In future, the target must be to move towards a network that can accommodate a range of generating sources: a mixed-fuel economy. The exact balance cannot be specified at present with any confidence.

3. Conclusions

The provision of a realistically priced and reliable supply of electricity which has due regard to environmental targets is a complex task. New technologies will make a contribution, but only after the relevant economic analysis. Fiscal instruments are increasingly being used to encourage the industry to adopt specific solutions: these must be accompanied by the necessary regulatory changes to give market steers to developers. However, at this stage it would be unwise to attempt to pick a winner from the list of contenders. Those responsible for balancing environmental imperatives with security of supply must be aware of the complicated interaction between these two features and economics.

Renewable energy, at first sight, offers an attractive option for electricity production with reduced GHG production. However, effective management of all prospective renewable-energy installations will need, above all, a technical assessment of the range of exploitation strategies; for example, a comparison may be made between local production of, say, hydrogen and the more traditional transmission of electricity. Such resources will have to compete with others in any national, or grid, system and detailed economic analysis to determine the approach to deployment which best fits the trading regime into which the energy will be sold. Consideration will also be necessary to determine how best to control the introduction of this radically new resource such that it does not attract punitive cost overheads before the technology reaches commercial maturity.

In terms of the different renewable options available, wind energy can be seen as a short-to-medium-term replacement as thermal plant closes. However, for wind energy to be successful, the network will have to be modified to absorb additional renewable capacity, but it has a massive potential for generating electricity that cannot be ignored.

Globally, hydroelectricity is currently the largest developed source of renewable electricity, but future large-scale projects will probably be limited to the less-developed world: the best schemes in the developed countries have already been exploited. Wave and tidal can be looked as medium- to long-term generators of electricity, as their respective industries are not as mature as competing renewable resources.

Municipal solid-waste combustion and landfill-gas technologies can be seen as a short-term generation solution. The waste is located near to the high demand areas where the network can cope with the extra capacity. Agriculture and forestry waste can be seen as a means of generating electricity for rural areas, which depend on imports from high generation areas.

Despite all that has been said above, nuclear power is proven and could take its place in any future generation portfolio. Unfortunately, there exists suspicion and mistrust of the technology, mainly surrounding waste management and radioactivity release. Unless this is overcome, the lack of confidence engendered by this public mistrust may result in few, if any, new nuclear power stations being built.

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Health and Safety Executive

Memorandum of guidance on the Electricity at Work Regulations 1989

Guidance on Regulations

HSE

Health and Safety Executive

Memorandum of guidance on the Electricity at Work Regulations 1989

Guidance on Regulations

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This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Contents

Foreword

This book is one of two that set out the Electricity at Work Regulations 1989 and give guidance on them. The other book relates specifically to mines.

This book is relevant to all work activities and premises except mines and quarries, certain offshore installations and certain ships.

This second edition updates references to relevant regulations, standards and publications. It replaces references to the Institution of Electrical Engineers' (IEE) Wiring Regulations with British Standard BS 7671.

After the *Introduction*, the text of each regulation is given in italics followed by guidance on that regulation. Regulations 17 to 28 (which apply to mines only) are omitted as are parts of regulation 2 which interpret terms found only in regulations 17 to 28.

Introduction

1 The Electricity at Work Regulations 1989 (the Regulations)* came into force on 1 April 1990. The purpose of the Regulations is to require precautions to be taken against the risk of death or personal injury from electricity in work activities. The full text of the Regulations, which includes those parts relevant to the mining industries, is set out in SI 1989/635 available from The Stationery Office.

2 The Regulations are made under the Health and Safety at Work etc Act 1974 (HSW Act). The HSW Act imposes duties principally on employers, the self-employed and on employees, including certain classes of trainees. The Regulations impose duties on people (referred to in this Memorandum as 'dutyholders') in respect of **systems**, **electrical equipment** and **conductors**, and in respect of work activities on or near electrical equipment. (The words in **bold** are defined in regulation 2.) The duties are in addition to those imposed by the HSW Act.

3 The guidance is intended to assist these dutyholders in meeting the requirements of the Regulations. It will be of interest and practical help primarily to engineers (including those involved in the design, construction, operation or maintenance of electrical systems and equipment), technicians and their managers. It sets out the Regulations and gives technical and legal guidance on the Regulations except as they apply to mines or quarries. While it reflects the Health and Safety Executive's (HSE's) view of the meaning of terms used in the Regulations only the Courts can provide a binding interpretation. The purpose of this Memorandum is to amplify the nature of the precautions in general terms so as to help in the achievement of high standards of electrical safety in compliance with the duties imposed. However, for detailed advice reference must be made elsewhere and some relevant sources of information available at the time of writing are made throughout the Memorandum.

4 When those who design, construct, operate or maintain electrical installations and equipment need advice they should refer to appropriate guidance, such as may be found in national, international, reputable foreign and harmonised or industry standards and codes of practice or HSE guidance, or they should seek expert advice. Only those who have both the knowledge and the experience to make the right judgements and decisions and the necessary skill and ability to carry them into effect should undertake work subject to these Regulations. A little knowledge is often sufficient to make electrical equipment function but a much higher level of knowledge and experience is usually needed to ensure safety.

5 Because the Regulations state principles of electrical safety in a form which may be applied to any electrical equipment and any work activity having a bearing on electrical safety, they apply to all *electrical systems* and equipment (as defined) whenever manufactured, purchased, installed or taken into use even if its manufacture or installation pre-dates the Regulations. Where electrical equipment pre-dates the Regulations this does not of itself mean that the continued use of the equipment would be in contravention of the Regulations. For example, much of the equipment to which the Regulations apply may have been made to a standard, such as a British Standard, which has since been modified or superseded. It is likely to be reasonably practicable to replace it with equipment made to a more recent standard when, but only when, it becomes unsafe or falls due for replacement for other than safety reasons, whichever occurs sooner. Equally, fixed installations to which BS 7671 is relevant may have been installed in accordance with an earlier edition, now superseded but then current; that, in itself, does not mean that the installation does not comply with the 1989 Regulations.

**As they apply to places of work other than mines and quarries.*

6 Advice on the application of the Regulations in particular circumstances can be obtained from local offices of the appropriate Inspectorate.

British Standard BS 7671 Requirements for Electrical Installations (also known as the IEE Wiring Regulations)

7 The British Standard BS 7671 *Requirements for Electrical Installations* is also known as the IEE Wiring Regulations* - they are non-statutory regulations. They 'relate principally to the design, selection, erection, inspection and testing of electrical installations, whether permanent or temporary, in and about buildings generally and to agricultural and horticultural premises, construction sites and caravans and their sites'. BS 7671 is a code of practice which is widely recognised and accepted in the UK and compliance with it is likely to achieve compliance with relevant aspects of the 1989 Regulations.

8 There are however many types of system, equipment and hazard to which BS 7671 is not applicable; for example, certain installations at mines and quarries, equipment on vehicles, systems for public electricity supply and explosion protection. Furthermore, BS 7671 applies only to installations operating at up to 1000 volts ac or 1500 volts dc.

9 Installations to which BS 7671 is relevant may have been installed in accordance with an earlier edition, now superseded but then current. That, in itself, would not mean that the installation would fail to comply with the 1989 Regulations.

Other, Statutory Regulations

10 The Electricity Safety, Quality and Continuity Regulations 2002 (SI 2002/2665) impose requirements regarding the installation and use of electric lines and apparatus of suppliers of electricity, including provisions for connections with earth. The safety aspects of these Regulations are administered by HSE; the remainder are administered by the Department of Trade and Industry. The Electricity Safety, Quality and Continuity Regulations may impose requirements which are in addition to those of the Electricity at Work Regulations.

Other sources of guidance

11 Guidance notes and other publications issued by HSE from time to time give detailed advice on such matters as design of certain equipment, safe working practices, maintenance and repair of equipment, and installation practice for particular environments. A list of some of these is given in Appendix 1.

12 There exist many codes of practice written by standards-making authorities, trade associations and other bodies setting out standards and procedures applicable to particular industries, processes or hazards. Such codes may provide useful, detailed expansion of the guidance given in this book but it must be borne in mind how and by whom these codes have been drawn up. A list of some of these is given in Appendix 2.

**Obtainable from the Institution of Engineering and Technology, Michael Faraday House,* 6 *Hills Way, Stevenage, Herts, SG1 2AY.*

European Directives

13 Purchasers and users of electrical equipment should be aware that Member States of the EU, and enforcing authorities such as HSE within Member States, are obliged* to accept for health and safety purposes equipment which conforms to certain Directives made under Article 100 of the Treaty of Rome. Further information about these Directives can be obtained from HSE.

**Subject to a procedure for appeal.*

Regulation 1

Citation and commencement

Regulation 1

These Regulations may be cited as the Electricity at Work Regulations 1989 and shall come into force on 1st April 1990.

Regulation 2

Interpretation

Regulation 2

(1) In these Regulations, unless the context otherwise requires -

"circuit conductor" means any conductor in a system which is intended to carry electric current in normal conditions, or to be energised in normal conditions, and includes a combined neutral and earth conductor, but does not include a conductor provided solely to perform a protective function by connection to earth or other reference point;

"conductor" means a conductor of electrical energy;

"danger" means risk of injury;

"electrical equipment" includes anything used, intended to be used or installed for use, to generate, provide, transmit, transform, rectify, convert, conduct, distribute, control, store, measure or use electrical energy;

"injury" means death or personal injury from electric shock, electric burn, electrical explosion or arcing, or from fire or explosion initiated by electrical energy, where any such death or injury is associated with the generation, provision, transmission, transformation, rectification, conversion, conduction, distribution, control, storage, measurement or use of electrical energy;

"system " means an electrical system in which all the electrical equipment is, or may he, electrically connected to a common source of electrical energy, and includes such source and such equipment.

Guidance 2

14 Words and phrases which are in bold type in the text of the regulation preceding the guidance on each regulation are those which have been assigned a special meaning by being defined in regulation 2.

Systems

15 The term 'system' includes all the constituent parts of a system, eg conductors and electrical equipment in it, and is not a reference solely to the functional circuit as a whole. It follows that something required of a system is required both of the system as a whole and of the equipment and conductors in it.

16 The definition refers to electrical systems. In the case of each system this will include all of the electrical equipment connected together and the various electrical energy sources in that system. In the case of transformers, even though there may be galvanic separation between the various windings of the transformers, where the energy is transmitted through these from one part of the electrical system to another, the transformer and all of its windings are part of the same system.

17 The definition of 'system' includes equipment which, although not energised, may be electrically connected to a common source of electrical energy. Equipment which is readily capable of being made live by a system is therefore considered to

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be part of that system. For example, a lighting circuit which has been disconnected from its source of electrical energy by means of removable links or fuses is still part of that system and so is such a circuit which has been switched off even though the switch might be a double pole switch.

18 Equipment which is in any way connected to a source of electrical energy, eg a test instrument containing a source and the equipment containing or connected to that source becomes part of a system and the Regulations apply to that system. Electrical equipment which is not connected, and cannot be readily connected, to a source of electrical energy is not part of a system. Protective conductors, if they are connected to a source, are part of that system.

19 The reference in the definition to a common source of electrical energy does not exclude systems fed by several generators or transformers. The word 'common' is included in the definition so that completely independent electrical installations are regarded as separate systems. If however they are electrically connected in any way they are part of the same system for the purposes of the Regulations, even though this may mean that in some cases the system may be an extensive electrical network covering large geographical areas over which several or even many people have control of various parts. In such cases the Regulations place duties on these people only in respect of those provisions of the Regulations which relate to matters which are within their control (see regulation 3).

20 Self-contained portable systems such as portable generating sets are electrical systems for the purpose of the Regulations as are transportable systems and systems on vehicles etc.

Electrical equipment

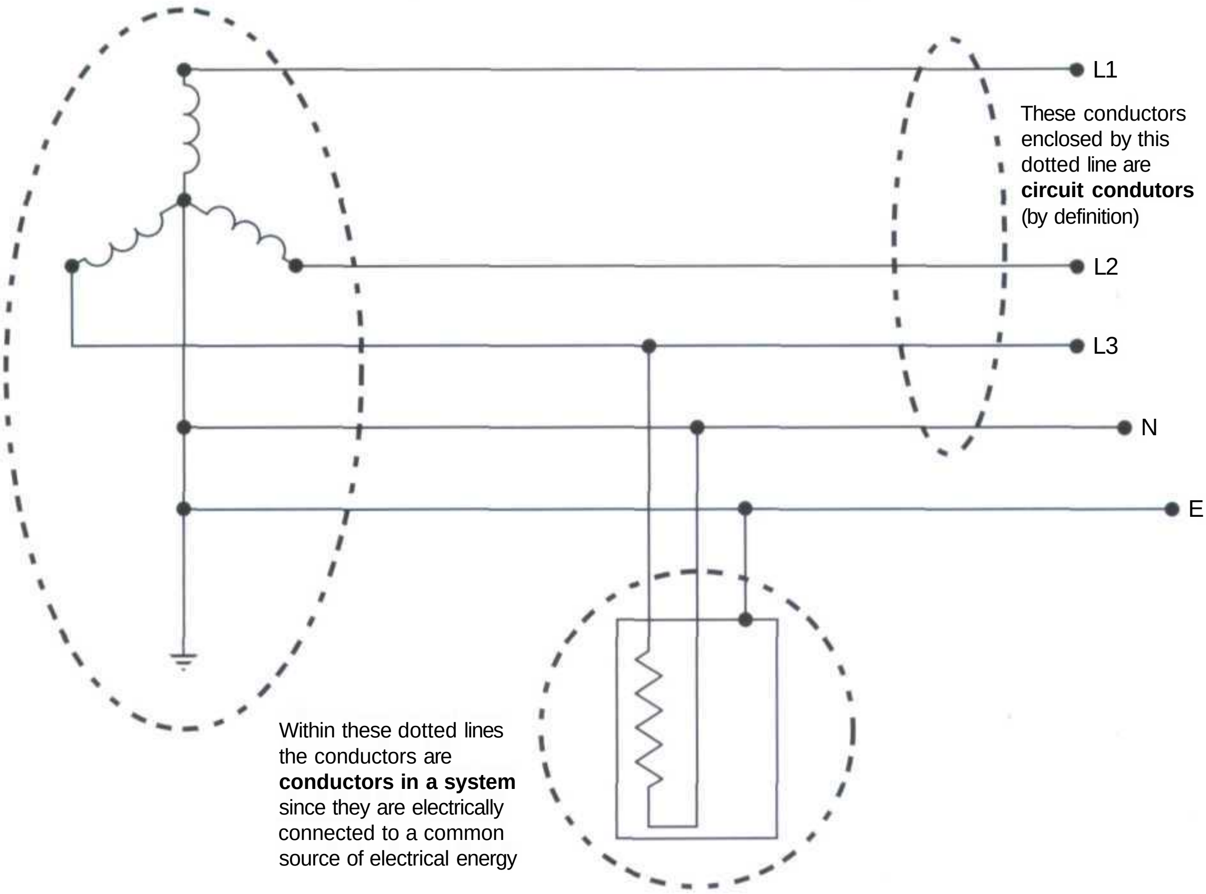
21 'Electrical equipment' as defined in the Regulations includes every type of electrical equipment from for example a 400 kV overhead line to a battery-powered hand lamp. It is appropriate for the Regulations to apply even at the very lowest end of the voltage or power spectrum because the Regulations are concerned with for example explosion risks which may be caused by very low levels of energy igniting flammable gases even though there may be no risk of electric shock or burn. Therefore no voltage limits appear in the Regulations. The criteria of application is the test as to whether 'danger' (as defined) may arise.

22 Electrical equipment (as defined) includes conductors used to distribute electrical energy such as cables, wires and leads and those used in the transmission at high voltage of bulk electrical energy, as in the national grid.

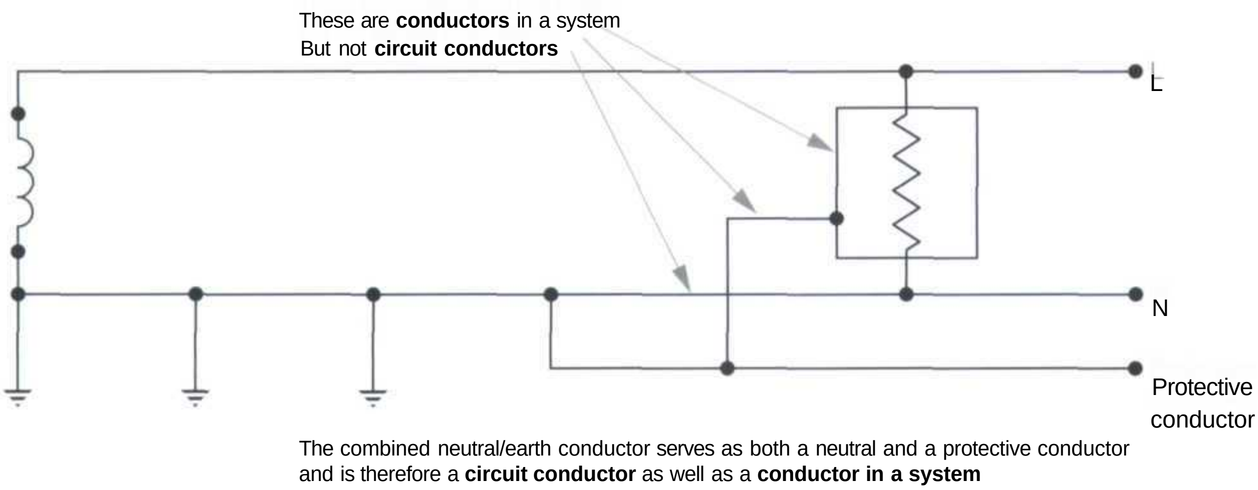
Conductors

23 Regulation 2 defines a conductor as 'a conductor of electrical energy'. This means any material which is capable of conducting electricity (electricity is synonymous with electrical energy) and therefore includes both metals and all other conducting materials. The definition is not limited to conductors intended to carry current and so includes, for example, metal structures, salt water, ionised gases and conducting particles. The conductance of most materials varies with parameters such as temperature; eg glass is conducting when molten (and is then a conductor as defined) whereas in its normal, solid, state it is a good insulator and finds many applications as such. For the purposes of the Regulations, while such materials conduct electricity, they are 'conductors'.

2



3 Phase system - separate neutral and earth



System including both combined and separate neutral and earth conductors (single phase only shown)

Figure 1 Types of conductor

Guidance

2

Circuit conductor

24 This definition is used in regulations 8 and 9 only. It distinguishes from all other conductors those conductors whose normal function is to carry load current or to be energised. (See Figure 1.)

Danger

25 The Regulations use the two defined terms, 'danger' and 'injury'. 'Danger' is defined as 'risk of *injury*'. 'Injury' is defined in terms of certain classes of potential harm to people.

26 Where the term 'prevent danger' is used it should therefore be read as 'prevent the risk of *injury*'.

27 The Regulations make requirements to 'prevent danger' or 'prevent injury' - or in the case of regulation 16 - 'to prevent danger or, where appropriate, injury'. The purpose of the distinction between 'injury' and 'danger' is to accommodate those circumstances when people must work on or so near live equipment that there is a risk of 'injury', ie where 'danger' is present and cannot be prevented. In these circumstances under regulation 14, danger may be present but injury must be prevented.

28 The type of injuries with which the Regulations are concerned are detailed in the definition of 'injury' in the regulation (see paragraphs 30 and 31). The scope of the Regulations does not include consequential dangers such as crushing injuries caused by a machine going out of control following an electrical malfunction. Such other dangers are subject to other legal requirements under for example the HSW Act, the Factories Act 1961 and the Offices Shops and Railway Premises Act 1963.

29 If no danger arises from a particular system, item of electrical equipment or conductor and will not arise, then the Regulations, although applying to it, do not require any precautions to be taken. However, in order for there to be no danger, there would have to be no risk of electric shock, electric burn, fire, arcing or explosion.

Injury

30 The purpose of the Regulations is to prevent death or personal injury to any person from electrical causes in connection with work activities.

31 'Injury' means death or injury to people from:

(a) electric shock;

(b) electric burn;

(c) fires of electrical origin;

(d) electric arcing; or

(e) explosions initiated or caused by electricity.

Guidance

(a) Electric shock

32 The human body responds in several ways to electrical current flowing through it. The sensation of shock is only one such effect and this can be extremely painful. When a shock is received, the electric current may take multiple paths through the body and its intensity at any one point is difficult or impossible to predict. The passage of electric current may cause muscular contractions, respiratory failure, fibrillation of the heart, cardiac arrest or injury from internal burns. Any of these can be fatal.

33 The nature and severity of injury depends upon the magnitude, duration and path of the current through the body and, in the case of alternating current, on its frequency. It is not possible to identify precise thresholds for the existence of hazard because a judgement has to be made in each case taking all the circumstances into account such as body weight, physical condition of the victim and so forth. Nevertheless, a guide to the sort of current magnitudes which mark the occurrence of various dangerous effects is given in the International Electrotechnical Commission's publication IEC TS/60479. Quite low currents, of the order of only a few milliamps (mA), can cause fatal electric shock.

34 Factors which mainly influence the likely effect of shock current are its voltage, frequency and duration and any impedance in the current path. The effects of electric shock are most acute at about the public electricity supply frequency of 50 hertz. Susceptibility to electric shock is increased if a person is in good electrical contact with earth, such as in damp or wet conditions or in conducting locations such as inside a metal tank. Hot environments where people may become damp due to perspiration or humidity, thus reducing the insulation protection offered by clothing, may present an increased risk from electric shock.

35 The variability of conditions makes it impossible to specify a voltage which is guaranteed to be safe in all situations. The risk of injury from electric shock in any situation must be considered against the background of the various national and international standards and technical publications giving guidance as to the voltages and other factors which have been found by extensive experience to be safe. These documents must be interpreted carefully and with a view to the limitation of their various scopes and assumptions. However, the conventional public electricity supply voltage of 230 volts ac should always be considered as potentially fatally dangerous. Many fatal electric shock accidents have occurred from contact with conductors live at this voltage and possibly the most dangerous situation is where contact is made with conductors by each hand, current then flowing 'hand to hand' across the heart region.

36 The following documents give some guidance:

(a) IEC Publication TS/60479 *Effects of current on human beings and livestock;*

(b) BS 7671 *Requirements for Electrical Installations;*

(c) IEC Guide 105 *Principles concerning the safety of equipment electrically connected to a telecommunications network.*

(b) Electric burn

2

37 Electric burns are different from burns due to fire (see paragraphs 40-41), arcing (see paragraphs 42-44) or explosion (see paragraphs 45-47).

Guidance

38 Electric burns are due to the heating effect caused by the passage of electric current through body tissues. They are most commonly associated with electric shock and often occur in and on the skin layers at the point of contact with the electrical conductors which gave rise to the electric shock.

39 At high frequencies, eg radio frequencies (RF), which include microwaves, it may not even be necessary for contact to be made with live conductors for an electric burn to be received. In the case of RF, the heating is by absorption of the electromagnetic wave energy by a dielectric loss process in the body of the victim. RF burns can thus be extremely deep within the body. RF burning can occur without the sensation of shock, particularly if no contact is made with the RF conductors, and can therefore cause severe injury before the victim is aware of their occurrence. Electric burns are usually painful and very slow to heal. Permanent scarring is common.

(c) Fires of an electrical origin

40 Fires may be started by electricity in a number of ways. The principal mechanisms are:

(a) overheating of cables and electrical equipment due to overloading of conductors;

(b) leakage currents due to poor or inadequate insulation;

(c) overheating of flammable materials placed too close to electrical equipment which is otherwise operating normally; and

(d) the ignition of flammable materials by arcing or sparking of electrical equipment, including the scattering of hot particles from electrical equipment.

41 The injuries associated with fire are usually burns but may include other injuries such as smoke inhalation.

(d) Arcing

42 Arcing causes a particular type of burn injury which is distinct from other types. Arcing generates ultra violet radiation which causes damage akin to severe sunburn. Molten metal particles from the arc itself can penetrate, burn and lodge in the flesh. These effects are additional to any radiated heat damage caused by the arc.

43 On its own, ultra violet radiation can cause damage; sensitive skin and eyes are especially vulnerable to arc flash. ('Arc eye' is commonly encountered with electric arc welding if the proper precautions are not adopted.)

44 Arcing faults can occur if the energy available at a piece of electrical equipment is sufficient to maintain a conductive path through the air or insulation between two conductors which are at different potentials. Under fault flashover conditions, currents many times the nominal rating or setting of a protective device may flow before those devices operate to clear the fault. Much energy is dissipated in the arc and depending on the electrical protection, may continue long enough to inflict very serious arcing burns or to initiate a fire in periods for example as short as 0.25 second, which is not an untypical minimum time for fault clearance. Arc flashovers caused during work on live circuit conductors are likely to be particularly hazardous because the worker is likely to be very near to or even enveloped by the arc. Such cases often lead to very serious, sometimes fatal, burn injuries.

2

Guidance

2

(e) Explosion

45 In this category are those injuries caused by explosions either of an electrical nature or those whose source of ignition is electrical.

46 Electrical explosions include the violent and catastrophic rupture of any electrical equipment. Switchgear, motors and power cables are liable to explode if they are subjected to excessive currents, which release violent electromagnetic forces and dissipate heat energy, or if they suffer prolonged internal arcing faults.

47 Explosions whose source of ignition is electrical include ignition of flammable vapours, gases, liquids and dusts by electric sparks, arcs or the high surface temperature of electrical equipment.

Other words used in the Regulations

Charged/live (as used in regulations 8, 13 and 14)

48 The terms 'charged' and 'live' have different meanings; they are not defined in the Regulations so they take their ordinary meaning. 'Live' means that the item in question is at a voltage, by being connected to a source of electricity for example as in normal use. 'Charged' means that the item has acquired a charge either because it is live or because it has become charged by other means such as by static or induction charging, or has retained or regained a charge due to capacitance effects even though it may be disconnected from the rest of the system.

Dead (as used in regulations 13, 14)

49 The term 'dead' is not defined in the Regulations so it takes its ordinary meaning. Thus, in the context of the Regulations, for a conductor to be 'dead' means that it is neither 'live' nor 'charged'.

Regulation 3

Persons on whom duties are imposed by these Regulations

Regulation

3

(1) Except where otherwise expressly provided in these Regulations, it shall be the duty of every -

(a) employer and self-employed person to comply with the provisions of these Regulations in so for as they relate to matters which are within his control; and

(b) (i) manager, in relation to a mine within the meaning of the Mines and Quarries Act 1954, and

(ii) operator, in relation to a quarry within the meaning of regulation 3 of the Quarries Regulations 1999, to ensure that all requirements or prohibitions imposed by or under these Regulations are complied with in so far as they relate to the mine of which he is the manager or quarry of which he is the operator and to matters which arc within his control.

(2) It shall be the duty of every employee while at work -

Regulation

3

(a) to co-operate with his employer so for as is necessary to enable any duty placed on that employer by the provisions of these Regulations to be complied with; and

(b) to comply with the provisions of these Regulations in so far as they relate to matters which are within his control.

Guidance

3

Employer

50 For the purposes of the Regulations, an employer is any person or body who (a) employs one or more individuals under a contract of employment or apprenticeship; or (b) provides training under the schemes to which the HSW Act applies through the Health and Safety (Training for Employment) Regulations 1990 (SI 1990/1380).

Self-employed

51 A self-employed person is an individual who works for gain or reward otherwise than under a contract of employment, whether or not they employ others.

Employee

52 Regulation 3(2)(a) reiterates the duty placed on employees by section 7(b) of the HSW Act.

53 Regulation 3(2)(b) places duties on employees equivalent to those placed on employers and self-employed people where these are matters within their control. This will include those trainees who will be considered as employees under the Regulations described in paragraph 50.

54 This arrangement recognises the level of responsibility which many employees in the electrical trades and professions are expected to take on as part of their job. The 'control' which they exercise over the electrical safety in any particular circumstances will determine to what extent they hold responsibilities under the Regulations to ensure that the Regulations are complied with.

55 A person may find himself responsible for causing danger to arise elsewhere in an electrical system, at a point beyond his own installation. This situation may arise, for example, due to unauthorised or unscheduled back feeding from his installation onto the system, or to raising the fault power level on the system above rated and agreed maximum levels due to connecting extra generation capacity, etc. Because such circumstances are 'within his control', the effect of regulation 3 is to bring responsibilities for compliance with the rest of the Regulations to that person, thus making him a dutyholder.

Absolute/reasonably practicable

56 Duties in some of the regulations are subject to the qualifying term 'reasonably practicable'. Where qualifying terms are absent the requirement in the regulation is said to be absolute. The meaning of reasonably practicable has been well established in law. The interpretations in paragraphs 58-60 are given only as a guide to dutyholders.

Guidance

Absolute

57 If the requirement in a regulation is 'absolute', for example if the requirement is not qualified by the words 'so far as is reasonably practicable', the requirement must be met regardless of cost or any other consideration. Certain of the regulations making such absolute requirements are subject to the Defence provision of regulation 29.

Reasonably practicable

58 Someone who is required to do something 'so far as is reasonably practicable' must assess, on the one hand, the magnitude of the risks of a particular work activity or environment and, on the other hand, the costs in terms of the physical difficulty, time, trouble and expense which would be involved in taking steps to eliminate or minimise those risks. If, for example, the risks to health and safety of a particular work process are very low, and the cost or technical difficulties of taking certain steps to prevent those risks are very high, it might not be reasonably practicable to take those steps. The greater the degree of risk, the less weight that can be given to the cost of measures needed to prevent that risk.

59 In the context of the Regulations, where the risk is very often that of death, for example, from electrocution and where the nature of the precautions which can be taken are so often very simple and cheap, eg insulation, the level of duty to prevent that danger approaches that of an absolute duty.

60 The comparison does not include the financial standing of the dutyholder. Furthermore, where someone is prosecuted for failing to comply with a duty 'so far as is reasonably practicable', it would be for the accused to show the court that it was not reasonably practicable for him to do more than he had in fact done to comply with the duty (section 40 of the HSW Act).

3

Regulation 4

Systems, work activities and protective equipment

Regulation

(1) All systems shall at all times be of such construction as to prevent, so far as is reasonably practicable, ***danger.***

(2) *As may be necessary to prevent* ***danger, all*** *systems shall be maintained so as to prevent, so far as is reasonably practicable, such* ***danger.***

(.3) Every work activity, including operation, use and maintenance of a system and work near a system, shall be carried out in such a manner as not to give rise, so far as is reasonably practicable, to ***danger.***

(4) *Any equipment provided under these Regulations for the purpose of protecting persons at work on or near* ***electrical equipment*** *shall be suitable for the use for which it is provided, be maintained in a condition suitable for that use, and be properly used.*

4

Guidance

61 Regulation 4 covers, in a general way, those aspects of electrical systems and equipment, and work on or near these, which are fundamental to electrical safety.

Regulation 4(1)

62 The word 'construction' in the regulation has a wide application. It may be considered to cover the physical condition and arrangement of the components of

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Guidance

a system at any time during its life. It will include aspects such as the design of the system and the equipment comprising that system.

63 In assessing the suitability of the construction of electrical systems, consideration should be given to all likely or reasonably foreseeable conditions of actual application or use of the electrical equipment in the system. This will include the testing, commissioning, operation and maintenance of the equipment throughout the life of the system.

64 In particular, consideration should be given to:

(a) the manufacturer's assigned or other certified rating of the equipment;

(b) the likely load and fault conditions;

(c) the need for suitable electrical protective devices;

(d) the fault level at the point of supply and the ability of the equipment and the protective devices to handle likely fault conditions;

(e) any contribution to the fault level from the connected loads such as from motors;

(f) the environmental conditions which will have a bearing on the mechanical strength and protection required of the equipment;

(g) the user's requirements of the installation;

(h) the manner in which commissioning, testing and subsequent maintenance or other work may need to be carried out.

65 The safety of a system depends upon the proper selection of all the electrical equipment in the system and the proper consideration of the inter-relationship between the individual items of equipment. For example, electrical protection against overloads and earth faults etc may need to be provided in one part of a system to protect another, possibly remote part of the system. Also, where electrical energy is transformed or converted from one voltage to another, precautions should be taken to prevent danger arising from the lower voltage conductors becoming charged above their normal voltage.

Regulation 4(2)

66 Regulation 4(2) is concerned with the need for maintenance to be done to ensure safety of the system, rather than with the activity of doing the maintenance in a safe manner (which is required by regulation 4(3)).

67 The obligation to maintain arises only if danger would otherwise result. The quality and frequency of maintenance should be sufficient to prevent danger so far as is reasonably practicable.

68 Regular inspection of equipment is an essential part of any preventive maintenance programme. Practical experience of use may indicate an adjustment to the frequency at which preventive maintenance needs to be carried out. This is a matter for the judgment of the dutyholder who should seek all the information he needs to make this judgment including reference to the equipment manufacturer's guidance.

4

Guidance

69 Records of maintenance, including test results, preferably kept throughout the working life of an electrical system will enable the condition of the equipment and the effectiveness of maintenance policies to be monitored. Without effective monitoring, dutyholders cannot be certain that the requirement for maintenance has been complied with.

70 British Standard Codes of Practice offering guidance on maintenance are referred to in Appendix 2. Advice on inspection and testing of some fixed installations is given in BS 7671 (see *Introduction* and Appendix 2).

Regulation 4(3)

71 Regulation 4(3) requires that work activities of any sort, whether directly or indirectly associated with an electrical system, should be carried out in a way which, as far as is reasonably practicable, does not give rise to danger. Regulations 12 to 16 provide more specific requirements in connection with work of an electrical nature on or near electrical systems.

Work activities associated with electrical systems

72 In the case of work of an electrical nature it is preferable that the conductors be made dead before work starts. (See regulations 12, 13 and 14.) In such cases it is essential that the equipment be isolated (note that 'isolation' is defined in regulation 12(2) which will include securing by locking off etc; see also paragraph 75) and the conductors proved dead at the point of work before the work starts. Where a test instrument or voltage indicator is used for this purpose this device should itself be proved preferably immediately before and immediately after testing the conductors.

73 Proper safe systems of work incorporating safety isolation procedures are important for work upon equipment which is to be made dead before work starts. These are also discussed under regulations 12 and 13. Some work, such as fault finding and testing, or live jointing by the electricity supply industry, may require electrical equipment to remain energised during the work. In these cases if there may be danger from live conductors, regulation 14 makes particular requirements and regulation 4(4) is also likely to be relevant in terms of the protective equipment which may need to be provided.

74 The operation, maintenance and testing of electrical systems and equipment should be carried out only by those people who are competent for the particular class of work. (See also regulation 16.)

Disused electrical equipment and systems

75 Before electrical equipment is decommissioned or abandoned for any reason it should be disconnected from all sources of supply and isolated. Isolation (as defined in regulation 12(2)) requires taking effective steps to ensure that it is dead and cannot become inadvertently re-energised or charged by induction or capacitance effects. (Regulations 12, 13 and 14 are also likely to be relevant.) Suitable labels or notices to bring people's attention to the state of the equipment are likely to be necessary in preventing inadvertent re-energisation.

Other work near electrical systems

76 Regulation 4(3) is wide in its application and includes work of a non-electrical nature where there is a risk of electrical injury. A common example is excavation near to live electric oower cables and work near live overhead power

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Guidance

lines, where the risks can be severe. Advice on these matters is given in HSE guidance notes which are listed in Appendix 1. The requirements of regulation 14 must also be taken into consideration.

Regulation 4(4)

77 The defence (regulation 29) is available in any proceedings for an offence under this part of regulation 4.

78 The term 'protective equipment' can be of wide application but typically includes those special tools, protective clothing and insulating screening materials etc necessary to undertake work safely on live electrical equipment. The requirement for suitable precautions to prevent injury may arise under regulation 14. The regulation makes three particular requirements of the protective equipment, that it be (a) suitable for use, (b) maintained in that condition and (c) properly used.

79 Regulation 4(4) is not qualified by 'so far as is reasonably practicable', nor does the regulation refer either to injury or the risk of injury, ie electrical danger. The impact of the regulation is that where protective equipment is provided in pursuance of compliance with any of the other regulations, that the equipment must conform to the requirements of regulation 4(4). Advice on safe working practices is given in HSE guidance notes (see Appendix 1). Specifications for certain types of protective equipment such as insulating gloves and floor mats are listed in Appendix 2.

4

Regulation 5 Strength and capability of electrical equipment

Regulation 5

No electrical equipment shall be put into use where its strength and capability may he exceeded in such a way as may give rise to danger.

Guidance

80 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

81 The regulation requires that before equipment is energised, the characteristics of the system to which the equipment is connected be taken into account, including those pertaining under normal conditions, possible transient conditions and prospective fault conditions, so that the equipment is not subjected to stress which it is not capable of handling without giving rise to danger. The effects to be considered include voltage stress and the heating and electromagnetic effects of current.

Strength and capability

82 The term 'strength and capability' of electrical equipment refers to the ability of the equipment to withstand the thermal, electromagnetic, electro-chemical or other effects of the electrical currents which might be expected to flow when the equipment is part of a system. These currents include, for example, load currents, transient overloads, fault currents, pulses of current and, for alternating current circuits, currents at various power factors and frequencies. Insulation must be effective to enable the equipment to withstand the applied voltage and any likely transient over-voltages.

83 A knowledge of the electrical specification and the tests, usually based on the requirements of national or international standards, which have been carried out

5

Guidance

5

either by the manufacturer or by an accredited testing organisation, will assist the user in identifying the withstand properties of the equipment so that it may be selected and installed to comply with this regulation.

Rating

84 The strength and capability of electrical equipment is not necessarily the same as its rating. Usually the rating is that which has been assigned by the manufacturer following a number of agreed tests.

85 It is recommended that electrical equipment be used within the manufacturer's rating (continuous, intermittent or fault rating as appropriate) and in accordance with any instructions supplied with the equipment.

Fault conditions

86 In order that equipment may remain safe under prospective fault conditions, it is necessary when selecting equipment to take account of the fault levels and the characteristics of the electrical protection which has been provided for the purpose of interrupting or reducing fault current (excess current protection is required by regulation 11). Most electrical equipment will be able to withstand short-circuit currents safely for limited periods only. The considerations extend also to conductors and equipment provided solely for protective purposes, eg earthing conductors must be adequately rated to survive beyond fault clearance times to ensure satisfactory protective gear operation and fault clearance.

Regulation 6

Adverse or hazardous environments

Regulation

6

Electrical equipment which may reasonably foreseeably be exposed to -

(a) mechanical damage;

(b) the effects of the weather, natural hazards, temperature or pressure;

(c) the effects of wet, dirty, dusty or corrosive conditions; or

(d) any flammable or explosive substance, including dusts, vapours or gases,

shall be of such construction or as necessary protected as to prevent, so for as is reasonably practicable, danger arising from such exposure.

Guidance

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87 The regulation draws attention to the kinds of adverse conditions where danger could arise if equipment is not constructed and protected to withstand such exposure. The regulation requires that electrical equipment should be suitable for the environment and conditions of use to which it may reasonably foreseeably be exposed so that danger which may arise from such exposure will be prevented so far as is reasonably practicable. The following paragraphs detail some of the conditions which electrical equipment may be subjected to. Guidance is given in these paragraphs and additional guidance may be found in the documents listed in Appendices 1 and 2. Particular attention should be paid to the IP rating (Index of Protection) of equipment (see paragraph 108). Guidance is also given under regulation 8 on the use of reduced voltage systems on construction sites and elsewhere where particularly arduous or conducting locations may exist (see paragraphs 143-145).

Guidance

Effects

88 The conditions at which the regulation is directed are those occurring naturally as well as those resulting from human activities, including the following:

(a) mechanical damage including impact, stress, strain, abrasion, wear, vibration and hydraulic and pneumatic pressure;

(b) effects of the weather, which include both short-term (eg wind, ice and snow, lightning) and long-term (eg temperature cycling) effects;

(c) natural hazards, which are those resulting from other than man's activities and include animals, trees and plants, tides and solar radiation etc;

(d) temperature and pressure;

(e) liquids which include water and other liquids and their effects, including humidity, condensation, flooding, splashing, or immersion in these, cleaning with liquids, hosing down and solvent and solvent vapour action (electrically conducting and non-conducting liquids may present different aspects of electrical danger);

(f) dirty conditions which include all contamination as a result of liquids or solids (electrically conducting and non-conducting dusts may present different aspects of electrical danger);

(g) corrosive conditions which include all chemical action and reactions and electrochemical effects;

(h) flammable substances including flammable dusts and flammable vapours;

(i) explosive substances which include both any mixture of solids, liquids or gases which is capable of exploding and substances intended to be explosive (ie explosives).

89 In gauging the suitability of equipment for particular environments or conditions of use it is necessary to consider only those effects or exposure which are reasonably foreseeable.

Mechanical damage

90 The mechanical damage to which electrical equipment may be subjected varies considerably from one environment to another. For example, equipment designed for use in an office is unlikely to be suitable, without further protection or careful siting, in a workshop or farm environment.

91 The effects covered by regulation 6(b), (c) and (d) may also impose mechanical stresses on electrical equipment. For example, ice and wind loading, or loss of mechanical strength due to expansion and contraction resulting from temperature changes, can give rise to mechanical damage.

92 This regulation requires the mechanical protection, if necessary, of the insulation which is required under regulation 7(a). Further suitable protection in addition to basic insulation may be necessary to form the physical protection necessary to ensure the continuing integrity of basic insulation, eg conduits or a trunking for single insulated conductors or the armouring or tough external sheathing of composite or multi-core electric cable.

6

Guidance

Weather, natural hazards and extreme conditions

93 Precautions which are taken to protect a site, structure or building from natural hazards and extreme weather conditions may give some protection to the associated electrical installation, but additional protection or precautions may be necessary.

94 Extremes of temperature, pressure or humidity may result either from climatic conditions or from adjacent plant or from the use of the electrical equipment itself. Standards frequently quote the range of service conditions for electrical equipment, including temperature limits, and users should consider these when selecting equipment.

95 Guidance on assessing the need for lightning protection of structures and buildings etc, the design and provision of systems and their inspection, testing and maintenance is given in publications listed in Appendix 2.

Corrosive effects

96 If substances are present in the environment which either alone, in combination, or in the presence of moisture can cause accelerated corrosion of metallic enclosures or fittings, special materials or surface treatments may be necessary. In these cases it would be recommended that much of the electrical equipment, eg motors, be of a type which is totally enclosed by an appropriate corrosion-resistant housing, ie not ventilated to the atmosphere.

97 Insulating materials and other materials used in electrical equipment may be affected by chemical agents or solvents. Cubicles housing electrical control equipment in hostile environments may need to be kept purged or pressurised with clean air or, in special cases, inert gas. See Appendix 2 for standards.

Dirt and dusts

98 Most industrial enclosures for electrical equipment do not resist the entry of fine dusts. Equipment should be constructed so as to resist the entry of dust and dirt where this may give rise to electrical and mechanical failures. Regular inspection and cleaning as necessary is recommended where dirt and dusts are likely to accumulate. A particular example is that of portable motor-driven equipment incorporating ventilation slots which can give rise to the accumulation of potentially hazardous layers of dirt and dust.

Combustible dusts

99 In cloud form, some dusts create an explosion hazard, while layers of combustible dust on electrical equipment can give rise to fire hazards. The selection, construction or installation of the equipment so exposed to combustible dust should be such as to guard against the possibility of ignition. The maximum temperature attainable on the surface of any electrical equipment where these dusts may be deposited should be considered in the selection of the equipment. The temperature of such surfaces should always be below the temperature at which any charring or smoking of dust takes place. However, appropriate dust control measures and general cleanliness which minimise the problem at source are to be preferred. See Appendix 2 for standards.

Potentially explosive atmospheres

6

100 If electrical equipment is used where a flammable or explosive atmosphere is likely to occur the equipment shall be so constructed that it is not liable to ignite that atmosphere.

Guidance

6

101 The selection and installation of equipment for use in potentially explosive atmospheres should be guided by the recommendations contained in the HSE guidance and British Standards on the subject (see Appendices 1 and 2). Existing installations complying with the recommendations of earlier standards should be acceptable for continuing service, subject to proper maintenance.

102 It is recommended that the choice of electrical equipment be from that which has been certified as being in conformity with an appropriate standard.

103 Uncertified electrical equipment should not be used unless it will provide at least an equivalent level of safety to that provided by appropriately certified equipment.

104 Some manufacturing processes, for example electrostatic paint spraying, make use of the characteristics of static electricity and the design of electrical equipment needs to be such that the ignition of solvents, vapours or particulate substances is prevented. See Appendix 2 for standards.

105 The maintenance and repair of explosion-protected equipment is a specialised field of work and should be undertaken only by those who have the necessary training and experience. See Appendix 2 for standards.

Other flammable substances

106 Much electrical equipment generates heat or produces sparks and this equipment should not be placed where either the heat emitted or the occurrence of sparking is likely to lead to the uncontrolled ignition of any substance.

107 The construction of the equipment should either exclude the substances from any part of the equipment which may be a source of ignition (eg by suitable enclosure) or should ensure that the equipment operates at sufficiently low temperature and energy levels as not to be a source of ignition under likely conditions of use and fault.

Classification system of ingress protection (IP rating)

108 There is an internationally recognised system of classifying the degree of protection provided by enclosures against the ingress of solid objects and moisture, and the protection afforded against contact with any live parts within the enclosure for all types of electrical equipment. The system is commonly known as the IP rating system (IP = Index of Protection) and is detailed in a number of standards which are listed in Appendix 2.

Regulation 7

Insulation, protection and placing of conductors

Regulation

7

All conductors in a system which may give rise to danger shall either -

(a) he suitably covered with insulating material and as necessary protected so as to prevent, so far as is reasonably practicable, danger; or

(b) have such precautions taken in respect of them (including, where appropriate, their being suitably placed) as will prevent, so far as is reasonably practicable, danger.

Guidance 7

109 The regulation requires that danger be prevented, so far as is reasonably practicable, by the means detailed in either part (a) or (b).

Guidance

110 The danger to be protected against generally arises from differences in electrical potential (voltage) between circuit conductors or between such conductors and other conductors in a system - usually conductors at earth potential. The conventional approach is either to insulate the conductors or to so place them that people are unable to receive an electric shock or burn from them.

111 Some form of basic insulation, or physical separation, of conductors in a system is necessary for the system to function. That functional minimum, however, may not be sufficient to comply with the requirements of regulation 7. Factors which must be taken into account are:

(a) the nature and severity of the probable danger;

(b) the functions to be performed by the equipment;

(c) the location of the equipment, its environment and the conditions to which it will be subjected;

(d) any work which is likely to be performed upon, with or near the equipment.

Insulation

112 Regulation 7(a) states the requirement that conductors are to be insulated. Suitable insulation of the conductors in an electrical system is, in the majority of cases, the primary and necessary safeguard to prevent danger from electric shock, either between live conductors or between a live conductor and earth. It will also prevent danger from fire and explosion arising from contact of conductors either with each other or with earth. Energy from quite low levels of voltage (and levels insufficient to create a shock risk) can ignite a flammable atmosphere. The quality and effectiveness of insulation therefore needs to be commensurate with the voltages applied to the conductors and the conditions of use.

113 BS 7671 gives some advice on these matters for fixed electrical installations up to 1000 volts ac or 1500 volts dc. See Appendix 2.

114 The regulation then requires that the insulation be protected as necessary, so that danger may be prevented so far as is reasonably practicable. Mainly, the protection required is to prevent mechanical damage to the insulation but may include any of the effects detailed under regulation 6. Examples of such protection would be the use of steel trunking and conduits or the use of steel armoured cables.

Other precautions including placing

115 Regulation 7(b) permits the alternative of having such precautions taken in respect of the conductors. These precautions may include the suitable placing of conductors. The precautions may comprise strictly controlled working practices reinforced by measures such as written instructions, training and warning notices etc. The precautions must prevent danger so far as is reasonably practicable. Examples where bare conductors are used in conjunction with suitable precautions are to be found in many applications including overhead electric power lines, down-shop conductors for overhead travelling cranes in factories etc, railway electrification using either separate conductor and running rails or overhead pick-up wires, and certain large electrolytic and electrothermal plants.

7

116 The design and construction of overhead electric power lines is specified in statutory regulations which are administered by the Department of Trade and Industry. (See *Introduction.*)

Guidance

117 Electric railway and tramway operators, in conjunction with the Office of the Rail Regulator (HM Railway Inspectorate), have developed standards and safety specifications for the construction of those parts of their systems which use bare conductors at overhead and at track level, together with safe systems of work.

118 Safety is ensured in electrochemical plants which use high current by such means as the separation of conductors which are at different potentials, the use of insulating working platforms and unearthed or isolated electrical supplies. (See paragraphs 122-124.)

119 Suitable placing of the conductors may alone go a considerable way towards preventing danger, for example where the conductors are within a secure enclosure or where they are placed overhead at such a height that contact with these conductors is not reasonably foreseeable. Guidance on the security and protection of enclosures and the measure of their accessibility as determined by standard (finger) tests is given in standards listed in Appendix 2.

120 However, if the placing of the conductors cannot alone be relied upon to prevent danger, then additional precautions need to be taken and rigorously applied. For example, in the case of live railway conductor rails the precautions may include warning notices, barriers and special training for railway staff. Electrolytic and electrothermal processes are further examples and these are the subject of paragraph 122.

121 Dutyholders should carefully consider the inherent risks that may exist if bare conductors are merely placed where they cannot normally be touched. Firstly, the protection of the equipment is required under regulation 6 for a range of reasonably foreseeable effects and secondly, there may be occasions when people will require access to the area or enclosure where such conductors are located, eg substations and test areas. Where work is to be done with the conductors live, regulation 14 is relevant and the guidance under that regulation also applies.

Electrolytic and electrothermal processes

122 It is often necessary, in connection with industrial electrolytic and electrothermal processes, including large secondary battery installations, to adopt a range of precautions. As the work activity is likely to be near the live and uninsulated conductors the precautions adopted will go towards satisfying both part (b) of regulation 7 and regulation 14.

123 Precautions may include:

(a) segregating the process area and limiting access to those people who are trained and experienced in the process and to people who are supervised so that injuries are prevented;

(b) ensuring a separation of conductors appropriate to the difference in potentials;

(c) use of insulating work platforms;

(d) use of electrical supplies which are isolated from earth together with protective devices to ensure this isolation;

(e) exclusion of unnecessary conducting materials and implements from the process area;

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Guidance

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(f) use of protective clothing, eg in electric arc welding processes, protective clothing offers protection against both the hot welding process and against the electric shock risk.

124 Details of advice on the safe use of electric induction furnaces and electric arc welding is given in Appendix 1.

Regulation 8

Earthing or other suitable precautions

Regulation

8

Precautions shall be taken, either by earthing or by other suitable means, to prevent danger arising when any conductor (other than a circuit conductor) which may reasonably foreseeably become charged as a result of either the use of a system, or a fault in a system, becomes so charged; and, for the purposes of ensuring compliance with this regulation, a conductor shall be regarded as earthed when it is connected to the general mass of earth by conductors of sufficient strength and current-carrying capability to discharge electrical energy to earth.

Guidance

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125 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

126 The regulation applies to any conductor, other than a circuit conductor, which is liable to become charged either as a result of the use of a system or a fault in a system. The regulation requires that precautions be taken to prevent danger resulting from that conductor becoming charged.

127 Because the regulation applies to any conductor (other than circuit conductors), this may include the conductive parts of equipment, such as outer metallic casings, which can be touched, which although not live, may become live under fault conditions.

128 Conductors which, although not part of a system, are within electrostatic or electromagnetic fields created by a system may be subject to this regulation. Appropriate precautions are necessary if the induced voltages or currents are large enough to give rise to danger.

Dangers

129 Dangers which may arise as a result of failure to take the necessary precautions include:

(a) risk of shock from such conductors which are or may be exposed so that they may be touched and which become charged at dangerous voltage relative to earth or to other exposed conductors;

(b) risk of burns, fire, arcing or explosion due to currents of excessive magnitude and/or duration in such conductors.

130 The requirements of the regulation may be responded to in several different ways, depending on the circumstances, including:

(a) ensuring that such conductors do not become charged. This has the effect of excluding the conductors from the scope of this regulation;

(b) ensuring that if such conductors do become charged the values of voltage and current and the duration are such that danger will not arise;

Guidance

(c) ensuring that if such conductors do become charged the environment is such that danger will not arise.

131 Techniques employed for achieving the above include:

(a) double insulation;

(b) earthing;

(c) connection to a common voltage reference point on the system;

(d) equipotential bonding;

(e) use of safe voltages;

(f) earth-free non-conducting environments;

(g) current/energy limitation; and

(h) separated or isolated systems.

The above techniques may be employed singly or in combination.

(a) Double insulation

132 The principle of 'double insulation' is that the live conductors of the electrical equipment are covered by two discrete layers or components of insulation each of which would adequately insulate the conductor but which together ensure an improbability of danger arising from insulation failure. This arrangement avoids the need for any external metalwork of the equipment to be connected to a protective conductor or to earth. Double insulation has been found to be particularly suitable for certain types of portable equipment, eg electric motor-driven tools etc, and the need for an earthing protective conductor is eliminated. See Appendix 2 for relevant standards. However, the integrity of this protective provision for safety depends upon the layers of insulation remaining in sound condition and this in turn requires that the equipment be properly constructed, used and maintained.

(b) Earthing

133 It is the practice in the UK for the public electricity supply system at the usual distribution pressures of 230 volts single phase, 400 volts three phase, to be referenced to earth by a deliberate electrical connection made at the distribution substations or power transformers. It is the existence of this system earthing which enables earth faults on electrical equipment to be detected and the electrical supply to faulty equipment to be cut off automatically.

134 Many 230/400 volt power installations are so designed that the automatic interruption of the supply upon the occurrence of an earth fault is performed by fuses or automatic circuit breakers (MCBs etc). In most cases these devices will have been selected to provide the additional protective function of interrupting excess current required under regulation 11. In these circumstances it is essential that the earth fault current be large enough to rupture the fuse quickly. The magnitude of the fault current under full earth fault conditions is governed mainly by the combined impedance of the fault loop which will include the impedance of the fault itself, that of the earthing or protective conductors, the circuit conductors and that of the source. Tests should therefore be carried out on new installations and at appropriate intervals thereafter to ascertain that the earth fault (loop)

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Guidance

impedances are low enough to ensure that the electrical protective devices such as fuses, circuit breakers etc will operate in the event of a breakdown of insulation leading to an 'earth fault'.

135 Acceptable parameters of earth loop impedance and interruption times etc for final installations up to 1000 volts may be found in BS 7671 (see Appendix 2). It is rarely sufficient to rely on an earth rod or rods to provide sufficient conductance for return fault currents. Separate protective earth cables or conductors connected to the neutral point of the supply are usually necessary unless other measures such as the use of sensitive residual current protection equipment is used to detect earth fault currents.

136 For the duration of the fault, the electrical bonding of exposed conductive parts and their connection to earth serves to limit the shock risk from the transient voltages appearing between metallic enclosures of equipment in the system or between a metallic enclosure and earth. Equipment earthing therefore includes the bonding of metallic enclosures, cable armouring, conduits and trunking etc, so that these conductors are electrically continuous and securely connected to the general mass of earth at one or more points.

137 Earthing and bonding conductors must be suitable for the maximum current which they may carry under fault conditions and be capable of surviving the worst-case fault (see paragraph 82). Their construction and strength must be adequate to withstand likely wear and tear. Where it might otherwise be difficult to ensure the continued effectiveness of earthing and bonding arrangements, it may be necessary to provide supplementary protection such as protective earth conductor monitoring.

138 Many accidents have been caused by the metalwork of portable or transportable equipment becoming live as a result of the combined effects of a fault and high impedance protective conductor connections. The danger may be reduced by the use of a residual current device (RCD) designed to operate rapidly at small leakage currents (typically not exceeding 30 mA), although these devices do not eliminate the risk of electric shock. RCDs should be considered only as providing a second line of defence. They should be operated regularly using the test trip button. This test trip procedure is important in maintaining the effectiveness of most types of RCD.

139 Electric arc welding brings special problems associated with earthing practices. Stray currents from electrical arc welding can damage the protective earthing conductors of electrical installations. Advice on electric arc welding safety is given in HSG1 18 listed in Appendix 1.

140 Information on earthing practice is available in a number of publications, some of which are listed in Appendix 2.

(c) Connection to a common voltage reference point on the system

141 In the case of UK public electricity supply systems where transformer neutral points are connected to earth, the voltage reference point is the general mass of earth. Other reference points, to which systems may be referenced and to which bonding conductors are connected, may be chosen to suit particular circumstances.

(d) Equipotential bonding

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142 Equipotential bonding is the electrical interconnection of all exposed and extraneous conductors, which may become electrically charged, in such a way that

Guidance

dangerous voltages between any of the conductors which may be simultaneously touched are limited.

(e) Use of safe voltages

143 Reduced voltage systems are particularly appropriate for portable and transportable equipment, in highly conducting locations such as boilers and tunnels where the risk of mechanical damage to equipment and trailing cables is high, where the body may be damp and have large areas of contact with the conducting location and on construction sites.

144 One example is that of building or construction site supply systems operating at 55-0-55 V ac single phase, or at 1 10 V three phase with a phase-earth voltage of 64 V ac. Another example is that of an extra low voltage system operating at or below 50 V ac or 120 V dc as recommended internationally. Supply systems like these are referenced to earth and are therefore a special case of systems operating at reduced voltage for which bonding and earthing of all metallic enclosures are still recommended.

145 Further advice on reduced voltage systems may be found in HSE guidance notes listed in Appendix 1 and in BS 7671 (see Appendix 2).

(f) Earth-free, non-conducting environments

146 If a system is supplied from a source which is earth-referenced, the path for fault current and the existence of dangerous potentials to earth can be eliminated in a defined area by ensuring that the area is 'earth-free'. This does not necessarily mean that metallic components or fittings need to be prohibited but rather that no part of the defined area is earthed. It is easier to ensure the integrity of an 'earth-free' area by constructing it from non-metallic components in which case it is more appropriately known as a non-conducting location or area. 'Earth-free' and 'non-conducting' areas are of rather specialised application and are used mainly in certain types of testing of electrical equipment, advice on which is available in the publications on electrical testing listed in Appendices 1 and 2.

(g) Current limitation

147 If fault currents which could cause electric shock are inherently limited by appropriate passive devices, eg high integrity resistors, then protection by earthing or other means may not be required. In the conventional dry, working environment, for example, if the current is limited preferably to 1 mA but certainly to no more than 5 mA this will not usually present a risk of injury from electric shock to people in good health who may be subjected to it only occasionally and for a short time only. However, even this low level of current may give perceptible shock which although by itself is unlikely to be physiologically dangerous, may give rise to a consequential injury such as from a fall induced by the shock (but see paragraph 31 on 'injury' under regulation 2, especially IEC publication TS/60479 (see Appendix 2)).

(h) Separated or isolated systems

148 If safety depends on the supply system not being referenced to its immediate environment, whether true earth or surrounding metalwork, no potential should normally exist between live conductors and earth or exposed metallic parts. However, all systems are to some extent referenced to their environment by capacitive or inductive coupling or by leakage. For this reason, reliance cannot

Guidance

necessarily be placed on the circuit conductors of separated or isolated* systems being at zero potential relative to their environment. Unless the isolated system is a very small and localised one, the leakage current may be large enough to provide a path for a fatal electric shock. Any difference in potential is likely to be greatest on extensive systems but, in all cases when the voltages or currents could be dangerous, precautions are needed. Examples of isolated systems are those supplied from the secondary winding of an isolating transformer or the winding of an alternator where there is no connection between them and any other source of electrical energy.

149 The isolation of a power system from earth may reduce the risks associated with a single fault. However, if this first fault has the effect of referencing the system to earth or other exposed conductor, subsequent faults may lead to very destructive and hazardous short circuits so extra precautions will be necessary to prevent this danger. These may include the bonding of metallic enclosures; earth fault detection; insulation monitoring or the use of an earth-free non-conducting environment. Regular inspection and testing to ensure that system isolation integrity is maintained will also be necessary.

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** 'Isolated' in this context means separate from all other systems and does not imply 'isolation' as defined specifically for the purpose of regulation 12.*

Regulation 9

Integrity of referenced conductors

Regulation 9

If a circuit conductor is connected to earth or to any other reference point, nothing which might reasonably be expected to give rise to danger by breaking the electrical continuity or introducing high impedance shall be placed in that conductor unless suitable precautions are taken to prevent that danger.

Guidance

150 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

151 In many circumstances the reference point is earthed because the majority of power distribution installations are so referenced by a deliberate connection to earth at the generators or distribution transformers.

152 The object of the regulation is to prevent referenced circuit conductors which should be at or about the same potential as the reference point from reaching significantly different potentials thereby giving rise to possible danger.

153 The most common situation in which this regulation is relevant is in systems having a neutral point which is earthed. Such systems can be subdivided:

(a) systems, or parts of systems, in which the neutral and protective conductor are combined (eg TN-C and the combined parts of TN-C-S systems);*

(b) systems or parts of systems in which the neutral and protective conductors are separate (eg TN-S and the separate parts of TN-C-S systems).

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**This terminology is explained in BS 7671.*

Guidance

Devices placed in the conductor

154 The regulation does not prohibit all electrical devices from being placed in referenced conductors. For example, a proper joint or a bolted link or a bar primary current transformer can be arranged to ensure the integrity of the conductor.

155 The regulation would also permit the inclusion of other devices such as a removable link, or even a manually-operated knife switch, provided that suitable precautions are adopted to ensure that these devices are not removed or operated in such a way as to give rise to danger. However, a number of other devices such as fuses, thyristors, transistors etc generally cannot be relied upon not to give rise to danger by becoming open circuit or introducing high impedance into the conductor. The regulation prohibits such applications.

Combined neutral and protective conductors

156 Open circuit of, or high impedance in, combined neutral and protective conductors will almost certainly result in the exposed and extraneous conductors which are connected to the protective conductors, eg metal enclosures of switchgear, being at a significant potential (up to phase-neutral volts) relative to earth. This could lead to a risk of electric shock or burn, thus the integrity of the combined neutral and earth conductor is very important. However, where the protective conductor is combined with the neutral conductor over some part of their length, precautions to prevent people coming into simultaneous contact with the protective conductors and earth (or conductors at earth potential) should be taken. Equipotential bonding of all metalwork within a building and the connection of this to the protective conductor or neutral is a commonly used approach. Generally, however, CNE systems should be confined to the public electricity supply network up to the point of supply to consumers.

Separate neutral and protective conductors

157 When deciding whether danger may result where there are separate neutral and protective conductors it is necessary to consider not only the normal operation of the system but also the situations that may arise when work is being carried out on or near the system. If voltage rises on the neutral conductor could result in danger during the work then the above restrictions on devices in the neutral should be observed. For example, a fuse should not be placed in a neutral of a fixed power distribution installation (typically 230 volts) because this places people working on the installation at risk of electric shock and burn should that fuse operate or otherwise become open circuit. Double pole fusing (fuses in both the phase and neutral) is acceptable, however, if these are fitted within self-contained electrical equipment which itself is not part of the fixed electrical installation, and is connected to the fixed installation by a plug and socket by means of which the equipment may be readily isolated from the system prior to work being done on that equipment.

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158 In general, if a neutral conductor is to be switched, a multipole switch or circuit breaker should be used which also switches all of the related phase conductors, the neutral breaking last and making first. Such switching should not interrupt the protective conductor.

Regulation 10

Connections

Regulation 10

Where necessary to prevent danger, every joint and connection in a system shall be mechanically and electrically suitable for use.

Guidance

159 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

Suitability of connections

160 The regulation requires that all connections in circuit and protective conductors, including connections to terminals, plugs and sockets, and any other means of joining or connecting conductors, should be suitable for the purposes for which they are used. This requirement applies equally to temporary and permanent connections.

161 The insulation and conductance of the connections should be suitable, having regard to the conditions of use including likely fault conditions.

162 The mechanical protection and strength should be such as to ensure the integrity of the insulation and conductance under all conditions of use including likely fault conditions, subject to the need for any maintenance which may be required by regulation 4(2).

163 Joints and connections in protective conductors should be made at least as carefully as those in circuit conductors and they should be of sufficient strength and conductance to allow for the passage of fault currents. Such connections may need to be treated so as to prevent corrosion. It is recommended that combinations of metals liable to produce damaging electrolytic action be avoided.

Plugs and sockets

164 Plug and socket connections and their use should be so arranged that accidental contact with conductors live at dangerous voltages is prevented. Mainly this should be achieved by selection of appropriate equipment but may involve some degree of operator skill and/or training depending on the circumstances.

165 In most applications, where a plug and socket type connector conveys a protective conductor as well as the circuit conductors, the protective conductor should be the first to be made and the last to be separated. The use of equipment made to appropriate standards should ensure that the principle is adhered to.

166 Where plug and socket connections are not rated for making or breaking the maximum load current, effective arrangements should be made, for example, by mechanical interlocking with the switch that controls the power, to ensure that the connections are made or broken only under no-load conditions.

Portable equipment

167 Special attention should be given to joints and connections in cables and equipment which will be handled, for example flexible cables for portable equipment. Plugs and sockets for portable equipment should be constructed in accordance with appropriate standards and arranged that, where necessary, earthing of any metal casing of the equipment is automatically effected by the insertion of the plug. HSE guidance notes and British Standards give further guidance on portable equipment (see Appendices 1 and 2).

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Regulation 11

Means for protecting from excess of current

Regulation 11

Efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger.

Guidance

168 The defence (regulation 29) is available in any proceedings for an offence under this regulation. (See paragraphs 178 to 180.)

169 It is recognised that faults and overloads may occur on electrical systems. The regulation requires that systems and parts of systems be protected against the effects of short circuits and overloads if these would result in currents which would otherwise result in danger.

170 The means of protection is likely to be in the form of fuses or circuit breakers controlled by relays etc or it may be provided by some other means capable of interrupting the current or reducing it to a safe value.

The need to anticipate abnormal conditions

171 The regulation requires the means of preventing danger to be provided in anticipation of excess current; a fault or overload need not have occurred. Fault currents arise as a result of short circuits between conductors caused either by inherent failure of the electrical equipment or some outside influence, eg mechanical damage to a cable. Overload currents can arise as a result of the inadequacy of a system to supply the load and may be caused by an increased demand created by outside influence on the electrical equipment, eg mechanical overloading of an electric motor.

The selection of excess current protection

172 In principle, every main circuit should be protected at its origin, ie at the source end of the circuit. Where the rating of the conductors forming a branch circuit is less than that of the conductors from which it is drawing power, it is conventional for protection to be placed at this point. In practice, however, there are exceptions to this principle and, depending on the nature of the system, a technical judgement must be made as to where the protection should be placed. Guidance on some aspects of this subject is given in BS 7671 (see Appendix 2).

173 When selecting the means of protection, consideration must be given to a number of factors among the more important of which are:

(a) the nature of the circuits and type of equipment to be protected;

(b) the short-circuit energy available in the supply (the fault level);

(c) the nature of the environment;

(d) whether the system is earthed or not.

(a) The nature of the circuits and type of equipment to be protected

174 The circuits to be dealt with may vary from high-power high-voltage circuits, for example for the inter-connection of substations or for the supply to large motors, down to the smallest final circuit supplying a few low-power lamps at say 6 volts. Over this range lies a great diversity of equipment each item of which will possess characteristics which must be carefully considered in the selection of appropriate devices to protect against excess current.

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Guidance

(b) Fault level

175 Due regard must be paid to the maximum short-circuit current with which the protective device may have to deal. (The ability of circuit breakers and fuses to operate successfully and without dangerous effects, serious arcing or, in the case of oil-filled equipment, the liberation of oil, is implicit in the requirements of regulations 4 and 5.) The design of the protective arrangement must also provide for sufficient current to be available to operate the protective devices correctly in respect of all likely faults.

(c) The nature of the environment

176 The nature of the environment may have a bearing on the choice of protective devices and their settings, for example where the possibility of a fire being started may be considerable. In all cases, however, the protection against excess current must be effective so that short circuits and earth faults are cleared promptly to minimise destructive arcing and heating. Protective devices, whether they be circuit breakers or fuses, should therefore be set or selected for the minimum tripping currents and times consistent with ensuring the reliable operation of the device and for the need for discrimination between successive stages of protection.

(d) Earthed system

177 Where a system is earthed, the nature and efficiency of the earthing system is important in relation to the design and reliability of the protective devices. In earthed systems, ie where some part of the windings of the machine or transformer from which the supply is derived is connected to earth, operation in the event of an earth fault of the protective device, whether circuit breaker or fuse, is dependent on sufficient current passing to operate the excess current or earth leakage tripping device or to blow the fuse. In many systems, the device provided in pursuance of the requirements of this regulation in respect of excess of current (very often a fuse) may also provide protection against earth faults - and thus be in pursuance of the requirements of regulation 8.

Defence in criminal proceedings

178 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

179 In some circumstances it will be technically impossible to achieve total compliance with the absolute requirement to prevent danger. If an excess of current is drawn due to a fault or overload, for example due to an arcing fault, then whatever form of electrical protection is provided, there will be some danger at the point of the fault during the finite time taken for the detection and interruption of the fault current. Nevertheless, the choice of electrical protection, be it by means of a simple fuse or whatever, must be properly chosen and installed in accordance with good electrical engineering practice. The protection must be efficient and effective.

180 In some circumstances it is undesirable to interrupt the current in a circuit because this may itself lead to a hazard. Examples of such circumstances include the excitation field current of direct current motors, trip coil circuits, lifting electromagnets and the secondary circuits of current transformers. In such cases, however, the circuit should be so rated or arranged not to give rise to danger from excess of current.

Regulation 12

Means for cutting off the supply and for isolation

Regulation

*(1) Subject to paragraph (3), where necessary to prevent **danger,** suitable means (including, where appropriate, methods of identifying circuits) shall be available for -*

*(a) cutting off the supply of electrical energy to any **electrical equipment;** and*

*(b) the isolation of any **electrical equipment.***

*(2) In paragraph (1), "isolation" means the disconnection and separation of **the electrical equipment** from every source of electrical energy in such a way that this disconnection and separation is secure.*

*(3) Paragraph (1) shall not apply to **electrical equipment** which is itself a source of electrical energy but, in such a case as is necessary, precautions shall be taken to prevent, so for as is reasonably practicable, **danger.***

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Guidance

181 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

Regulation 12(l)(a)

182 The objective of this part of the regulation is to ensure that, where necessary to prevent danger, suitable means are available by which the electricity supply to any piece of equipment can be switched off. Switching can be, for example, by direct manual operation or by indirect operation via 'stop' buttons in the control circuits of contactors or circuit breakers. There may be a need to switch off electrical equipment for reasons other than preventing electrical danger but these considerations are outside the scope of the Regulations.

Regulation 12(1)(b)

183 Whereas regulation 12(l)(a) requires means to be provided whereby the supply of electrical energy can be switched off, 12(1){b) requires that there will be available suitable means of ensuring that the supply will remain switched off and inadvertent reconnection prevented. This is isolation. This provision, in conjunction with safe working practices, will enable work to be carried out on electrical equipment without risk of it becoming live during the course of that work, for example if the work is to be done under the terms of regulation 13.

184 In some cases the equipment used to perform the requirement under regulation 12(1)(a) may also serve to perform the requirement under 12(1)(b). It must be understood that the two functions of ***switching*** off and ***isolation*** are not the same, even though in some circumstances they are performed by the same action or by the same equipment.

Regulation 12(3)

185 Regulation 12(3) recognises the impracticability in some cases of switching off or of isolating that equipment which is itself an integral part of a source of electrical energy, for example the terminals of accumulators, large capacitors and the windings of generators. The regulation requires precautions to be taken in these circumstances so that danger is prevented so far as is reasonably practicable. See Appendix 1 for guidance on working practices.

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Guidance

"Where necessary to prevent danger"

186 The need for means to cut off the supply and effect isolation depends on factors such as likely danger in normal and abnormal conditions. This assessment may be influenced by environmental conditions and provisions to be made in case of emergencies, such as a fire in a premises. It includes consideration of which electrical equipment could be a source of danger if such means were not provided and of the installation, commissioning, operational and maintenance requirements over the life of the equipment.

Suitable means for cutting off the supply

187 The suitable means for cutting off the supply (regulation 12(l)(a)) should:

(a) be capable of cutting off the supply under all likely conditions having regard to the equipment, its normal operation conditions, any abnormal operating or fault conditions, and the characteristics of the source(s) of electrical energy;

(b) be in a suitable location having regard to the nature of the risks, the availability of people to operate the means and the speed at which operation may be necessary. Access to switches etc should be kept clear and unobstructed, free of tripping and slipping hazards etc;

(c) be clearly marked so as to show its relationship to the equipment which it controls, unless there could be no doubt that this would be obvious to any person who may need to operate it; and

(d) only be common to several items of electric equipment where it is appropriate for these to be energised and de-energised as a group.

Suitable means of isolation

188 The suitable means of isolation of equipment (regulation 12(l)(b)) should:

(a) have the capability to positively establish an air gap or other effective dielectric, which together with adequate creepage and clearance distances, will ensure that there is no likely way in which the isolation gap can fail electrically;

(b) include, where necessary, means directed at preventing unauthorised interference with or improper operation of the equipment, for example means of locking off;

(c) be located so that the accessibility and ease with which it may be employed is appropriate for the application. The time and effort which must be expended to effect isolation should be reasonable having regard to the nature of the equipment and the circumstances under which isolation may be required, eg a very remote means of isolation may be acceptable if isolation is only needed infrequently and any additional time taken to effect isolation does not result in danger;

(d) be clearly marked so as to show to which equipment it relates, unless there could be no doubt that this would be obvious to any person who may need to operate it;

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(e) only be common to several items of electrical equipment where it is appropriate for these to be isolated as a group.

Selection of isolator switches

189 Isolator switches (or disconnecters) will often be employed as the means of effecting disconnection and secure separation from the supply. In selecting appropriate equipment to perform this function particular regard should be given to:

(a) the isolating distances between contacts or other means of isolation which should be in accordance with an appropriate Standard or be otherwise equally effective;

(b) the position of the contacts or other means of isolation which should either be externally visible or clearly and reliably indicated. An indication of the isolated position, other than by direct observation of the isolating gap, should occur when the specified isolating distance has been achieved in each pole;

(c) provision to enable the prevention of unauthorised, improper or unintentional energisation, eg locking-off facilities.

190 For further information on the selection of isolators/disconnectors reference should be made to appropriate standards, see Appendix 2.

Regulation 13

Precautions for work on equipment made dead

Regulation

13

Adequate precautions shall be taken to prevent electrical equipment, which has been made dead in order to prevent danger while work is carried out on or near that equipment, from becoming electrically charged during that work if danger may thereby arise.

Guidance

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191 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

192 Regulation 13 relates to situations in which electrical equipment has been made dead so that work either on it or near it may be carried out without danger. The regulation may apply during any work, be it electrical or non-electrical. The regulation requires adequate precautions to be taken to prevent the electrical equipment from becoming electrically charged, from whatever source, if this charging would give rise to danger. 'Charged' is discussed under regulation 2.

193 The regulation uses the term 'electrical equipment' which is defined by regulation 2. This will include any cables, conductors, wires, connectors etc which may have been arranged to connect together the various other items of electrical plant or equipment such as motors, transformers, switch gear etc. The regulation may therefore apply to any or all of these.

The precautions

194 The precautions should be effective in preventing the electrical equipment from becoming charged in any way which would give rise to danger.

195 In the first place, the procedures for making the equipment dead will probably involve use of the means required by regulation 12(1)(a) for cutting off

Guidance

the supply of electrical energy. Isolation of the electrical equipment will be necessary and the means required by regulation 12(1)(b) will facilitate this. Ideally a means of locking off an isolator can be used. Where such facilities are not available, the removal of fuses or links and their being held in safe keeping can provide a secure arrangement if proper control procedures are used.

196 These precautions will prevent the equipment from becoming charged by connection to its own or normal sources of electrical energy but may not alone be sufficient to prevent charging. The presence of electrical energy as a result of electromagnetic induction, mutual capacitance or stored electrical energy may have to be guarded against, for example by applying earthing connections for the duration of the work (temporary earths). The precautions may need to include means of preventing further accumulation of electrical charge, following initial discharge, because latent energy may be stored in the system, for example in the dielectric of high voltage cables. In the case of work upon high voltage power distribution circuits, isolation procedures should include the back-up measure of applying circuit main earths (primary earths) at points of isolation by means of purpose-built facilities.

197 Where work is to be done on or near conductors that have been isolated, the conductors should be proved dead at the point of work before the work starts. Where a test instrument or voltage indicator is used for this purpose this should itself be proved, preferably immediately before and immediately after testing the conductor. (See also regulation 4(3).)

198 The regulation does not preclude the application of a test voltage to equipment provided that this does not give rise to danger.

Written procedures

199 It may also be appropriate for the safety isolation procedures to be formalised in written instructions or house rules. 'Permits-to-work' may form part of the written procedures and their use is considered essential to ensuring a safe system of work where this involves work on the conductors or equipment of high voltage power distribution systems (typically where the working voltage exceeds 1000 volts) or where the system is very complex. Properly formulated and regulated 'permit-to work' procedures focus the minds both of those issuing and of those receiving the permits both on the manner in which the work is to be done and on how the equipment has been made safe. Further advice on these procedures and precautions may be found in the guidance listed in Appendices 1 and 2.

Decommissioned equipment

200 Before electrical equipment is decommissioned, dismantled or abandoned for any reason, it should be disconnected from all sources of supply and effective steps taken to ensure that it is dead and cannot inadvertently become re-energised or dangerously charged. It may be necessary to securely mark or otherwise suitably label equipment, circuits, switches etc to guard against inadvertent re-energisation. (See also the requirement for identifying circuits under regulation 12(1).)

13

Regulation 14

Work on or near live conductors

Regulation 14

No person shall be engaged in any work activity on or so near any live conductor (other than one suitably covered with insulating material so as to prevent danger) that danger may arise unless -

Regulation

14

(a) it is unreasonable in all the circumstances for it to be dead; and

(b) it is reasonable in all the circumstances for him to be at work on or near it while it is live; and

(c) suitable precautions (including where necessary the provision of suitable protective equipment) are taken to prevent injury.

Guidance

14

201 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

202 Regulation 14 addresses the situation where, either permanently or temporarily, danger from conductors is not prevented by the precautions specified in regulation 7(a).

203 The regulation is concerned only with those situations where people are at work on or near live electrical conductors which may foreseeably give rise to danger. Such work is permitted only if conditions (a) and (b) and (c) are satisfied. 'Work' is not confined to electrical work but includes any work activity

(a) The need for the conductor to be live

204 If danger may otherwise arise it is always preferable from the point of view of safety that work on or near such electrical equipment should be carried out when that equipment is dead. (See regulation 13 and guidance.) Regulation 14 recognises that there are circumstances, however, in which it is unreasonable, having regard to all relevant factors, for the equipment to be dead while work proceeds. An example of this might be where it was found necessary to undertake some maintenance, checking or repair on a busy section of electric railway track where it would be disproportionately disruptive and costly in many ways for the live conductors to be isolated for the period of the work. Other examples are to be found in the electrical supply industry, particularly live cable jointing, and in much of the work done on telephone network connections.

205 Equipment users should bear in mind at the time of ordering, purchase and installation of plant, the manner of operation, maintenance and repair of the electrical equipment which will be necessary during the life of the plant.

206 It is recommended that the design of electrical equipment and of the installation should eliminate the need for live work which puts people at risk of injury. This can often be done by careful thought at the design stage of installations, for example by the provision of alternative power infeeds, properly laid out distribution systems to allow parts to be isolated for work to proceed and by designing equipment housings etc to give segregation of parts to be worked on and protect people from other parts which may be live.

207 It is recommended that equipment which combines power and control circuitry should be arranged so that the power circuits are physically separate and segregated from logic and control circuits or so placed, recessed or otherwise arranged that the risk of accidental contact is eliminated. Diagnostic work on the low power/voltage circuits may then proceed with less risk to personnel. Where regular measurements of say voltage, current etc are to be made, consideration should be given to appropriate test and measuring equipment, eg voltmeters, ammeters, etc or test points being built into the equipment.

208 Live work includes live testing, for example the use of a potential indicator on mains power and control logic circuits (but see paragraph 220).

Guidance

14

209 The factors which would be considered in deciding whether it was justifiable for work to proceed with the conductors live would include the following:

(a) when it is not practicable to carry out the work with the conductors dead, eg where for the purposes of testing it is necessary for the conductors to be live;

(b) the creation of other hazards, by making the conductors dead, such as to other users of the system, or for continuously operating process plants etc;

(c) the need to comply with other statutory requirements;

(d) the level of risk involved in working live and the effectiveness of the precautions available set against economic need to perform that work.

(b) The need to be near uninsulated live conductors

210 People at work are permitted to be near live conductors only if this is reasonable in all the circumstances. If, for example, it would be reasonable for the work to be carried out at a safe distance from the conductors then it would be prohibited for that work to be done near the conductors.

211 People whose presence near the live conductors is not necessary should not be so near the conductors that they are at risk of injury.

(c) The need to take precautions to prevent injury

212 The precautions necessary to comply with regulation 14(c) need to be commensurate with the risk.

213 The system of work should: allow only people who are competent to do so to work on or near exposed, live conductors (competence for these and other purposes is further dealt with at regulation 16); indicate within what limits the work is to be attempted; indicate what levels of competence apply to each category of such work; and incorporate procedures under which the person attempting the work will report back if the limits specified in the system are likely to be exceeded. This usually requires detailed planning before the work is started.

214 Suitable precautions should include as appropriate:

(a) the use of people who are properly trained and competent to work on live equipment safely (see also regulation 16);

(b) the provision of adequate information to the person carrying out the work about the live conductors involved, the associated electrical system and the foreseeable risks;

(c) the use of suitable tools, including insulated tools, equipment and protective clothing (see also regulation 4(4));

(d) the use of suitable insulated barriers or screens (see also regulation 4(4));

(e) the use of suitable instruments and test probes;

(f) accompaniment by another person or people if the presence of such person or people could contribute significantly to ensuring that injury is prevented;

Guidance

(g) the restriction of routine live test work (for example product testing) to specific areas and the use of special precautions within those areas such as isolated power supplies, non-conducting locations etc;

(h) effective control of any area where there is danger from live conductors.

Accompaniment

215 A dutyholder's judgement as to whether someone carrying out work subject to regulation 14 should be accompanied should be based on considerations of how injury is to be prevented. If an accompanying person can substantially contribute towards the implementation of safe working practice, then they should be present. They should be trained to recognise danger and, if necessary, to render assistance in the event of an emergency.

216 Some examples of electrical work where it is likely that the person carrying out the work should be accompanied are:

(a) electrical work involving manipulation of live, uninsulated power conductors at say, 230 volts using insulated tools; and

(b) other work on or near bare live conductors where someone working on their own would not be capable of undertaking the work safely without assistance in, for example, keeping other people from the work area.

Control of the area

217 Effective control of an area where there is danger from live conductors means ensuring that those who are not competent to prevent the occurrence of injury and those whose presence is unnecessary are not permitted into the area. If the person undertaking the work is continuously present while danger exists from the live conductors, and the area is small enough to be under their constant supervision and control, then further precautions to control access may not be necessary. If, however, the area is too large for them to exercise effective surveillance, or they are not continuously present, then effective control will need to be secured by other means such as the provision of lockable enclosures or barriers, and warning notices indicating the presence of live conductors.

(The above examples are given without prejudice to the requirements of regulation 14, the criteria of which must be followed in each case before live work is undertaken.)

Testing

218 Regulation 14 will often apply to electrical testing. Testing to establish whether electrical conductors are live or dead should always be done on the assumption that they may be live and therefore it should be assumed that this regulation is applicable until such time as the conductors have been proved dead.

219 When testing for confirmation of a 'dead' circuit, the test instrument or voltage indicator used for this purpose should itself be proved, preferably immediately before and immediately after testing the conductors.

14

220 Although live testing may be justifiable it does not follow that there will necessarily be justification for subsequent repair work to be carried out live.

Guidance

Protective equipment

221 Examples of protection of someone from the effects of electricity are suitable clothing including insulating helmets, goggles and gloves, insulating materials used as fixed or temporary screening to prevent electric shock and to prevent short circuit between live conductors or between live conductors and earth, insulating mats and stands to prevent electric shock current via the feet and insulated tools and insulated test probes.

222 There should be procedures for the periodic examination and where necessary testing of this protective equipment and replacement as necessary. See also the requirements of regulation 4(4). See Appendices 1 and 2 for further guidance on working procedures, standards etc.

Emergency resuscitation and first aid

223 It may be helpful to place notices or placards giving details of emergency resuscitation procedures in the event of electric shock at those locations where people may be at greater risk of electric shock than most. Such places might include electrical test areas, substations and laboratories but for resuscitation techniques to be effective, those required to exercise them must receive proper training and regular practice. The Health and Safety (First Aid) Regulations 1981 make various requirements for the provision of suitably trained first aiders at places of work.

Work near underground cables and overhead power lines

224 Serious injuries have occurred during excavation and other work near underground power cables and work under or near overhead power lines. This work comes within the scope of regulation 14 if there is a risk of injury from these cables or power lines.

225 Underground power cables present a risk of serious or fatal injury during excavation or similar work, particularly to people using hand tools (eg picks, concrete breakers, etc). Precautions should include:

(a) mapping, recording and marking on site of cable runs;

(b) use of cable locating devices; and

(c) safe digging practices.

226 Overhead power lines may be readily accessible to people working on elevated platforms, scaffolding or roofs. People working with tall vehicles such as cranes, tipper lorries, or farm machinery or handling metal ladders, pipes or other long articles may also be at risk from a flashover or contact with overhead power lines.

14

227 Well established advice on matters in paragraphs 225 and 226 is given in HSE guidance notes which are listed in Appendix 1.

Regulation 15

Working space, access and lighting

Regulation 15

For the purposes of enabling **injury** *to be prevented, adequate working space, adequate means of access, and adequate lighting shall be provided at all electrical* ***equipment*** *on which or near which work is being done in circumstances which may give rise to* ***danger.***

Guidance

228 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

229 The purpose of the regulation is to ensure that sufficient space, access and adequate illumination are provided while people are working on, at or near electrical equipment so that they may work safely. The requirement is not restricted to those circumstances where live conductors are exposed but applies where any work is being done in circumstances which may give rise to danger. The regulation makes no requirement for such space, access or illumination to be provided at times other than when work is being done. (But see guidance under regulation 12(1)(a), paragraph 187(b) in respect of safe access to means of cutting off the supply.)

Working space

230 Where there are dangerous exposed live conductors within reach the working space dimensions should be adequate:

(a) to allow people to pull back away from the conductors without hazard; and

(b) if people need to pass one another, to do so with ease and without hazard.

23 1 Among the legal provisions revoked upon the coming into force of these Regulations were the Electricity (Factories Act) Special Regulations 1908 and 1944. Regulation 17 of those Regulations specified minimum width and height dimensions of switchboard passageways where there were bare conductors exposed or arranged to be exposed when live so that they may be touched. That regulation and the relevant definitions used are reproduced at Appendix 3 to this Memorandum. The dimensions specified were arrived at after much consideration of the circumstances in a Public Inquiry at the time that those Regulations were being drafted. However, those dimensions can still be taken as providing guidance for an appropriate level of safety in many circumstances and where the voltages do not significantly exceed 3000 volts. This is not to condone the use of equipment having normally bare and exposed conductors if a safe alternative can reasonably be adopted.

Lighting

232 Natural light is preferable to artificial light but where artificial light is necessary it is preferable that this be from a permanent and properly designed installation, for example in indoor switchrooms etc. However, there will always be exceptions and special circumstances where these principles cannot be achieved where handlamps or torches etc will be the sole or most important means of lighting. Whatever level of lighting is used, it must be adequate to enable injury to be prevented. See Appendix 1 for further guidance on lighting.

15

Regulation 16

Persons to be competent to prevent danger and injury

Regulation 16

No person shall be engaged in any work activity where technical knowledge or experience is necessary to prevent danger or, where appropriate, injury, unless he possesses such knowledge or experience, or is under such degree of supervision as may be appropriate having regard to the nature of the work.

Guidance 16

233 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

Guidance

234 The object of the regulation is to ensure that people are not placed at risk due to a lack of skills on the part of themselves or others in dealing with electrical equipment.

"... prevent danger or, where appropriate, injury ..."

235 This regulation uses both of the terms, 'injury' and 'danger'. The regulation therefore applies to the whole range of work associated with electrical equipment where danger may arise and whether or not danger (or the risk of injury) is actually present during the work. It will include situations where the elimination of the risk of injury, ie the prevention of danger, for the duration of the work is under the control of someone who must therefore possess sufficient technical knowledge or experience, or be so supervised, etc to be capable of ensuring that danger is prevented. For example, where someone is to effect the isolation of some electrical equipment before they undertake some work on the equipment, they will require sufficient technical knowledge or experience to prevent danger during the isolation. There will be no danger from the equipment during the work, provided that the isolation has been carried out properly; danger will have been prevented but the person doing the work must have sufficient technical knowledge or experience so as to prevent danger during that work, for example by knowing not to work on adjacent 'live' circuits.

236 But the regulation also covers those circumstances where danger is present, ie where there is a risk of injury, as for example where work is being done on live or charged equipment using special techniques and under the terms of regulation 14. In these circumstances, people must possess sufficient technical knowledge or experience or be so supervised etc, to be capable of ensuring that injury is prevented.

Technical knowledge or experience

237 The scope of 'technical knowledge or experience' may include:

(a) adequate knowledge of electricity;

(b) adequate experience of electrical work;

(c) adequate understanding of the system to be worked on and practical experience of that class of system;

(d) understanding of the hazards which may arise during the work and the precautions which need to be taken;

(e) ability to recognise at all times whether it is safe for work to continue.

Allocation of responsibilities

238 Employees should be trained and instructed to ensure that they understand the safety procedures which are relevant to their work and should work in accordance with any instructions or rules directed at ensuring safety which have been laid down by their employer.

Supervision

239 The regulation recognises that in many circumstances people will require to be supervised to some degree where their technical knowledge or experience is not of itself sufficient to ensure that they can otherwise undertake the work safely. The

Guidance 16

responsibilities of those undertaking the supervision should be clearly stated to them by those dutyholders who allocate the responsibilities for supervision and consideration should be given to stating these responsibilities in writing. Where the risks involved are low, verbal instructions are likely to be adequate but as the risk or complexity increase there comes a point where the need for written procedures becomes important in order that instructions may be understood and supervised more rigorously. In this context, supervision does not necessarily require continual attendance at the work site, but the degree of supervision and the manner in which it is exercised is for the dutyholders to arrange to ensure that danger, or as the case may be, injury, is prevented.

240 Further advice on working procedures is given in guidance publications listed in Appendix 1.

241 Note that regulations 17 to 28 inclusive apply only to mines (see SI 1989/635).

Regulation 29 — Defence

Regulation 29

In any proceedings for an offence consisting of a contravention of regulations 4(4), 5, 8,9, 10, 11, 12, 13, 14, I5, 16 or 25, it shall be a defence for any person to prove that he took all reasonable steps and exercised all due diligence to avoid the commission of that offence.

Guidance 29

242 Regulation 29 applies only in criminal proceedings. It provides a defence for a dutyholder who can establish that they took all reasonable steps and exercised all due diligence to avoid committing an offence under regulations 4(4), 5, 8, 9, 10, 11, 12, 13, 14, 15 or 16. (Regulation 25 applies only to mines.)

Regulation 30 — Exemption certificates

Regulation 30

(1) Subject to paragraph (2), the Health and Safety Executive may, by a certificate in writing, exempt -

(a) any person;

(b) any premises;

(c) any electrical equipment;

(d) any electrical system;

(e) any electrical process;

(f) any activity,

or any class of the above, from any requirement or prohibition imposed by these Regulations and any such exemption may be granted subject to conditions and to a limit of time and may be revoked by a certificate in writing at any time.

(2) The Executive shall not grant any such exemption unless, having regard to the circumstances of the case, and in particular to -

(a) the conditions, if any, which it proposes to attach to the exemption; and

Regulation

30

(b) any other requirements imposed by or under any enactment which apply to the case,

it is satisfied that the health and safety of persons who are likely to be affected by the exemption will not be prejudiced in consequence of it.

Guidance

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243 HSE is given power to issue general or special exemptions and to impose conditions and time limits on them. It is a standard power given to allow the variation of legal duties where, in circumstances unforeseen by those drafting the legislation, they are in practice unnecessary or inappropriate. Exemptions would be granted only in very exceptional circumstances.

Regulation 31

Extension outside Great Britain

Regulation

31

These Regulations shall apply to and in relation to premises and activities outside Great Britain to which sections 1 to 59 and 80 to 82 of the Health and Safety at Work etc Act 1974 apply by virtue of Articles 6 and 7 of the Health and Safety at Work etc Act 1974 (Application outside Great Britain) Order 1977[(a)] as they apply within Great Britain.

(a) SI 1977/12.12.

Guidance

31

244 The application of the Regulations is co-extensive with the application of the HSW Act outside Great Britain but within territorial waters as regards the premises and activities (but no others) set out in Articles 6 and 7 of the 1977 Order. Great Britain is the United Kingdom of England and Scotland (Union with Scotland Act 1706).

245 Article 6 of the 1977 Order refers to mines, which are not dealt with in this Memorandum.

246 Article 7 of the 1977 Order refers to construction work, loading and unloading ships, diving and ship repair (see the Order itself for the precise definition).

247 Articles 4 and 5 of the 1977 Order refer to oil rigs and pipelines which thereby are not subject to the Regulations, nor are other premises or activities, outside Great Britain but not referred to in the Order, subject to the Regulations.

248 Equipment manufactured onshore for subsequent use where the Regulations do not apply does not become 'equipment' for the purposes of the Regulations if it will not be used or installed for use in Great Britain. However, if it is energised by connection to a source, eg during testing at a manufacturer's works, it will be subject to the Regulations during such testing.

Regulation 32

Disapplication of duties

Regulation

32

The duties imposed by these Regulations shall not extend to -

(a) the master or crew of a sea-going ship or to the employer of such persons, in relation to the normal ship-board activities of a ships crew under the direction of the master; or

(b) any person, in relation to any aircraft or hovercraft which is moving under its own power.

Guidance

Sea-going ships

249 Sea-going ships are subject to other electrical safety legislation which gives protection to people on board. Regulation 32 disapplies the Electricity at Work Regulations from these ships as far as the normal ship-board activities of a ship's crew under the direction of the master is concerned. It does not disapply them in respect of other work activities however, for example where a shore-based electrical contractor goes on board to carry out electrical work on the ship. That person's activities will be subject to the Regulations within the general applicability of the Regulations and in particular only within the territorial waters as provided for under regulation 31.

Aircraft and hovercraft

250 The Regulations may apply only while an aircraft or hovercraft is not moving under its own power.

Vehicles

251 The Regulations may apply to electrical equipment on vehicles if this equipment may give rise to danger.

32

Regulation 33

Revocations and modifications

Regulation

(1) The instruments specified in column 1 of Part I of Schedule 2 are revoked to the extent specified in the corresponding entry in column 3 of that Part.

(2) The enactments and instruments specified in Part II of Schedule 2 shall be modified to the extent specified in that Part.

(3) In the Mines and Quarries Act 1954, the Mines and Quarries (Tips) Act 1969[(a)] and the Mines Management Act 1971[(b)], and in regulations made under any of those Acts, or in health and safety regulations, any reference to any of those Acts shall be treated as including a reference to these Regulations.

(a) 1969 c. 10.
(b) 1971 c.20.

33

Guidance

252 The Regulations replace or modify a number of statutory provisions in accordance with the intention of the HSW Act section 1(2).

253 Systems and equipment which were subject to provisions which have been revoked are now subject to these Regulations.

33

Appendix 1 HSE and HSC publications on electrical safety

Title	*Regulations particularly relevant*
Electrical risks from steam/water pressure cleaners Plant and Machinery Guidance Note PM29 (Second edition) HSE Books 1995 ISBN 978 0 7176 0813 3	4, 6, 7, 8 and 10
Selection and use of electric handlamps Plant and Machinery Guidance Note PM38 (Second edition) HSE Books 1992 Web only: www.hse.gov.uk/pubns/pm38.pdf	4, 6, 7, 8, 10 and 12
Avoidance of danger from overhead electric powerlines General Guidance Note GS6 (Third edition) HSE Books 1997 ISBN 978 0 7176 1348 9	4, 14, 15 and 16
Electrical test equipment for use by electricians General Guidance Note GS38 (Third edition) HSE Books 1995 ISBN 978 0 7176 0845 4	10, 14 and 16
Electrical safety at places of entertainment General Guidance Note GS50 HSE Books 1997 ISBN 978 0 7176 1387 8	4, 5, 6, 7, 8, 10, 11 and 12
Lighting at work HSG38 (Second edition) HSE Books 1997 ISBN 978 0 7176 1232 1	4, 13, and 15
Avoiding danger from underground services HSG47 (Second edition) HSE Books 2000 ISBN 978 0 7176 1744 9	4, 14 and 16
Electricity at work: Safe working practices HSG85 (Second edition) HSE Books 2003 ISBN 978 0 7176 2164 4	4, 7, 12, 13, 14, 15 and 16
Electrical safety in arc welding HSG118 HSE Books 1994 ISBN 978 0 7176 0704 4	4, 6, 7, 8, 10, 12, 14, 16
Electrical safety on construction sites HSG141 HSE Books 1995 ISBN 978 0 7176 1000 6	4-16 inclusive
Keeping electrical switchgear safe HSG230 HSE Books 2002 ISBN 978 0 7176 2359 4	4, 5, 6, 11 and 12
Electrical safety and you Leaflet INDG231 HSE Books 1996 (single copy free or priced packs of 15 ISBN 978 0 7176 1207 9) Web version: www.hse.gov.uk/pubns/indg231.pdf	2-16 inclusive

Note: The publications listed in Appendix 1 are available from HSE Books (see inside back cover for address etc).

Appendix 2

Other publications having an electrical safety content

Standards, Codes of Practice and other publications which contain guidance relevant to the Regulations and electrical safety, which have been published by bodies other than either HSE or HSC, are given in this appendix. Most of these documents are the product of technical committees on which HSE has been represented. This does not mean, however, that the documents are concerned solely with safety and users should bear in mind the scope of the safety content of these documents and the fact that they have largely been arrived at through a process of consensus.

Note: British Standards Institution publications are obtainable from BSI Customer Services, 389 Chiswick High Road, London W4 4AL Tel: 020 8996 9001 Fax: 020 8996 7001 e-mail: cservices@bsi-global.com Website: www.bsi-global.com.

(BS = British Standard)

Title of publication	*Principal regulations relevant*	*Comments*
IEC/TR 60479-2: 1987 *Effects of current passing through the human body* (Second edition)	2	Definition of 'danger' and 'injury' - electric shock
IEC Guide 105 *Principles concerning the safety of equipment electrically connected to a telecommunications network*	2	Ditto, on telecommunication systems
IEC 61201: 1992 *Extra-low voltage (ELV) - Limit values*	2	Electric shock - sets out limit values
BS 7671: 2001 *Requirements for Electrical Installations. IEE Wiring Regulations. Sixteenth edition*	4(1), 5-12 inclusive	Selection of equipment and construction of installations up to 1000 volts ac
BS 4363: 1998 *Specification for distribution assemblies for reduced low voltage electricity supplies for construction and building sites*	4, 6, 10	
BS 7375: 1996 *Code of practice for distribution of electricity on construction and building sites*	4, 6, 10	
BS EN 60439-1: 1999 *Low-voltage switchgear and controlgear assemblies. Type-tested and partially type-tested assemblies* BS EN 62271-100: 2001 *High-voltage switchgear and controlgear. High-voltage alternating-current circuit breakers*	4,5,12,15	Particular attention for switchgear clearance distances. Safety clearances and work sections
BS 6423: 1983 *Code of practice for maintenance of electrical switchgear and controlgear for voltages up to and including 1 kV*	4(2), 4(3), 12, 13	Precautions to secure safety of maintenance, personnel isolation procedures
BS 6626: 1985 *Code of practice for maintenance of electrical switchgear and control gear for voltages above 1 kV and up to and including 36 kV*	4(2), 4(3), 12, 13	Precautions to secure safety of personnel
BS 6867: 1987 *Code of practice for maintenance of electrical switchgear for voltages above 36 kV*	4(2), 4(3), 12, 13	Ditto
BS EN 60204-1: 2006 *Safety of machinery. Electrical equipment of machines. General requirements*	4,6	

Title of publication	*Principal regulations relevant*	*Comments*
BS EN 60903: 2003 *Live working. Gloves of insulating material*	4(4), 14	
BS 921: 1976 *Specification. Rubber mats for electrical purposes*	4(4), 14	Mats for covering floor near electrical equipment where direct contact may occur
BS EN 60529: 1992 *Specification for degrees of protection provided by enclosures (IP Code)*	6, 7	Index of Protection system against contact with live and moving parts and ingress of solids and moisture and Finger Test
BS EN 60947-1: 2004 *Specification for low voltage switchgear and control gear. General rules*	6, 7	Ditto
BS EN 60034-5: 2001 *Rotating electrical machines. Degrees of protection provided by the internal design of rotating electrical machines (IP Code). Classification*	6,7	Index of Protection (IP) system against contact with live and moving parts and ingress of solids and moisture
BS EN 60079-14: 2004 *Electrical apparatus for explosive gas atmospheres. Electrical installations in hazardous areas (other than mines)*	4(1), 4(2), 6	
BS EN 60079-0: 2004 *Electrical apparatus for explosive gas atmospheres. General requirements*	4(1), 6	
BS EN 50050: 2001 *Electrical apparatus for potentially explosive gas atmospheres. Electrostatic hand-held spraying equipment*	6	Protection against ignition
BS EN 61241: 2004 *Electrical apparatus for use in the presence of combustible dust. Protection by enclosure 'tD'*	6	Ditto
BS EN 61241-14: 2004 *Electrical apparatus for use in the presence of combustible dust. Selection and installation* BS EN 61241-17: 2005 *Electrical apparatus for use in the presence of combustible dust. Inspection and maintenance of electrical installations in hazardous areas (other than mines)*	4, 5, 6	Ditto
BS 6651: 1999 *Code of practice for protection of structures against lightning*	6	As relevant to protection of electrical equipment from lightning
BS PD CLC/TR 50404: 2003 *Electrostatics. Code of practice for the avoidance of hazards due to static electricity*	6	Precautions against ignition and electric shock
BS 4444: 1969 (1989) *Guide to electrical earth monitoring and protective conductor proving*	8	
BS 7430: 1998 *Code of practice for earthing*	8	
BS EN 60947-3: 1999 *Specification for low voltage switchgear and controlgear. Switches, disconnectors. switch disconnectors and fuse-combination units*	12	

Title of publication	*Principal regulations relevant*	*Comments*
BS 2754: 1976 *Memorandum. Construction of electrical equipment for protection against electric-shock*	7, 8	
BS E.N 81-1: 1998 *Safety rules for the construction and installation of lifts. Electric lifts*	15	Clear areas in front of electric equipment specified (Clause 6.3.3.1)
BS EN 62271-102: 2002 *High voltage switchgear and controlgear. High voltage alternating current disconnectors and earthing switches*	12	

Appendix 3

Working space and access; historical comment on revoked legislation (see regulation 15)

Among the legal provisions revoked upon the coming into force of the Electricity at Work Regulations 1989 were the Electricity (Factories Act) Special Regulations 1908 and 1944. Regulation 17 of those Regulations specified minimum width and height dimensions of 'switchboard passage-ways' if there were 'bare conductors' exposed or arranged to be exposed when 'live' so that they may be touched. These related to what are commonly known as 'open type' switchboards which had much exposed copper work, knife switches etc. That regulation (and the key definitions used at that time) are reproduced below for information. The dimensions which were specified by that regulation were arrived at after much consideration of the circumstances at the time. A compromise was struck between the objective of achieving the safety of those who had to work at and operate these 'open type' switchboards and the need to recognise the constraints imposed by the installations existing and the nature of the technology in 1908. Even though the dimensions were a compromise, it was widely recognised that they were a good minimum standard which had been found necessary following a number of severe and fatal accidents in factories and power stations due to inadequate space or cluttered access in the vicinity of bare live conductors at these 'open type' switchboards. The dimensions chosen allowed workmen to operate or otherwise work upon the switchboard in reasonable safety and allowed, for example, people to pass one another in the switchboard passageway without being placed at unacceptable risk of touching live conductors.

Where the need does arise to work on or near live conductors, the principles of providing adequate working space and uncluttered access/egress, which were expressed in regulation 17 of the Electricity (Factories Act) Special Regulations 1908 and 1944, should be given proper consideration.

Regulation 17 (of 1908 Regulations)

At the working platform of every switchboard and in every *switchboard passage-way,* if there be *bare conductors* exposed or arranged to be exposed when *live* so that they may be touched, there shall be a clear and unobstructed passage of ample width and height, with a firm and even floor. Adequate means of access, free from danger, shall be provided for every *switchboard passage-way.*

The following provisions shall apply to all such *switchboard* working platforms and *passage-ways* constructed after January 1, 1909 unless the bare conductors, whether overhead or at the sides of the *passage-ways,* are otherwise adequately protected against *danger* by divisions or screens or other suitable means:

(a) Those constructed for *low pressure* and *medium pressure switchboards* shall have a clear height of not less than 7 ft and a clear width measured from *bare conductor* of not less than 3 ft.

(b) Those constructed for *high pressure* and *extra high pressure switchboards,* other than operating desks or panels working solely at *low pressure,* shall have a clear height of not less than 8 ft and a clear width measured from *bare conductor* of not less than 3 ft 6 in.

(c) Bare conductors shall not be exposed on both sides of the *switchboard passageway* unless either (i) the clear width of the passage is in the case of *low pressure* and *medium pressure* not less than 4 ft 6 in and in the case of *high pressure* and *extra high pressure* not less than 8 ft in each case measured between bare conductors, or (ii) the *conductors* on one side are so guarded that they cannot be accidentally touched.

Key definitions used in the 1908 Regulations

Switchboard means the collection of switches or fuses, *conductors,* and other *apparatus* in connection therewith, used for the purpose of controlling the current or pressure in any *system* or part of a *system.*

Switchboard passage-way means any passage-way or compartment large enough for a person to enter, and used in connection with a *switchboard* when *live.*

Low pressure means a *pressure* in a *system* normally not exceeding 250 volts where the electrical energy is used.

Medium pressure means a *pressure* in a *system* normally above 250 volts, but not exceeding 650 volts, where the electrical energy is used.

High pressure means a *pressure* in a *system* normally above 650 volts, but not exceeding 3000 volts, where the electrical energy is used or supplied.

Extra-high pressure means a *pressure* in a *system* normally exceeding 3000 volts where the electrical energy is used or supplied.

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Health and Safety Executive

Memorandum of guidance on the Electricity at Work Regulations 1989

Guidance on Regulations

This new edition of HSR25 is intended to help dutyholders meet the requirements of the Electricity at Work Regulations 1989. It will be of interest and practical help to all dutyholders, particularly engineers (including those involved in the design, construction, operation or maintenance of electrical systems), technicians and their managers. It sets out the Regulations and gives technical and legal guidance on them except as they apply to mines and quarries (there is separate guidance for this). The purpose of this Memorandum is to highlight the nature of the precautions in general terms to help in the achievement of high standards of electrical safety in compliance with the duties imposed. The book also contains references to HSE guidance and advice and codes of practice from other standard-making bodies and trade associations.

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FRIDAY, DECEMBER 17, 1909

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ATMOSPHERIC ELECTRICITY[1]

THE industrial application of electricity for light and for power began about thirty years ago. There were then no schools or laboratories in which applied electricity was taught. The science or profession of electrical engineering did not exist. Electricity was taught as a part of the physics course in schools or colleges and, incidentally thereto, brief descriptions of its application to telegraphy were included. Electroplating, the electric arc and electromagnetism were studied chiefly from books and sometimes illustrated with such instruments and apparatus as were to be found in the apparatus collection.

When, however, the great growth or expansion began, about thirty years ago, courses in electrical engineering were gradually added in some of the schools, usually in conjunction with the teaching of physics, to which the new study was most closely allied. The physics department of Princeton under Professor Brackett was among the very earliest to provide instruction in what was in fact the incipient stage of the now highly developed and important science of applied electricity. Those in the field whose memories carry them back to that early time, will easily recall the important contributions made by Professor Brackett and his department to the development of the infant science. On this present occasion Princeton is to be congratulated on the opening of its magnificent new laboratory, the generous gift of Mr. Palmer, which assures the possibil-

[1] Address at the formal opening of the Palmer Physical Laboratory at Princeton University, October 21, 1909.

ity of continued growth and usefulness, in larger measure, in those sciences to the study of which it is devoted.

As a part of the commemorative exercises at this formal opening of the Palmer laboratories, I have been requested to address you upon some topic connected with physics and electrical engineering. Out of a number of subjects which suggested themselves I have chosen "atmospheric electricity"—a subject which permits of a treatment not too technical and which more or less concerns us all. Its relation to the science of physics is evident, and as to electrical engineering, we electrical engineers are sometimes made to experience a wish that it were not so closely related, for, under certain conditions it is perhaps the one thing which menaces in a high degree the integrity of the delicate contrivances which make up an electric installation; interfering most unexpectedly with continuity of service.

I hope that in what I shall say on the subject my physicist friends will bear with me, for I realize that there is little of novelty that I can present. I can but emphasize what I believe to be correct views and treat the matters discussed very generally, if not popularly. While my attitude towards the subject itself has always been that of a learner, it has often fallen to my lot to exert myself to provide means for the protection of electrical installations from such damage by lightning storms as would involve great inconvenience and perhaps heavy monetary loss. The engineer must produce things that do the work and often the need is immediate and compelling. The student of pure science is under no such stress.

From the remotest times the thunderstorm has been one of the most impressive of natural phenomena, inspiring terror in men and other creatures alike. The realization of its interest and grandeur is probably of comparatively modern origin. It is indeed not surprising that in pagan mythology the lightning stroke was ascribed to the anger of the greatest of the gods. It is no wonder that, in one of the greatest poems of the Bible, Job is asked, "Canst thou send lightnings that they may go and say unto thee, 'Here we are'?"

With the decay of authority and miraculous interpretation of natural phenomena and the gradual growth of rationalism and scientific study the recognition of the lightning and the thunder as a result of natural processes gradually came about. In the seventeenth century began that gradual awakening to the possibilities of the conquest of nature, the outcome of which is modern science with all its great achievements. It was the period of Bacon, Galileo, Gilbert, Descartes, Newton and others. At first the explosive action of lightning, the noise of the thunder and the subsequent strong smell of ozone, which often exists, suggested a kinship with gunpowder, or, that certain nitrous and sulphurous constituents of the atmosphere supposedly had become fired. This naturalistic view even the self-constituted witchcraft exponent, Cotton Mather, willingly adopts in one of his books.

Priestley, the discoverer of oxygen gas, in his "History of Electricity," published in 1767, makes an interesting quotation from a paper of a certain Dr. Wall in the *Philosophical Transactions*. This Dr. Wall, an experimenter in electricity in the latter half of the seventeenth century, and a contemporary of Otto Guericke and later of Newton, after describing his experiments with rubbed amber and the production of light and the cracklings therefrom, says, "Now, I make no question but upon using a longer and larger piece of amber, both the cracklings and light would be much greater." Then further he says: "This light and crackling seems in some degree to represent thunder and lightening." I believe this to be the first reference to the possible relationship between electricity and lightning. The later history of Franklin's suggestion of identity, D'Alibard's experiment and that of the famous kite furnishing experimental proof, are too well known to be dwelt upon here.

The practical genius of Franklin led him at once to the suggestion of protection from lightning by means of a conducting rod of metal, well connected to the moist ground at its lower end, and projecting beyond the highest parts of the building or structure to be protected. In these later years it is not unusual to meet with statements of discredit or denial of the efficacy of this simple device. There seems to be a tendency among the uninformed to regard it as an old-fashioned and useless if not a dangerous contrivance. Often the question has been asked whether it is not an exploded notion that such rods have any value for protection. It may well be that the "lightning-rod agent" of former times is largely responsible for the distrust. He was a sort of confidence man, who supplied a sham appliance, often of marvelous makeup. A structure of twisted metal tube topped with glittering gilt points in clusters, mounted on green glass insulators, the whole as extensive as the unhappy victim could be frightened into paying for, was erected, and often left without any adequate connection to the ground. It was a tree without roots; lacking, in fact, the most essential part of its structure.

Let us add with emphasis that the Franklin rod when properly installed undoubtedly secures practical immunity from lightning damage. Its installation is an engineering undertaking demanding study of varied conditions and proper care and judgment in meeting these conditions. The one consideration originally left out was that if there were any better or more direct paths for lightning existing in the building or structure or better ground connections than the rod possessed these must be included in the protective system. But it is also a fact that the construction of most modern buildings, particularly in cities, involves so much metal in roofing, ventilating and other pipes, wires and the like, that it is generally unnecessary to resort to any separate means for protection.

In cities there are many lofty structures framed in steel, piping that projects above the roof, and metal stacks, generally in good connection with the underground pipe systems; all of which together tend to minimize danger from strokes of lightning. The best vindication of Franklin will, however, be found in the fact that the firmest reliance is placed by the trained electrical engineer upon the provision of an easy path for the electricity of lightning to reach the ground. Practically all his protective appliances or arresters used in electric systems are based on that principle, with modifications and additions to suit particular conditions of use. To provide such modifications and adaptations is by no means an easy task. There is still a possibility of insufficiency such that the menace of breakdowns and damage by lightning still remains a *bête noir* to the engineer. The tremendous discharge of energy possible in a lightning stroke may be sufficient to defeat our efforts. Breaking through insulation and causing short circuits, burning of wires and rupture of circuit, and damage to apparatus are still occasional experiences in spite of our safeguards. Even at a considerable distance away a stroke of lightning, by its inductive action may set up electric waves or surgings which require to be provided against.

The extremely uncertain value of the effects, the irregularity and impossibility of calculation or prediction, render the problem of protection difficult. The effects of these secondary surges are generally incomparably less violent than direct strokes, and they are seldom dangerous to life.

So long indeed as our electric lines are extended above the ground, so long must this disturbing factor be reckoned with. Fortunately it has been possible by constant effort and study to secure more and more effective appliances so that the lightning menace grows steadily less. Research and experimentation in this direction have constituted an important part of the development of electrical engineering.

Having thus at some risk of your patience vindicated our earliest worker in the study of atmospheric electricity—Franklin—let us turn from the practical issues and consider the electricity of the air from a more general standpoint.

The study of the nature and origin of electrical storms or disturbances throughout the atmosphere is of much interest; our knowledge is yet meager; there is much more yet to be learned in this fascinating field. Exploration of the electrification of the air at varying heights by captive balloons, by kites and upon elevations of land, has generally shown an increasing electric potential upward from the earth, and usually positive in relation thereto. Sometimes this relation is reversed. It has been roughly estimated that if the differences noted can be assumed to be extended to include the total depth of the atmospheric layer, the earth's surface might be negative to the surrounding space, 150,000 volts more or less. This condition would not admit of being regarded as constant or stable, since widespread electric storms occur in both our upper and lower air levels. In the highest regions of our atmosphere they take the form of diffuse discharges as in a high vacuum and are called auroras. They either accompany or give rise to magnetic storms, which affect the direction and intensity of the earth's magnetism temporarily, and hence disturb the compass needle, sometimes through many degrees. Within a few weeks past we have experienced such a storm of a remarkable intensity; sufficient in fact to cause interruptions to telegraphic and cable transmission during several hours. Brilliant auroras were at the time seen in some places.

The frequency of auroral phenomena, and perhaps also to some extent the frequency of thunder-storms, seems to keep pace with the sunspot period, at least in our latitudes. At times of sunspot activity, the surface layers of the sun, upon the energy radiated from which so much of earthly activity depends, are stirred by great storms, or immense cyclones of hot gas or metallic vapors; storms seen as dusky spots on the sun's disc. They can attain enormous size—20,000, 30,000 or even 50,000 miles in diameter, though these dimensions are exceptional. They are visible, as is well known, not because they are non-luminous, but because they are less luminous than the surrounding solar surface. In like manner bright spots or faculæ may also be seen, because they are on the whole brighter than the sun's surface adjoining them.

There is much reason to believe that, in accordance with suggestions made many years ago, these solar storms are accompanied by exceptionally vigorous projection outward from the sun to immense distances, of streams of electrified matter. Should the earth happen to be in a position to be swept by such a stream, an aurora may be produced. During a total solar eclipse the so-called coronal streamers are seen to extend from the sun's surface to distances of upwards of two millions of miles or possibly farther than that, but doubtless they keep on outwardly, and invisibly, to relatively enormous distances. It is not unreasonable as a hypothesis to imagine that they may extend at times as far as the orbit of the earth and may, if the direction is the proper one, reach our outer air.

Further, if they consist of electric ions or particles conveying electric charges, an aurora may result. Dr. Hale, of Mt. Wilson Observatory, has indeed recently shown by the spectroscope that great solar storms are in fact attended by the motion of electric ions at enormous velocities. The phenomena of auroras present peculiar difficulties in their study, since, as in the case of the rainbow, no two observers at a distance from each other see the same or identical appearances. Hence attempts to determine the height by triangulation at which auroras exist give most contradictory results, for it is impossible to fix upon any condensation or streamer which may not be displaced or absent to another observer some distance away. This is understood when we bear in mind that the luminous appearances are not located in one plane, but are distributed in space; condensations of light being the result of superposition in the line of observation.

I have come to the opinion that the auroral streamers often extend in a general direction outwardly from the earth, sometimes to very great distances relatively to the known extent of our atmosphere. The effects observed appear unaccountable upon any other supposition, while they are consistent with the idea of outwardly directed streams of great extent. In April, 1883, there occurred an aurora which was at its maximum a little after midnight. It was the most magnificent display of the kind, which, in spite of a continual vigilance on my part, it has been my fortune to witness. It was upon such a scale that, so to speak, the mechanism of the streamers stood revealed. At that time I could not avoid the conclusion that the auroral streamers must have extended outwardly several thousand miles. There is no space here to present the argument involved. Perhaps the most significant fact is that precisely the same general appearances were noted in Chicago as in the east, and that they occurred simultaneously. The interesting question arises, does the earth temporarily acquire streamers similar in nature to the solar coronal streamers? The answer is as yet unknown. At the time of the great display mentioned there was a sunspot near the center of the sun's disc of about 50,000 miles in diameter. During that disturbance long telegraphic lines could not be operated, owing to arcing at the keys which prevented interruption of the circuits. Apparently in subtle sympathy with its master orb, the sun, the earth's electric and magnetic equilibrium was for a time profoundly disturbed.

While it is by no means certain that auroras and magnetic storms are always dependent on solar outbursts, it is now generally recognized that the observed coincidences are too frequent to be the result of chance. It is perhaps safe to assume that although solar storms and sunspots can occur without provoking auroras or magnetic storms here, it may be doubted if these latter occur on any great scale unless solar activity is coincident therewith. And it seemingly is true that only when the projected electrified matter actually reaches the earth or comes near enough to inductively affect its electrical equilibrium are the terrestrial phenomena produced thereby.

It has even been suspected that a greater frequency and severity of thunder-storms in our lower air accompanies the active period of the sun or sunspot maximum. This is a hypothesis which would require a careful collection and comparison of data over a long period to give it status as a scientific fact or wholly to disprove it. Be that as it may, experience with lightning damage in electric installations seemingly supports the idea, and led me in a paper given some seven or eight years ago during the minimum period, to predict a severe ordeal a few years in advance. As a matter of fact the prediction was to a large extent verified with the result of extraordinary activity in devising safeguards from which the electrical engineering art now benefits. In general the harm done by thunderstorms is due directly or indirectly to the heavy spark discharges called lightning flashes or strokes of lightning.

It may be of interest to refer briefly to the conditions existing in a cloud which is the source of such destructive energy. As is well known, clouds consist of fine water particles suspended in the air. When frozen these particles are crystalline like minute snow crystals. All clouds above the snow line are likely to be of that character. At a temperature above freezing the particles of water are microscopic spheroids which may by gradual coalescence form drops of rain. This process of coalescence necessarily diminishes the total surface of the water existing as such in the cloud. Should, however, the original particles possess even a slight electric charge, the union of the drops, by lessening the total surface, or diminishing the electric capacity, results in a great rise of potential or electric pressure on the surface of the drops. The process of coalescence continues and the water falls out of the cloud as rain. If the cloud particles are frozen the diminution of surface and consequent increase of electric pressure can not take place. This would seem sufficient to account for the general absence of thunder-storms in winter, though perhaps other causes contribute.

A thunder-cloud has been compared to an insulated charged conductor, such as a body of metal hung upon a silk cord, but in reality the two are not at all comparable. It is a mistake to assume any close analogy to exist. The cloud being only an air body containing suspended water particles, is not a conductor, nor can it, as in the case of metal, permit the accumulation of its electric charge on its outer surface. In fact it possesses no true definite outer surface but blends with the clear air around it. The electric charge it possesses remains disseminated, so to speak, throughout, and must reside chiefly upon the surface of its constituent water drops. Accumulation in any part would require the insulating air between the drops to be overcome.

A lightning stroke from such a mass may indeed represent a discharge of hundreds of amperes at millions of volts. We must, however, be cautious not to exaggerate either the current or the potential present in a lightning flash. The current in a flash can at times be only a few amperes or may in the heavier discharge reach perhaps hundreds, or possibly in extreme cases some few thousands of amperes. It is doubtful if the potential much exceeds at any time more than a few millions of volts as it is probable that small local breakdowns start the disruptive process which then extends through miles of length. The individual water particles even when collected into drops can not be charged to such enormous potentials as millions of volts. In reality it is the combined effect of the numerous particles acting inductively that accounts for such pressures. A combined stress is set up towards the earth or towards another cloud mass of opposite charge. The lightning stroke results from a breakdown of the insulating air layer between them, and also all through the cloud itself, and for a time a partial neutralization or electric equilibrium is effected. This continues until a further redistribution of charges is required and until again the breakdown potential is reached. The continued coalescence of charged water particles which were not discharged at the first breakdown, repeats the original condition, and so on. Unlike the case of a suspended charged metal body, a single discharge does not usually equalize the electric potential of cloud and earth. Instead, many successive discharges occur. It is probably fortunate for us that the process is as gradual as it is, for the ordinary partial discharges of the cloud are each terrific enough and tax our resources sufficiently when we seek to protect ourselves and our effects from them.

Various hypotheses have been proposed to account for the presence of electric charges in cloud masses, but there is no time to discuss them here, and there is in fact little that is really known as to the origin of the electricity of clouds. We shall briefly refer to the phenomena which characterize or accompany the electric discharges. The usual form which the discharge takes is that known as disruptive spark or fork lightning, a long flash or electric spark, joining earth and cloud, or cloud and cloud, and branching within the cloud mass like a tree. Oftentimes between cloud and earth there is seen the single streak zigzag in its course, but within the cloud it ramifies or branches extensively in several directions. In this way only can any considerable part of the cloud contribute its portion to the main discharge path, for, as stated before, the cloud can not act as a conducting body.

Some authorities treat lightning as a discharge of very high frequency like the ordinary discharge of a condenser or Leyden jar. In fact it has not been unusual to assume that such apparatus can be substituted and inferences drawn as to the nature and character of the lightning discharge from experimentation and tests with these laboratory appliances. There is, however, abundant reason to doubt that lightning discharges are really oscillatory. If they oscillate the conditions are such as to forbid such oscillation being of a high frequency order. The cloud discharge represents what is known as a discharge of a large capacity, and the length of the path or spark may reach thousands of feet or even many miles; a long inductive path, while the heat and light given out in every part of the path indicate a high resistance to the passage of the discharge. All of these conditions are together known to be inconsistent with the idea of high frequency oscillation. But the breakdown or discharge is extremely sudden and involves an almost instant rise of the current to a large value, so that the inductive effects upon surrounding structures, such as electric lines or circuits, are very energetic and sharp like a quick blow struck; and these lines or structures become the seat of rapid vibration or high frequency oscillations. The sudden blow of the hammer on a bell in like manner brings out all the rates of the vibration, fundamental and overtones, of which the bell is capable and in which the hammer itself takes no part.

The very sudden startling character of a lightning discharge leads to an exaggeration in the popular estimate of its more evident effects. The amount of light given out is not so great as is often assumed. It does not give effects at all comparable with full sunshine. While doubtless the intrinsic brilliancy is very high the duration of the flash is small, generally only a minute fraction of a second. In photographs of lightning the landscape is generally seen only in outline or poorly lighted by the discharge. In the daytime, when the clouds are not dense enough to greatly darken the sky, the flash loses most of the blinding character it has when seen in the blackness of night. Similarly, the sound of thunder, though of terrifying quality, is not extraordinarily loud. It is a common experience when traveling in a train to note that the sound of even near-by flashes is smothered by the roar of the train so that no thunder is heard. The noise of thunder can not be due in any part, as is sometimes erroneously assumed, to collapse of the air upon itself and into a partial vacuum left by the spark. I have seen this error even recently repeated and even extended to include all the noise of thunder as due to such collapse. When, however, we consider that in a minute fraction of a second the air in the path of the discharge is so highly heated that, if it were confined, its pressure due to heat expansion alone would rise to more than ten atmospheres we can readily understand the explosive shock given to the surrounding air and the propagation therethrough of an intense air wave. In fact such waves from electric spark discharges and from dynamite explosions have been clearly recorded by photography. Moreover, that the collapse of the air after expansion can have little or no effect in the sound production, follows from the fact that the heated gas streak left in the path of the discharge takes an appreciable time to cool on account of its low radiating power. This is shown by the observation that a lightning discharge in dusty air is often succeeded by a luminosity of the streak which persists for a perceptible time and slowly fades away like the luminous trail of a meteor.

Another common misconception is that the prolonged rolling character of thunder is due to reverberations or echoes. In mountain regions with steep rock walls such reverberations possibly contribute to the effect, but it is now clearly recognized that a sufficient single explanation suffices for most cases. Owing to the great length of the lightning spark or path, we receive the sound from the nearer parts of the discharge far in advance of that from the more remote portions, and between these sounds are those from parts of the path at intermediate distances from the observer. It follows from this that no two observers at a distance from each other hear the same succession of sounds in the thunder of a discharge. Whenever portions of the discharge path are situated or extended in an approximate direction at right angles to the line from the observer, the sound from that part of the path is louder or of high amplitude owing to the sound from that part of the path reaching the observer's ear at the same instant. Whenever the path leads directly away from the observer the amplitude is less, the sound is less explosive and takes the character of an extended roll or rumble.

It will be seen from this that every twist and turn and every change of direction of the spark path with respect to the observer's position gives a varying loudness and sequence of sounds. Every branch of the main discharge in like manner records its position and direction, its twistings and bendings in these sound vibrations and sequences. It would seem possible even to record on a phonograph noises from sparks invisible to the eye and map the positions of the sparks in space from records so produced. If this were done as it were stereoscopically or stereographically from two or more separated observing or recording places, the records would contain the necessary data for the reconstruction of the spark and its branches in space.

From the above considerations an attempt to determine the distance of a lightning stroke to earth by counting seconds elapsing between the flash and the first thunder and allowing five seconds to a mile approximately is seen to be futile. Should one of the cloud ramifications or branches of the great tree-like discharge extend in the cloud overhead with relation to the observer, and that part of the discharge be nearer to him than any other he will first hear a receding rumble above him, followed it may be by a heavy explosion from the main or approximately vertical spark between cloud and earth and from the parts of which his distance is nearly the same. This louder explosion will then be followed generally by a prolonged rumble of diminishing loudness which is the sound coming from the ramifications which lead farther to the distant parts of the cloud. Manifestly the counting of time should be between the flash and the heavy explosive sound due to the vertical part of the flash.

Bearing in mind that over the extent of cloud the charged water particles may be said to be waiting for a chance to discharge to earth, it is not surprising that any path which has been opened or broken down by disruption of the insulating layer of air should serve for the discharge of an extended body of cloud. The heated vapor or gas in the path of the discharge is a relatively good conductor of electricity serving to connect the cloud mass to the earth below. The significance of this is understood when it is known that many lightning discharges are multiple. Instead of a single discharge they consist of a number rapidly following one another through the path or spark streak opened to them by the first discharge. This first discharge opens the way or overcomes the insulating barrier to the discharge of portions of the cloud mass, which, on account of remoteness or lower potential, could not themselves have caused the breakdown. These repeated or multiple flashes are exceedingly dangerous, both to life and property. The first discharge may reduce wood to splinters and the subsequent ones set it on fire. The time interval between the successive discharges in such a multiple flash is quite variable and may be long enough to be easily perceptible by the eye. The multiple character is easily disclosed by the image in a revolving mirror. If a strong wind be blowing at the time of such a multiple flash, the hot gas conducting the discharges may be displaced laterally in the direction of the wind with the result of spreading out the discharges into a ribbon more or less broad. Photographs of these ribbon flashes show their true character plainly; each separate discharge appearing as a streak of light parallel to the others and at varying distances apart. In fact parallel discharges of exactly the same contour are sometimes observed many feet apart. Here the hot gas of the first discharge has evidently been shifted by the wind over a considerable space before the second and subsequent discharges took place. Heavy rain seems to weaken the air and help to precipitate a discharge. From the fact that strokes of lightning are often followed by increased fall of rain within a few seconds it is a prevalent idea that the increased downpour is caused by the discharge. In reality the reverse is the case, for just when a gush of rain has reached from the cloud down to within a hundred feet or more from the ground, by far the major part of the air layer has been so weakened electrically by the presence of the water drops, that the discharge itself anticipates the completion of the distance of fall of the rain, and is therefore a short time in advance of the time when the descending gush of rain actually reaches the ground. As the gusts or gushes of rain are more or less local and sweep along with the storm cloud, they are apt to mark out the places of the most frequent lightning strokes. Shelter sought at such times under tall trees is particularly dangerous.

The amount of energy which may be concerned in a lightning discharge is neither definite nor capable of estimation. It would seem that the widest variations in energy may occur and this would account largely for the observed differences in the severity of the effects. It must be remembered also that by far the larger part is expended in the long spark in the air and cloud. Even when much damage is done to objects struck it is only a small fraction of the total energy which is expended on them. Most of the damage to property comes indirectly from the electric discharge by its energy being instantaneously converted into heat. This heat evolves steam and expanded gases in the interior of such materials as wood and causes explosion, shown in the splintering or rupture.

A curious effect, often noted when a tree is struck and shattered, is that when the splinters, sometimes of large size, are thrown bodily out to distances of many feet from the shattered tree, the splinters in their movement remain in parallel to the tree and in a vertical position. They are frequently found standing upright after a stroke and at distances ranging up to sixty or eighty feet away. This fact indicates that the projecting force is quite instantaneous and is exerted equally and at the same moment throughout the length of the splinter in a direction transverse to its length. Such splinters are sometimes ten or twelve feet in length and several inches thick. As will be seen, a person near a large tree which is so disrupted is in danger of being struck in a different way, even if he escapes being included in the path of the stroke itself. Aside from this mechanical danger it is known that to take refuge under a tall tree during a heavy thunderstorm is particularly hazardous. This is so because the human body is a better conductor than the tree trunk, particularly as the trunk itself is the last part to become thoroughly wetted by the rain. The leaves and upper parts are wet and more or less conducting while the tree trunk itself may be yet dry. In such a case the body of a person forms a good path or shunt to the dry trunk and is therefore particularly apt to be traversed by any stroke which reaches the tree.

As before indicated, damage to buildings and other such structures can in all cases be prevented by the provision of an effective shunting path to earth. A most essential feature of such a structure as the Franklin conductor is its good connection with the ground, or better its connection with what we know as a good ground. In early times it was considered that it was quite important that the tip or upper end of the conducting rod should be sharply pointed, or should bristle with sharp points, so to speak. The tips were gilded and the points made of gold or platinum to prevent rusting. The points were supposed to draw off the lightning silently from the cloud and so prevent strokes of lightning. But for millions of volts at cloud distances almost all irregular objects on the surface of the earth are practically pointed. Perhaps on this erroneous assumption of the action of points as applied here little stress was laid on the direct path to earth being chosen and on the necessity of including with it or connecting to it other good paths such as gas pipes, bell wires and the like. There is no need of any special provision of points. A blunt end will do as well, for after all there is practically no silent drawing off of the charge from the cloud, for it is not an insulated conductor. The provision of a lightning conductor on a building undoubtedly increases its chances of being struck by lightning, but if properly arranged it also ensures that the structure shall suffer no harm therefrom. Viewed from our present standpoint it is a curious historical fact that in 1777, just after the war of the American revolution broke out, a miniature verbal war between the advocates of *blunts* and *points*, respectively, as applied to lightning conductors raged. In England party politics led many to condemn *points* as revolutionary and stick to *blunts*. The Royal Society by majority vote decided for points, but those who so voted were considered friends of the rebels in America. George III. took the side of *blunts*. Franklin, who from the first had prescribed points, wrote from France: "The King's changing his pointed conductors for blunt ones is a matter of small importance to me. For it is only since he thought himself safe from the thunders of Heaven that he dared to use his own thunder in destroying his own subjects." The king is reputed to have tried to get Sir John Pringle, then president of the Royal Society to work for blunts, but received the reply: "Sire, I can not reverse the laws and operations of nature." As stated above, it matters not at all which we may use. I have, indeed, seen a number of cases in which the sharp points of lightning conductors had been melted into rounded ends by lightning.

In the foregoing we have been considering the effects of such ordinary discharges of electricity as the disruptive spark, or zigzag flash. Apparently if the testimony is reliable there are other and more rare forms of discharge. I allude to sheet lightning, so-called globular lightning and to bead lightning. But it may be asked, why call sheet lightning a rare form? It is, indeed, true that when a storm is so far distant that the spark discharges can not be seen, as when it is below the horizon, or when the spark is blanketed by a mass of mist or cloud there is to be noted a diffused light or extended illumination, which, on account of distance, may not appear to be attended by thunder. This and similar effects are often called sheet lightning. From observations during a few heavy storms, however, I am led to infer the existence at rare intervals of a noiseless discharge between cloud and earth—a silent effect attended by a diffused light, and which may be the true sheet lightning. In my experience it has accompanied an unusually heavy downpour of rain, the whole atmosphere where the rain fell most heavily being apparently momentarily lighted up by a purple glow, seemingly close at hand in the space between the rain drops. The appearance has been seen in the daytime as an intense bluish or purplish momentary glow without any accompanying sound. It could scarcely have been illusory. It is hoped that other observers will carefully note any such like effect if it occurs. It is certainly a rare phenomenon.

It is quite common that any very bright flash, the details of which from its suddenness and intensity are unobservable, be alluded to as a ball of fire. Doubtless many of the reported cases of so-called ball or globular lightning may be explained as instances of this condition of things. Nevertheless, there are so many recorded instances, apparently in substantial agreement, that it is difficult to escape the conclusion that there in reality exists this rare form of electric effect, globular lightning.

We can not properly discredit observations of phenomena which are so rare that our own chance for confirmation of them may never come. We must, in such cases, carefully scrutinize the testimony, examine the credibility of witnesses and their chances of being mistaken. It is certainly impossible at present to frame any adequate hypothesis to account for this curious and obscure electric appearance. The witnesses agree that it is an accompaniment of thunder-storms and that it resembles a ball of fire floating in the air or moving along a surface, such as the ground. It is not described as very bright or dazzling, and the size of the ball itself may be from an inch or two to a foot or more in diameter. Observers agree that it can persist for some time and that its slow movement allows it to be readily kept under observation while it lasts. When it disappears there is usually an explosion and a single explosive report like that of gun fire. Sometimes it is said to disappear silently. Usually the damage done by its explosion is only slight. This summary of characteristics is common to all accounts. Some accounts are even more detailed, mentioning that the fiery ball seemed to be agitated or with its surface in active motion. I have found two instances occurring many years apart and in widely different localities in which it is described as having a reddish nucleus, in diameter some considerable fraction of the whole. The outer fiery mass has been described as yellowish in color. In some instances it has been seen to fall out of a cloud. It is described as entering buildings and moving about therein. Personally I was for a long period in doubt as to the reality of this strange appearance, deeming it the result of some illusion, or a fanciful myth. But on hearing descriptions by eye witnesses known to me as persons not given to romancing, and finding their accounts to correspond closely with the best detailed descriptions in publications, my doubts have disappeared.

In one instance, while observing the lightning during a heavy thunderstorm, a companion, whose eyes were turned in a direction nearly opposite to my own, suddenly called to me that a ball had just dropped out of the cloud some distance away. The view of the ground was obstructed by buildings and I unfortunately just missed it. The noise of its explosion was, however, heard in the direction indicated by my fellow observer, as a single report like the firing of a gun. At the time I closely questioned him as to details of the appearance. Our ignorance of its possible nature is complete. No rational hypothesis exists to explain it. Science has in the past unraveled many obscure phenomena. The difficulty here is that it is too accidental and rare for consistent study, and we have not as yet any laboratory phenomena which resemble it closely.

Sometimes photographs taken during thunder-storms have been found to carry curiously contorted streaks in some degree resembling lightning flashes. Generally they have been found on plates upon which undoubted lightning discharges have been recorded. In some instances which have come to my notice the streaks have had the appearance of a string of dots or beads and have been taken to represent a very rare form of lightning known as bead lightning. A number of such photographs have been submitted to me for opinion as to the nature of the curious streaks. In all cases they are explained as due to the camera having been moved without capping the lens, permitting images of lights, such as arc lights, or spots of reflected light from wet or polished surfaces to traverse the plate in an irregular course. They are then only records of the inadvertence of the lightning photographer. In one instance the effect was so curious that it was several years before the true explanation was found. In that case there were two wavy contorted streaks of perfectly parallel and of similar outline, but unequal in intensity, rising each from a rail of a single track railway, and apparently terminating in the air fifteen or twenty feet above the tracks. They were finally traced to a moving camera, and a reflection from the wet and polished rail surfaces of the light of an arc lamp located outside the field of view. It required a visit to the place itself to enable this conclusion to be reached. The particular beaded streaks or lines of dots were traced to the fact that the arc lamps causing them were operated by alternating currents which naturally give light interrupted at the zero of current; one hundred and twenty times per second being the usual rate. All this emphasizes the need of care and wholesome scrutiny or even skepticism before reaching a conclusion in such cases.

Is bead lightning, which has at times been described as observed visually, a reality? If it is it appears to be even rarer than the globular variety. Perhaps it is a string of globules; a variety of globular lightning. But we can not make assumptions. As in the case of globular lightning there is some testimony, which can not be wholly disregarded, tending to show that a form of discharge resembling a string of beads can actually exist. An account of an instance was given me within one hour after the occurrence itself. The witness was known to me as perfectly reliable. The appearance was described as a festoon of finely colored oval beads hung as it were from one part of cloud to another, and as persisting for some seconds while gradually fading away. The opposite ends of each bead were said to be different in color. It was seen during an afternoon thunderstorm and spoken of as very beautiful, and altogether different from the usual zigzag flash.

If I have dwelt upon these exceptional appearances at some length it is because they seem to show that in electricity there is much yet to learn and abundant opportunity for future investigation. It is certainly literally true that, in the language of Shakespeare, "There are more things in Heaven and earth, Horatio, than are dreamt of in your philosophy." Such work belongs to the science of physics, now recognized as fundamental in all study of nature's processes. In electrical engineering, which is in reality an art based upon applied physics, the subject of lightning protection has always been one of considerable if not vital importance. Just as a lightning discharge from a cloud clears up a path for other discharges to follow, so in electric undertakings it opens up paths for the escape of the electricity we are sending out to do the work intended, such as for lighting, power or other use. In the past, disablement of machinery in electric stations has not been rare. The recent growth of long-distance transmission involving hundreds of miles of wire carried on poles across country, over hills and through valleys, has set new problems of protection, and called for renewed activity in providing means for rendering the lines and apparatus immune to the baneful effects of electric storms. Judging the future by the past, we may conclude that, whatever difficulties of the kind arise, in the great future extensions of such engineering work, science and invention will provide resources ample for the needs, and the rapid advance will be continued unchecked.

ELIHU THOMSON

Experimental Researches in Electricity. [Abstract]
Author(s): Michael Faraday
Reviewed work(s):
Source: *Abstracts of the Papers Printed in the Philosophical Transactions of the Royal Society of London*, Vol. 3 (1830 - 1837), pp. 91-93
Published by: The Royal Society
Stable URL: http://www.jstor.org/stable/110293
Accessed: 21/03/2012 17:14

PROCEEDINGS

OF

THE ROYAL SOCIETY.

1831–1832. No. 8.

December 8, 1831.

HIS ROYAL HIGHNESS THE DUKE OF SUSSEX, K.G., President, in the Chair.

Thomas Maclear, Esq., Philip Hardwick, Esq., the Right Hon. Lord Oxmantown, and Henry Robinson Palmer, Esq., were elected Fellows of the Society.

The reading of a paper, entitled "Experimental Researches in Electricity," by Michael Faraday, Esq. F.R.S. was commenced.

December, 15, 1831.

JOHN WILLIAM LUBBOCK, Esq. M.A., V.P. and Treasurer, in the Chair.

The reading of Mr. Faraday's paper, entitled "Experimental Researches in Electricity," was concluded.

This paper is divided into four parts: the first being on the Induction of Electric Currents; the second, on the Evolution of Electricity from Magnetism; the third, on a new Electrical Condition of Matter; and the fourth, on Arago's Magnetic Phænomena.

The author defines *electrical induction* to be the power which electrical currents possess of *inducing* any particular state upon matter in their immediate neighbourhood. A great length of copper wire, 1-20th of an inch in diameter, was wound round a cylinder of wood so as to compose two helices, the coils of which were intermixed, but prevented from touching each other by interposed threads of twine and calico. One helix was connected with a voltaic battery, and the other with a galvanometer. No effect was perceived on the latter, with a battery of 10 plates: a slight effect only with one of 100 plates; and a distinct deflection of the needle of the galvanometer occurred when the contact was made with a battery of 120 plates. While the contact was preserved, the needle returned to its natural position, and was unaffected by the electric current passing through the wire connected with the battery; but on breaking the connexion, the needle of the galvanometer was again deflected, but in a direction contrary to that of its former deflection. Hence it is inferred that the electric current sent by the battery through one wire, induced a similar current through the other wire, but only at the moment the contact was made; and a current in the contrary direction when the passage of the electricity was suddenly interrupted. These transitory currents, resembling waves, were found to be capable of magnetizing needles placed within the helix. Collateral currents, either in the same or in opposite directions, exert no permanent inductive power on each other.

No other evidence of the electric action of these induced currents could be detected, such as the appearance of a spark, the ignition of fine wires, or of charcoal, impressions on the tongue, contractions in the muscles of frogs, or chemical decompositions. Yet these induced currents were found to be capable of passing through fluids, when interposed to a small extent in the circuit.

Similar effects were apparently produced by the inductive influence of ordinary electricity directed through the first set of wires.

The second part of this paper contains the account of experiments in which the helix connected with the voltaic battery was wound round one side of an iron ring, welded from soft round bar-iron; while another helix connected with a galvanometer was coiled round the opposite side of the ring. The electrical indications obtained by this apparatus were much more considerable than in the former case, but were equally transitory, and were of opposite kinds on the interruption of the contacts with the battery. By interposing charcoal points in the circuit of the induced helix, a minute spark was perceived whenever the contacts were made or broken off; but no ignition of wires or other electric effects could be obtained. Electric currents were also induced in a helix into which a soft iron cylinder was introduced, whenever that iron was rendered magnetical by induction from magnets applied to its ends. The sudden introduction or removal of a magnet, in the place of the iron cylinder, produced similar effects on the helix.

In many of these experiments the author employed the large compound magnet constructed by Dr. Gowin Knight, and belonging to the Royal Society. Similar effects were produced when the iron was surrounded by a piece of copper-plate wrapped once round it with its edges connected with the wires of the galvanometer. Currents were induced on a wire coiled into a flat spiral, by bringing one of the poles of the powerful magnet of Dr. Knight opposite to its centre. Even single wires brought near the pole of this magnet had electric currents induced in them. But all attempts to obtain chemical effects by these currents of electricity induced by magnetism were unsuccessful.

In the third part of the paper the author regards the condition in which a conducting wire exists while it is subject either to volta-electric, or magneto-electric induction, as a peculiar one, which he designates by the term *Electro-tonic state*. This peculiar condition shows no electrical effects while it continues, nor does it exert any sensible action on matter, or on other electrical currents, either of an attractive or repulsive kind; nor does it tend either to accelerate or to retard those currents.

In the fourth part of the paper the author relates a great number of experiments, which concur in proving that when a piece of metal is moved in any particular direction, either in front of a single magnetic pole, or between the opposite poles of a horse-shoe magnet, electrical currents are developed which pass along the substance of the metal in a direction transverse to that of its own motion. By the application of this principle, the author is enabled to explain the various phænomena which take place in the experiments of Arago and others, where magnetic action appears to be developed by rotation; and which have been erroneously attributed to simple magnetic induction, and to the time supposed to be required for the progress of that induction. The electro-magnetic effect of the electric current induced in a conductor by a magnetic pole, in consequence of their relative motion, is such as tends continually to diminish that relative motion; that is, to bring the moving bodies into the state of relative rest; so that if the one be made to revolve by an extraneous force, the other will tend to revolve with it in the same direction, and with the same velocity.

A paper was read, entitled "Some Remarks on the internal Structure of the Platypus Anatinus (*Ornithorhyncus paradoxus*, Blum.)." By Richard Griffin, Esq. Communicated by Dawson Turner, Esq. F.R.S.

Having an opportunity of examining two specimens of the Ornithorhyncus, the one male, the other female, belonging to the Norfolk and Norwich Museum, the author found in the latter two large mammary glands, one on each side of the chest, and covering nearly the whole under surface of the animal; numerous ducts proceeded from them, perforating the skin, at two circular portions, which presented no elevation corresponding to nipples. The Fallopian tubes terminate by very small orifices in the cloaca: posterior to their terminations the author observed two slightly projecting processes, containing each the orifice of a duct which proceeds to a length of at least two inches, but the continuation of which could not be traced in the specimen examined in consequence of the injuries it had received. In the male, three pointed processes were noticed at each extremity of the corpora cavernosa of the penis, the cavities of which do not communicate with one another, and are separated before their termination. The spur of the male is furnished with a sac, of the size of a pea, containing a poisonous fluid, which by means of a canal is conducted into a wound inflicted by the spur.

December 22, 1831.

HIS ROYAL HIGHNESS THE DUKE OF SUSSEX, K.G.,
President, in the Chair.

The Right Hon. Sir James Graham, Bart. was elected a Fellow of the Society.

A paper was read, entitled "Some Account of a New Volcano in

"Licenciamento Na Indústria de Refinação/ Recipientes sob Pressão"

Universidade do Porto
FEUP Faculdade de Engenharia

Gisela Caridade

Porto 2 de Janeiro de 2010

RESUMO

Este documento académico é realizado no âmbito da disciplina de Segurança: do Projecto ao Usufruto do Mestrado de Engenharia de Segurança e Higiene Ocupacionais.

Tendo como fonte da base do licenciamento industrial, o Decreto-Lei nº 102/2009 de 10 de Setembro, artigo 12º, este trabalho pretende de uma forma geral proceder a uma introdução à complexa etapa do licenciamento industrial, de uma unidade de refinação de combustíveis sujeita a alteração de equipamentos de pressão do seu lay-out, promovendo a integração dos princípios gerais de prevenção na fase de projecto. Para além das normas jurídicas aplicáveis é realizada uma abordagem às normas técnicas que definem os parâmetros normativos básicos, dos coeficientes de segurança aplicáveis aos métodos construtivos.

Com o objectivo de melhor caracterizar este processo foi seleccionada como actividade, a indústria petroquímica, nomeadamente um estabelecimento de refinação, uma vez que esta selecção incide numa actividade que não promove qualquer dúvida sob a sua classificação. A indústria petroquímica é considerada como um estabelecimento de superior perigosidade, de acordo com o Decreto-lei nº 254/2007 de 12 de Julho, sob o tema "***Licenciamento na Industria de Refinação de Recipientes sob Pressão"***.

Frequentemente estes estabelecimentos procedem à remoção/substituição de equipamentos sob pressão, que fazem parte integrante do lay-out, os quais estão sujeitos à regulamentação de funcionamento, de Reparação e de Alteração de Equipamentos sob Pressão (ESP), nos quais se incluem, nomeadamente, os reservatórios de gás, de ar comprimido e de oxigénio ou outros gases criogénicos. O principal risco considerado neste trabalho, é o risco de atmosferas explosivas por via da não conformidade dos equipamentos.

Apenas se considerada, o licenciamento do ponto de vista da descrição dos equipamentos sob pressão, colocados nas instalações, de forma a implementar medidas de protecção e de intervenção para limitar as consequências dos acidentes graves envolvendo substâncias perigosas. Esta opção implica a adopção de critérios de selecção e simplificação, durante a etapa de descrição do processo de licenciamento, descritos ao longo do documento.

ÍNDICE

ÍNDICE DE ANEXOS

ÍNDICE DE DIAGRAMAS

1.INTRODUÇÃO

Estabelecer um guia de apoio ao "***Licenciamento na Industria de Refinação de Recipientes sob Pressão"*** de acordo com os principais diplomas legais aplicáveis é o que se propõe com este estudo. Neste guia apenas se consideram medidas de prevenção de carácter da segurança em projecto. Medidas adicionais, por exemplo, implementação de protecções colectivas colocadas à posteriori do dimensionamento do equipamento, passam a ser consideradas como medidas de carácter correctivo, uma vez que não foram consideradas em projecto.

O início de uma nova etapa do planeamento construtivo integrado nos princípios gerais de prevenção, durante a fase de concepção e construção de equipamentos sob pressão, nos estabelecimentos industriais, de forma a implementar medidas de prevenção e limitação da exposição dos trabalhadores e de toda a envolvente da instalação industrial aos acidentes graves envolvendo substâncias perigosas de acordo com:

- O actual regime da promoção da segurança e saúde no trabalho, Lei 102/2009 de 10 de Setembro. Introduz uma nova referência no âmbito da prevenção dos riscos profissionais nomeadamente ao nível do regime de licenciamento, artigo 12º, Licenciamento e autorização de laboração**:** **"** *A legislação sobre licenciamento e autorização de laboração contém as especificações adequadas à prevenção de riscos profissionais e à protecção da saúde." (in Diário da República, 1ª série – nº176 – 10 de Setembro de 2009);*

- O regime de exercício da actividade industrial (REAI). O REAI encontra-se legislado através do Decreto-lei nº 209/2008 de 29 de Outubro. Assim como no diploma anteriormente mencionado, procede à implementação dos princípios gerais de prevenção na fase de projecto, no artigo 21º, ponto 2, onde nos elementos instrutórios definidos na secção 1 do anexo IV, ponto 9 alínea c), passam a ser incluídos os princípios de Segurança e saúde no trabalho e segurança industrial;

- O regime de prevenção de acidentes graves que envolvam substâncias perigosas e a limitação das consequências das suas consequências para o homem e ambiente, Decreto-lei nº 254/2007 de 12 de Julho (SEVESO II);

- Regulamento de Instalação, de Funcionamento, de Reparação e de Alteração de Equipamentos sob Pressão (ESP), nos quais se incluem, nomeadamente, os reservatórios de gás, de ar comprimido e de oxigénio ou outros gases criogénicos, bem como as caldeiras para a produção de vapor, Decreto lei nº 90/2010 de 22 De Julho;

- Normas técnicas estabelecidas no Decreto-lei nº 90/2010 de 22 De Julho;

- As prescrições mínimas destinadas a promoverem a melhoria da protecção da segurança e da saúde dos trabalhadores susceptíveis de exposição a riscos derivados de atmosferas explosivas no local de trabalho, Decreto-Lei nº 236/2003 de 30 de Setembro.

Deste guia consta a descrição da actividade industrial seleccionada, a sua contextualização no panorama económico nacional, a selecção e justificação do risco considerado. A actividade de refinação e o respectivo risco são integrados no regime de exercício da actividade industrial o nos respectivos regimes jurídicos aplicáveis.

2. INDÚSTRIA DE REFINAÇÃO

" «Grandes instalações petrolíferas» as refinarias, as grandes instalações de armazenamento e os sistemas de transporte de produtos de petróleo por conduta, integrados ou não em centros de operação logística." (in Diário da República, 1ª série - A – nº33 – 15 de Fevereiro de 2006).

A Refinação em Portugal

"O aparelho refinador nacional é constituído pelas refinarias de Sines e do Porto, as quais asseguram cerca de 88% das necessidades de combustíveis petrolíferos do país. A sua capacidade de armazenagem assegura também grande parte das reservas nacionais.

Ao nível da península ibérica, as duas refinarias representam cerca de 21% da capacidade de refinação (14,5 milhões de toneladas/ano de capacidade de destilação).

Nos últimos anos, mercê de sucessivos projectos de reconfiguração processual, a Petrogal tem vindo a adequar o seu aparelho refinador não só à produção de combustíveis de acordo com as especificações ambientais, mas também ao alinhamento das suas instalações com as Melhores Técnicas Disponíveis." (in dgge em 27/12/2010).

A escolha desta actividade foi fundamentada quer pela inegável classificação de estabelecimento de nível de superior perigosidade, quer pela evolução do mercado do petróleo ao nível mundial, obrigando à reestruturação das refinarias que existem no território nacional.

A actividade de refinação é regulamentada através do Decreto-lei 31/2006 de 15 de Fevereiro.

> *"O presente decreto-lei estabelece as bases gerais da organização e funcionamento do Sistema Petrolífero organização e funcionamento do Sistema Petrolífero Nacional (SPN), bem como as disposições gerais aplicáveis ao exercício das actividades de armazenamento, transporte, distribuição, refinação e comercialização e à organização dos mercados de petróleo bruto e de produtos de petróleo. "* (in Diário da República, 1ª série -A – nº33 – 15 de Fevereiro de 2006)

Nos projectos gerais de dimensionamento de equipamentos mecânicos são considerados os seguintes parâmetros: a resistência, a rigidez, a fiabilidade, o risco de corrosão, o atrito e o desgaste, o conforto térmico, a finalidade, o custo, o processo de fabrico, o peso, a segurança, o ruído, o design, a lubrificação e a manutenção e o controle. A conjugação deste conjunto de parâmetros, condicionam o desempenho global do equipamento a todos os níveis, especialmente ao nível da segurança. Na maioria dos projectos de dimensionamento os parâmetros não são conjugados da mesma forma, sendo que na maioria dos casos o parâmetro com maior relevância é o custo.

O risco considerado, o risco de atmosferas explosivas por via da não conformidade dos equipamentos, advêm da falhas de construção e inspecção durante a fase de implementação. Os equipamentos sujeitos às diversas solicitações podem sofrer rupturas promovendo a ocorrência do risco de atmosferas explosivas.

As medidas preventivas aplicáveis a este tipo de incidentes apenas podem ser implementadas na fase de projecto, aquando do licenciamento industrial e do equipamento.

3. LICENCIAMENTO INDUSTRIAL

3.1 Enquadramento

A antiga "lei dos petróleos" (Lei n.º 1947, de 12 de Fevereiro de 1937 que definiu o regime legal para a importação, o armazenamento e o tratamento industrial dos petróleos brutos, seus derivados e resíduos), e parte do Regulamento (Decreto n.º 29034, de 1 de Outubro de 1938) estão revogados por virtude da liberalização da economia nacional.

No que respeita às Refinarias, a Base XII da Lei n.º 1947 referia que o seu estabelecimento dependia de autorização prévia do Governo, concedida por decreto do Ministro, e a Base XIV impunha um certo número de obrigações ao titular da autorização. A Base XII foi revogada pelo Decreto-Lei n.º 109/91, de 15 de Março que estabeleceu as normas disciplinadoras do exercício da actividade industrial. (in dgge em 16 de Novembro de 2010).

O Decreto-Lei n.º 109/91 foi entretanto revogado pelo Decreto-Lei n.º 69/2003, de 10 de Abril que aprovou o RELAI (Regulamento para o exercício e licenciamento da Actividade Industrial). (in dgge em 16 de Novembro de 2010)

Actualmente o Decreto-lei nº 69/2003 de 10 de Abril foi revogado pelo Decreto-lei nº 209/2008, de 29 de Outubro que aprova o regime de exercício da actividade industrial (REAI).

A classificação das actividades económicas (CAE), estabelecida pelo Decreto-Lei nº 381/2007 de 14 de Novembro considera a refinação como uma actividade de fabricação de produtos petrolíferos refinados como uma actividade industrial.

Conforme disposto no Decreto-Lei n.º 31/2006, de 15 de Fevereiro, o acesso à "actividade de refinação" é livre, mas sujeito a um processo administrativo de licenciamento que seguirá o actual Regime de Licenciamento Industrial, acrescido de uma avaliação das capacidades do proponente. (in dgge em 16 de Novembro de 2010).

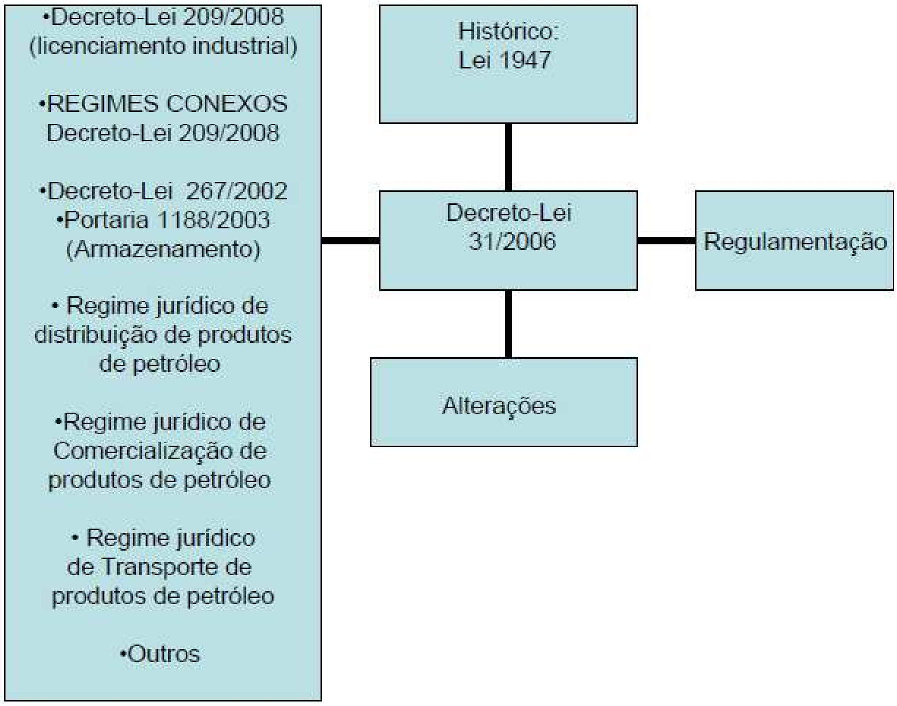

Diagrama 1 – Cruz de Malta do Decreto -Lei nº 31/2006

Conforme disposto no Decreto-Lei n.º 31/2006, de 15 de Fevereiro, o acesso à "actividade de refinação" é livre, mas sujeito a um processo administrativo de licenciamento que seguirá o actual Regime de Licenciamento Industrial, acrescido de uma avaliação das capacidades do proponente. (in dgge em 16 de Novembro de 2010)

A actividade de refinação é uma actividade industrial, cujas normas disciplinadoras do respectivo exercício foram estabelecidas pelo Decreto-Lei nº 209/2008, de 29 de Outubro que aprova o regime de exercício da actividade industrial (REAI).

Ou seja, o exercício da actividade de refinação de petróleo bruto não carece de licenciamento autónomo, mas depende do licenciamento das instalações a conceder pelo Ministro da Economia e da Inovação, tendo em conta a idoneidade e capacidade técnica, económica e financeira do requerente, a conformidade do respectivo projecto com a política energética nacional, os planos de ordenamento do território e os objectivos de política ambiental. (in Diário da República, 1ª série -A – nº33 – 15 de Fevereiro de 2006).

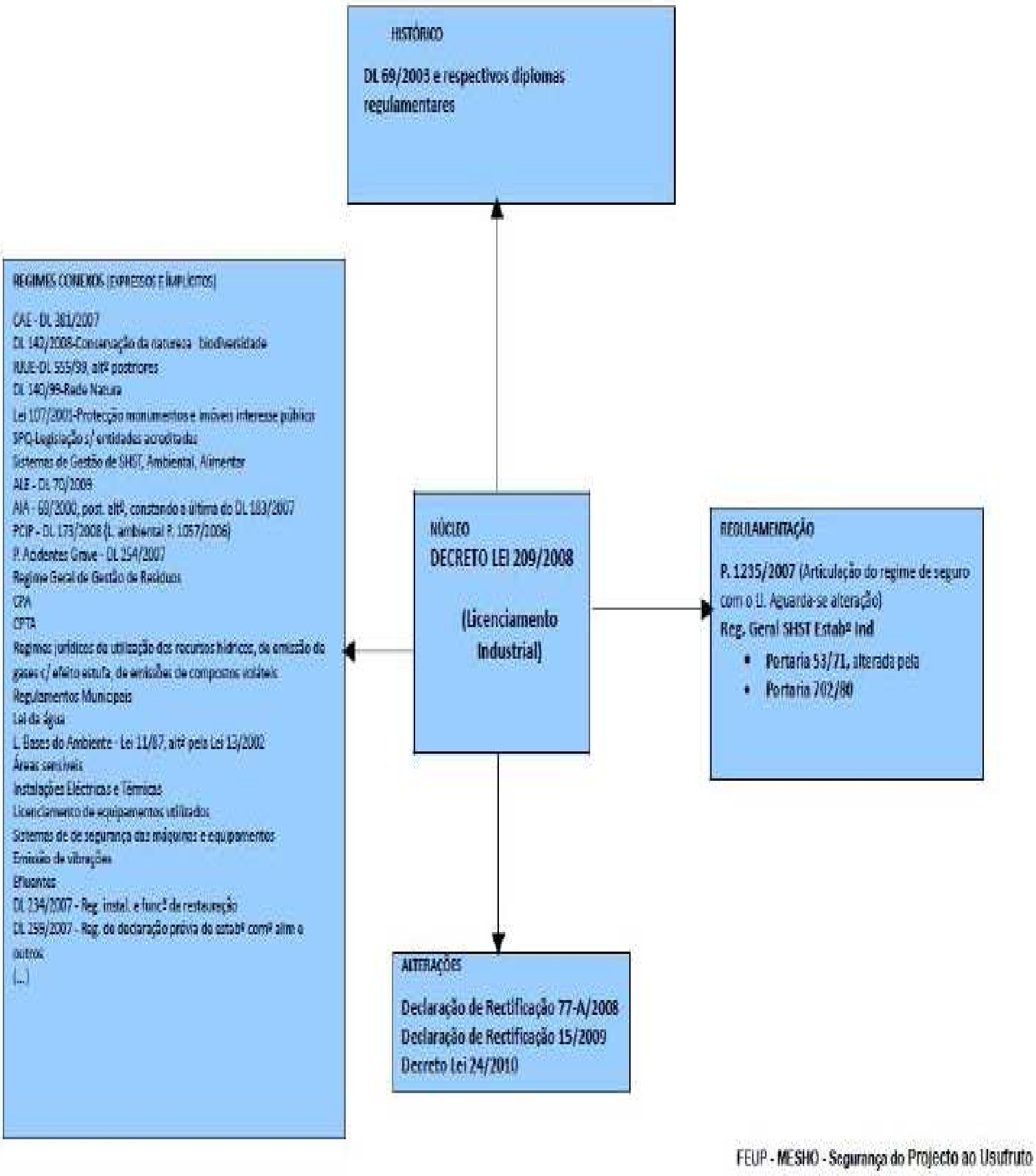

Diagrama 2 – Cruz de Malta do Decreto -Lei nº 209/2008 (in apontamentos da FEUP-MESHO-Segurança: do Projecto ao Usufruto) (Ver ANEXO I)

3.2 Etapas do licenciamento

As etapas de licenciamento descritas neste ponto consideram-se subordinadas ao Decreto-lei nº 254/2007, de 12 de Julho (SEVESO II), de acordo com o risco e seleccionado de atmosferas, sendo que a abordagem ao REAI é simplificada.

O processo de licenciamento de uma refinaria abrange as seguintes etapas:

1. **Classificação dos estabelecimentos industriais**

A actividade industrial é definida através da alínea a) artigo 2º:

Grupo	Classe	Subclasse	Designação
191	1910	19201	Fabricação de produtos petrolíferos refinados

Diagrama 3 – Selecção da actividade económica

A refinaria é classificada como um estabelecimento de tipo 1, sendo abrangida pelos seguintes regimes jurídicos:

a) Avaliação de impacte ambiental, previsto no Decreto--Lei n.º 69/2000, de 3 de Maio;

b) Prevenção e controlo integrados da poluição, previsto no Decreto -Lei n.º 173/2008, de 26 de Agosto;

c) Prevenção de acidentes graves que envolvam substâncias perigosas, previsto no Decreto -Lei n.º 254/2007,de 12 de Julho (SEVESO II);

d) Operações de gestão de resíduos, nomeadamente os previstos nos Decretos -Leis n.os 152/2002, de 23 de Maio, 3/2004, de 3 de Janeiro, 85/2005, de 28 de Abril, e178/2006, de 5 de Setembro, quando estejam em causa resíduos perigosos, de acordo com a lista europeia de resíduos.

2. Procedimento para instalação e exploração de estabelecimento industrial

A instalação e a exploração de estabelecimento industrial ficam sujeitas ao procedimento de Autorização Prévia de acordo com tipologia de estabelecimento industrial de Tipo 1. O procedimento para o regime de autorização prévia está definido no Capítulo II do REAI.

3. A presentação da Autorização Prévia à Entidade Coordenadora

A determinação da entidade coordenadora no procedimento relativo ao estabelecimento industrial é feita, de acordo com o anexo III ao presente decreto -lei:

Subclasse CAE — rev. 3	Tipologia dos estabelecimentos	Entidade coordenadora
08920 19201 24460	Todos os tipos. . .	Direcção-Geral de Energia e Geologia.
08931 10110 a 10412 10510 e 10893 10911 a 10920	Tipos 1 e 2	Direcção regional de agricultura e pescas territorialmente competente ou entidade gestora da ALE.
11011 a 11013 11021 a 11030 35302 56210 e 56290	Tipo 3	Câmara municipal territorialmente competente ou entidade gestora da ALE.
Subclasses previstas na secção 1 do anexo I e não identificadas nas linhas anteriores desta coluna.	Tipos 1 e 2	Direcção regional de economia territorialmente competente ou entidade gestora da ALE.
	Tipo 3	Câmara municipal territorialmente competente ou entidade gestora da ALE.

Diagrama 4 – Selecção da entidade coordenadora

Sendo a Direcção Geral de Energia e Geologia a responsável pela coordenação do licenciamento da refinaria. A esta entidade, compete a condução, monitorização, e dinamização dos procedimentos de Administrativos, nomeadamente:

- Prestar informação e apoio técnico ao industrial;
- Identificar os condicionamentos legais e regulamentos;
- Monitorizar a tramitação dos procedimentos;
- Analisar as solicitações de alterações e elementos adicionais e reformulação de documentos;

- Reunir com o requerente, responsável técnico do projecto e demais entidades intervenientes.
- Promover e conduzir a realização de vistorias;
- Disponibilizar informação sobre o andamento do processo.

Para além das entidades coordenadora o processo de licenciamento estará sujeito a pronúncia de entidades públicas, definidas no artigo 12º do REAI.

4. Regimes Conexos

A tipologia da instalação industrial obriga ainda a que estando sujeita a controlo prévio, exista uma articulação entre o regime previsto no presente decreto -lei e o regime jurídico de urbanização e edificação (RJUE), aprovado pelo Decreto -Lei n.º 555/99,de 16 de Dezembro. Logo o requerente pode apresentar à câmara municipal competente, antes de iniciado o procedimento à câmara municipal:

a) Pedido de informação prévia sobre a operação urbanística, não estando a decisão deste pedido dependente de decisão da entidade coordenadora sobre o pedido de autorização ou sobre a declaração prévia;

b) Pedido de licença ou comunicação prévia, mas a câmara municipal só pode decidir depois de proferida a decisão favorável ou favorável condicionada sobre o pedido de autorização ou sobre a declaração prévia de actividade industrial, ou emitida a certidão comprovativa do respectivo deferimento tácito

5. Sistemas de informação e instrumentos de apoio

Decreto-Lei n.º 209/2008, prevê no seu art. 14º que a tramitação dos procedimentos previstos no presente decreto-lei é realizada por via electrónica através de plataforma de interoperabilidade da Administração Pública, não podendo ser entregue em suporte de papel. Para as instalações cujas actividades a licenciar se encontrem abrangidas por este regime, é recomendável a consulta prévia à respectiva Entidade Coordenadora (EC) para mais informações do procedimento a realizar.

3.2 SEVESO

Considera-se a SEVESO II, o principal diploma a ter em consideração neste guia, uma vez que tem como regime conexo o REAI.

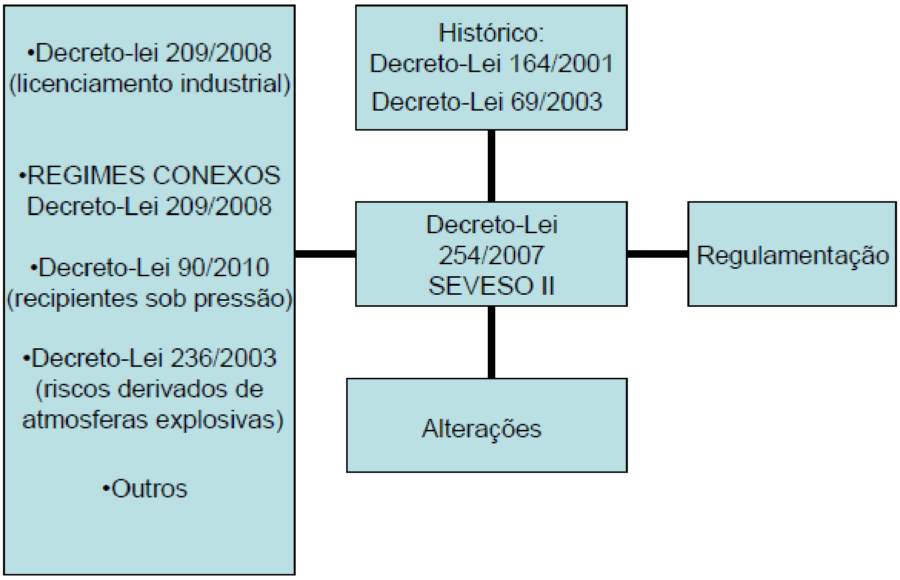

Diagrama 5 – Cruz de Malta do Decreto -Lei nº 254/2007

"O presente decreto-lei estabelece o regime de prevenção de acidentes graves que envolvam substâncias perigosas e a limitação das suas consequências para o homem e o ambiente, transpondo para o direito interno a Directiva n.º 2003/105/CE, do Parlamento Europeu e do Conselho, de 16 de Dezembro, que altera a Directiva no 96/82/CE, do Conselho, de 9 de Dezembro, relativa ao controlo dos perigos associados a acidentes graves que envolvam substâncias perigosas, com as alterações introduzidas pelo Regulamento (CE) n.º 1882/2003, do Parlamento Europeu e do Conselho, de 29 de Setembro." (in Diário da República, 1ª série – nº133 – 12 de Julho de 2007).

De acordo com o artigo 3º, da SEVESO II, a refinaria é considerada como um estabelecimento de superior perigosidade. A quantidade e tipologia de substâncias perigosas existentes no estabelecimento excedem ou igualam as quantidades indicadas na coluna 3 das partes 1 e 2 do Anexo I.

Neste âmbito são estabelecidos pelo artigo 4º os deveres do operador, nomeadamente:
“1— Incumbe ao operador tomar todas as medidas necessárias para evitar acidentes graves envolvendo substâncias perigosas e para limitar as suas consequências para o homem e o ambiente.
2— O operador tem o dever de demonstrar à Agência Portuguesa do Ambiente, abreviadamente designada APA, à Inspecção-Geral do Ambiente e Ordenamento do Território, abreviadamente designada IGAOT, à Autoridade Nacional de Protecção Civil, abreviadamente designada ANPC, no âmbito das respectivas competências, que tomou todas as medidas que são exigidas nos termos do presente decreto-lei.” (in Diário da República, 1ª série – nº133 – 12 de Julho de 2007).

O processo de licenciamento de estabelecimentos abrangido pela SEVESO II, fica condicionado ao parecer da Agência Portuguesa do Ambiente, à notificação apresentada pelo operador, de acordo com artigo 8º. O conteúdo da notificação está definido no anexo II do Decreto-Lei nº 254/2007. Deve ainda ser assegurado a elaboração, revisão e alteração dos planos municipais de ordenamento do território em todo este processo.

Uma vez considerado como um estabelecimento de superior perigosidade, este está sujeito ao estabelecido no Capitulo IV (artigo10º a artigo 20º) com a elaboração dos seguintes documentos:

- Relatório de Segurança (artigos 10º, 13º e 14º);
- Auditoria ao Sistema de Gestão de Segurança (artigo 16º);
- Plano de Emergência Interno (PEI): elaboração, revisão e actualização (artigos 17º e 18º);
- Exercícios de simulação do PEI (artigo 18º);
- Elementos para a elaboração do Plano de Emergência Externo: elaboração e actualização (artigo 19º);
- Efeito dominó (1): exercícios de simulação do PEI conjuntos (artigo 21º).

"4— Os estudos de segurança, os relatórios ou partes de relatórios elaborados no âmbito de outra legislação aplicável ao estabelecimento podem ser compilados num único relatório de segurança, desde que sejam respeitadas todas as exigências do presente decreto-lei" (in Diário da República, 1ª série – nº133 – 12 de Julho de 2007)."

A elaboração dos documentos acima referidos remete para os vários regimes conexos, salientando-se o regime jurídico relativo à classificação, embalagem, rotulagem e transporte de substâncias e preparações perigosas.

Do risco seleccionado para a elaboração deste guia, atmosferas explosivas por via da não conformidade de equipamentos sob pressão, o relatório de segurança é aquele que evidencia maior interesse. O relatório é elaborado de acordo com os elementos referidos no anexo IV, dos quais se destaca o ponto V, ALINEA A), Descrição dos equipamentos colocados nas instalações para limitar as consequências dos acidentes graves envolvendo substâncias perigosas. O regime jurídico aplicável às medidas de protecção e de intervenção para limitar as consequências de um acidente de equipamentos sob pressão, é apresentado no ponto 3.3.

3.3 ESP

Equipamentos sob pressão (ESP), são todos os recipientes, tubagens, acessórios de segurança, acessórios sob pressão, abrangendo os componentes ligados às partes, sob pressão, tais como flanges, tubuladuras, acoplamentos, apoios e olhais de elevação. O Decreto-lei nº 90/2010 de 22 de Julho aplica-se a todos os ESP destinados a conter um fluido, líquido, gás ou vapor — a pressão superior à atmosférica, projectados e construídos de acordo com o Decreto – Lei n.º 211/99, de 14 de Junho, e com o Decreto -Lei n.º 103/92,de 30 de Maio.

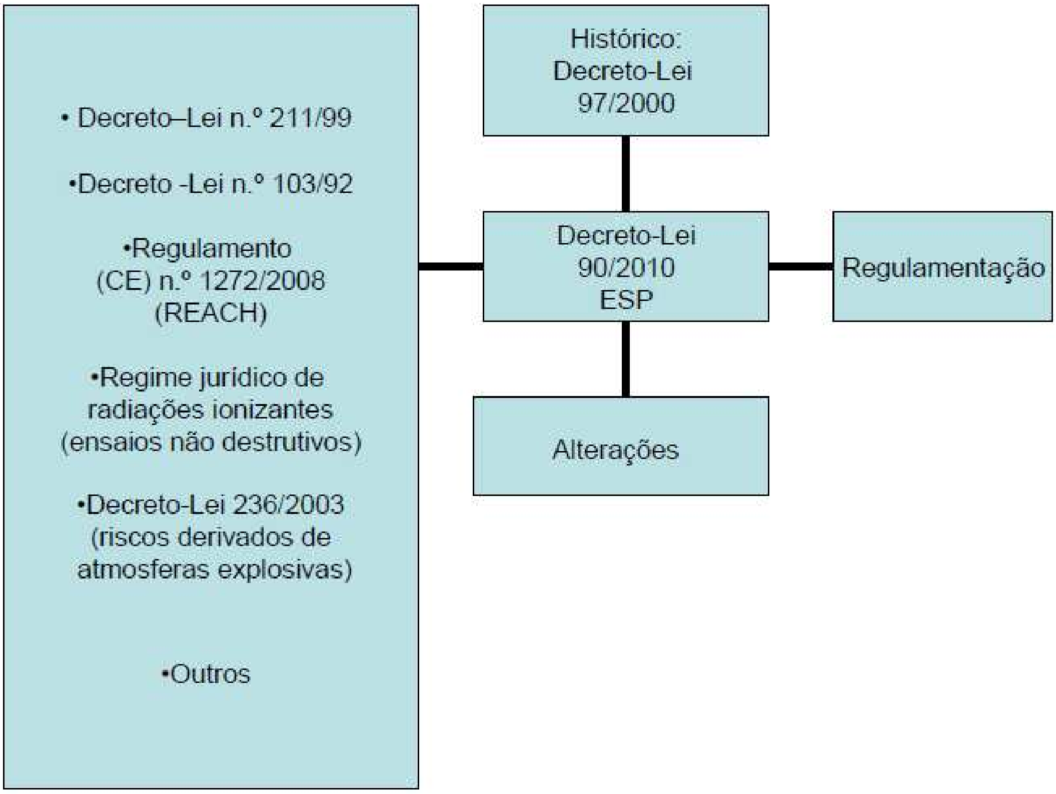

Diagrama 6 – Cruz de Malta do Decreto -Lei nº 90/2010

O licenciamento dos equipamentos abrangidos pelo Decreto-lei nº 90/2010 compreende os seguintes actos:

- Autorização prévia de instalação;

- Autorização de funcionamento, bem como a sua renovação.

Autorização prévia de Instalação

O pedido de autorização prévia é realizado através de requerimento de acordo com os elementos que constam do anexo II do presente regulamento, à Direcção Geral de Economia (DRE). Após o pagamento de uma taxa a DRE procede a análise do pedido e pronuncia-se num prazo de 45 dias. Caso considere necessária a entidade competente pode proceder à realização de uma vistoria ao local. Quaisquer alterações ao equipamento implicam a emissão de renovação da autorização prévia de instalação.

Autorização de funcionamento, bem como a sua renovação

O procedimento a realizar para a obtenção desta autorização é em todo semelhante ao anterior descrito, com as algumas alterações:

- O requerimento é elaborado de acordo com o anexo III do presente regulamento (ESP);
- A autorização de funcionamento é realizada através da emissão de um certificado. O certificado é emitido pela DRE, nos termos do anexo IV do regulamento de ESP e tem uma validade de 5 anos. A renovação de funcionamento deve ser realizada sempre que surjam alterações ao equipamento ou 60 dias antes do término da validade do certificado de acordo com o definido no artigo 10º do Regulamento ESP.

Todos os ESP devem estar devidamente identificados de acordo com o definido no capítulo II, "Registo do ESP", do regulamento que se enuncia (artigo 3º a artigo 5º) .Durante o período de "vida" os ESP estão sujeitos a três tipos de inspecção, inicial, intercalar e periódica. A inspecção é realizada por um organismo notificados (OI). Os OI devem comunicar à DRE, com pelo menos três dias úteis de antecedência, a data, a hora e o local em que vão ter lugar as inspecções e os ensaios, previstos no n.º 3 do artigo 21.º, podendo a DRE fazer -se representar naqueles actos.

As prescrições de segurança a que estão sujeitos os ESP, em fase de instalação, estão descritas no capítulo IV (artigo 15 º a artigo 16º). Para além das normas jurídicas são consideradas as normas técnicas para a garantia dos requisitos de segurança.

5 — Os demais órgãos de segurança e controlo devem estar de acordo com a norma ou código de construção adoptado e as prescrições indicadas nas respectivas ITC, devendo cumprir a legislação específica. (artigo 16º)
7 — São aplicáveis aos órgãos de segurança e de controlo o disposto nos n.os 1 a 6 sem prejuízo das demais norma que venham a ser editadas ou adoptadas pelo IPQ, I. P.,no âmbito do Sistema de Normalização. (artigo 16º)

Quando os ESP são alterados ou reparados, devem ser sujeita a aprovação o respectivo projecto, pelo Organismo notificado. As entidades que procedam às alterações e reparações devem, para o efeito, possuir os meios técnicos adequados e o pessoal qualificado para execução das intervenções previstas no presente Regulamento, podendo subcontratar, sem prejuízo da responsabilidade própria por qualquer deficiência que venha a ocorrer no ESP.

.
O projecto deve ser elaborado com base nas normas harmonizadas aplicáveis, ou em códigos adoptados na construção, ou em normas e em códigos equivalentes.
2 — O projecto deve ser elaborado por um profissional dos Engenheiros ou na Associação Nacional dos Engenheiros Técnicos ou por projectista inscrito no Colégio de Mecânica da respectiva associação.
3 — O projecto deve ser acompanhado de termo de responsabilidade, datado e assinado pelo seu autor, plano de inspecção e de ensaios, memória descritiva, nota de cálculo, se aplicável, e desenhos, em conformidade com o anexo VI ao presente Regulamento, do qual faz parte integrante.
4 — Se o projecto estiver em conformidade, o OI comunica, no prazo de 30 dias, a sua aprovação ao requerente acompanhado dos documentos elencados no anexo VI ao presente Regulamento.
5 — A cópia da memória descritiva e da comunicação a que se refere o número anterior devem ser remetidas pelo OI à DRE, no prazo de 15 dias, sem prejuízo daquela poder solicitar o processo completo. (artigo 18º)

As alterações e reparações são acompanhadas pela OI, que analisa processo, valida os ensaios realizados e verifica o cumprimento do respectivo projecto, devendo ser efectuada uma prova de pressão uma vez terminada a reparação ou a alteração. Estando conformes as reparações e as alterações constantes do projecto aprovado, o OI emite e entrega, no prazo de 15 dias, o relatório da aprovação de reparação e da alteração com as informações constantes no anexo VII do presente Regulamento, do qual faz parte integrante, remetendo uma cópia à DRE respectiva.
Os ensaios e as verificações (artigo 21º a artigo 25º), referidos no presente Regulamento ESP, devem ser efectuados de acordo com os respectivos códigos ou com as normas europeias, com as normas internacionais ou nacionais aplicáveis, identificando-se no relatório de inspecção o respectivo documento normativo aplicado.

A ocorrência de incidentes em equipamentos sob pressão implica a comunicação imediata à DRE da ocorrência e das acções implementadas. Tendo também a DRE a função de alertar as entidades de fiscalização (Autoridade de Segurança Alimentar e Económica) sempre que detecte uma situação de perigo grave para a saúde pública, para a segurança de pessoas e de bens, para a higiene e para a segurança dos locais de trabalho ou para o ambiente.

3.3 ATMOSFERAS EXPLOSIVAS

Este último ponto termina o guia proposto para o licenciamento da indústria de refinação aplicável a recipientes sob pressão não conformes que potenciem a ocorrência de atmosferas explosivas.

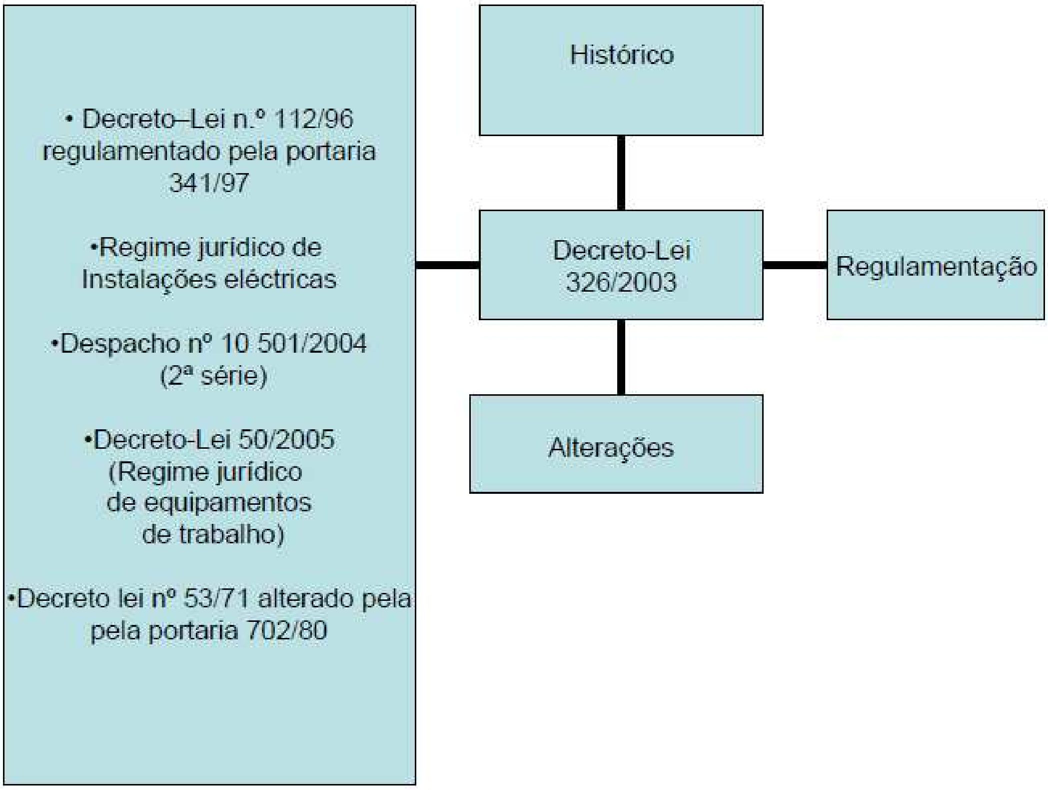

Diagrama 7 – Cruz de Malta do Decreto -Lei nº 326/2003

De acordo com a definição estabelecida pelo Decreto – Lei nº 236/2003, artigo 3, «Atmosfera explosiva» é uma mistura com o ar, em condições atmosféricas, de substâncias inflamáveis, sob a forma de gases, vapores, névoas ou poeiras, na qual, após a ignição, a combustão se propague a toda a mistura não queimada.

Os equipamentos sob pressão podem sofrer rupturas promovidas pelas diversas solicitações a que estão sujeitos. A ruptura destes equipamentos promove a libertação de hidrocarbonetos que estão no seu interior potenciando-se a explosão.

Em caso e explosão, os trabalhadores ficam expostos a riscos devido aos efeitos incontrolados das chamas e da pressão, sob a forma de radiação térmica, chamas, ondas de pressão e projecção de destroços, bem como em virtude de produtos de reacção nocivos e do consumo do oxigénio do ar indispensável à respiração.(in Segurança e Saúde dos Trabalhadores Expostos a Atmosferas Explosivas, Guia de Boas Prática)

O Decreto-Lei nº236/2003 é um manual de orientação, a aplicar pelo operador do estabelecimento industrial de forma a limitar a ocorrência de explosões. O “manual” engloba as seguintes directrizes:

1. Avaliação dos Riscos de Explosão;
2. Medidas Técnicas de Protecção Contra Explosões;
3. Medidas Organizacionais de Protecção Contra Explosões;
4. Obrigação de Coordenação;
5. Manual de Protecção Contra Explosões.

Das directrizes consideradas aquela que melhor define o objectivo da disciplina de Segurança do Projecto ao Usufruto é o Requisito número 2 “Medidas Técnicas de Protecção Contra Explosões”. Consideram-se medidas de protecção contra explosões todas as medidas que previnam a formação de atmosferas explosivas perigosas, evitam a ignição de atmosferas perigosas, ou reduzem os efeitos de explosões de modo a garantir a segurança e saúde dos trabalhadores.

No caso de equipamentos sob pressão as medidas de técnicas de protecção passam por dimensionar e seleccionar ESP que garantam que (artigo 11º, artigo 12º,artigo 14ª)
- A concentração das substâncias permanecerá dentro dos limites de explosividade;
- Os diversos componentes não potenciem alterações nas substâncias;
- Em caso de ruptura do ESP existam elementos de corte que isolem o sistema e que possuam substâncias capazes de proceder a inertização da substância armazenada.

Para além dos requisitos definidos nas norma jurídicas tem de ser considerados os requisitos definidos nas normas técnicas, nomeadamente as Normas Portuguesas que transpõem as normas harmonizadas no âmbito da Directiva nº94/9/CE, de 23 de Março relativa aos aparelhos e sistemas de protecção destinados a ser utilizados em atmosferas potencialmente explosivas e publicadas no Despacho nº 10501/2004, de 27 de Maio (2ª Série).

4. CONCLUSÃO

Promover uma maior cooperação entre as entidades licenciadoras, os Organismos Notificados, e os operadores por via de inspecções mais rigorosas durante o processo de licenciamento de equipamentos sob pressão, e dar uma maior relevância ao parâmetro segurança durante o dimensionamento geral de equipamentos de acordo com o artigo 21º, ponto 2, onde nos elementos instrutórios definidos na secção 1 do anexo IV, ponto 9 alínea c), passam a ser incluídos os princípios de Segurança e saúde no trabalho e segurança industrial:

c) Segurança e saúde no trabalho e segurança industrial:

i) Estudo de identificação, avaliação e controlo de riscos para a segurança e saúde no trabalho, incluindo:

1) Identificação dos factores de risco internos, designadamente no que se refere a agentes químicos, físicos e biológicos, bem como a perigos de incêndio e de explosão inerentes aos equipamentos ou de produtos armazenados, utilizados ou fabricados, nomeadamente os inflamáveis, os tóxicos ou outros perigosos;

2) Escolha de tecnologias que permitam evitar ou reduzir os riscos decorrentes da utilização de equipamentos ou produtos perigosos;

3) Condições de armazenagem, movimentação e utilização de produtos inflamáveis, tóxicos ou outros perigosos;

4) Descrição das medidas e meios de prevenção de riscos profissionais e protecção de trabalhadores, em matéria de segurança e saúde no trabalho, incluindo os riscos de incêndio e explosão, adoptadas a nível do projecto e as previstas adoptar aquando da instalação, exploração e desactivação;

5) Indicação das principais fontes de emissão de ruído e vibrações e das certificações e sistemas de segurança, das máquinas e equipamentos a instalar;

6) Meios de detecção e alarme das condições anormais de funcionamento susceptíveis de criarem situações de risco;

7) Descrição da forma de organização dos serviços de segurança e saúde no trabalho adoptada, incluindo, nomeadamente:

I) Os procedimentos escritos, tendo em vista reduzir os riscos de acidentes e doenças profissionais e as suas consequências, assim como a prevenir a sua ocorrência;

II) Os meios de intervenção humanos e materiais em caso de acidente;

III) Os meios de socorro internos a instalar e os meios de socorro públicos disponíveis;

ii) Os estabelecimentos abrangidos pela legislação relativa à prevenção dos acidentes graves que envolvam substâncias perigosas devem mencionar as condições que implicam que a instalação seja abrangida pelo Decreto –Lei n.º 254/2007, de 12 de Julho e apresentar, conforme aplicável:

1) Notificação acompanhada da política de prevenção de acidentes graves;

2) Notificação e relatório de segurança, incluindo o sistema de gestão de segurança;

(in Diário da República, 1ª série – nº210 – 29 de Outubro de 2008).

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Guia de Boas práticas

Ferreira, José Martins
Órgãos de Máquinas Vol.1
Departamento de Engenharia mecânica

Apontamentos da disciplina de Segurança: Do Projecto ao Usufruto do Mestrado de Engenharia de Segurança e Higiene Ocupacionais Engenharia da Segurança

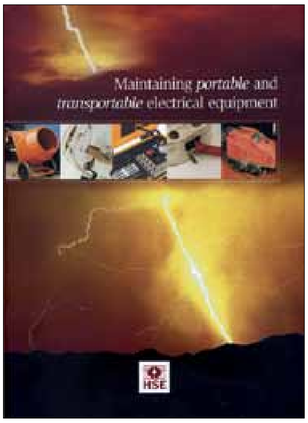
Diplomas legais aplicáveis

Normas Portuguesas

Ferramentas Web:
http://www.dgge.pt/
http://www.apambiente.pt/Paginas/default.aspx
http://www.apambiente.pt/Instrumentos/LicenciamentoAmbiental/Paginas/default.aspx
http://www.min-economia.pt/
http://www.dre.pt/

Health and Safety Executive

Maintaining *portable* and *transportable* electrical equipment



This is a free-to-download, web-friendly version of HSG107 (Second edition, published 2004). This version has been adapted for online use from HSE's current printed version.

You can buy the book at www.hsebooks.co.uk and most good bookshops.

ISBN 978 0 7176 2805 6
Price £7.95

Nearly a quarter of all reportable electrical accidents involve portable or transportable equipment. If you use this type of equipment in your workplace, this book can help you to maintain it in a safe condition and prevent accidents. This new edition contains updated advice, with new sections on cables and repair/replacement.

First published 1994
Second edition 2004

ISBN 978 0 7176 2805 6

This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Contents

Introduction

1 Nearly a quarter of all reportable electrical accidents involve portable equipment. The vast majority of these accidents result in electric shock. This book gives advice on how to maintain portable and transportable electrical equipment safely and avoid such accidents. This new edition contains updated advice, with new sections on cables and repair/replacement.

2 The guidance covers equipment that may be connected to the fixed mains supply, or to a locally generated supply, and could result in an electric shock or burn, or fire due to damage, wear or misuse. It covers electric drills, extension leads, portable handlamps, portable grinders, pressure water cleaners, floor cleaners, electric kettles and similar equipment used in all environments. It also gives advice on what the legal requirements for maintenance can mean in practice.

3 This book should assist employers, employees and the self-employed who use, or have control over, portable or transportable electrical equipment. It describes what action can be taken to maintain the equipment in a safe condition, wherever it is used, and help prevent danger arising. The recommended maintenance strategy is based on a straightforward, inexpensive system of visual inspection that can be undertaken by an employee. The strategy is explained in more detail in paragraphs 37-53. People in control are, however, free to take other action or use alternative control measures that achieve an equivalent standard of safety.

4 In addition to the general principles set out here, more detailed guidance has been produced for offices and other low-risk environments, for the hotel sector, and for construction sites.[1, 2, 3]

5 Portable and transportable electrical equipment should only be used for its intended purpose, and in the environment it was designed and constructed for. Maintenance will not allow safe use of equipment in circumstances it is not intended for, eg using a table lamp as a hand lamp, or equipment that is not waterproof in a wet environment.

Examples of portable and transportable equipment

6 Major items of plant, such as vehicles, cranes and generators, are beyond the scope of this book, as are electromedical equipment and electrostatic spraying equipment, and equipment used below ground in mines, for which there are special requirements.

7 Specialised business equipment, such as computers, printers, photocopiers etc, does not present the same degree of risk as equipment such as electric drills, providing the leads and plugs are protected from mechanical damage or stress. Movement, and therefore damage through being moved, is less likely to occur, and the equipment is often double-insulated and used in a dry, clean environment with non-conducting floors.

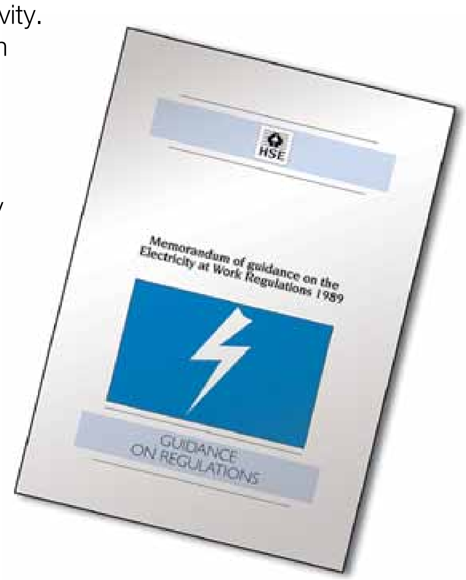
8 Detailed information on inspection and testing of electrical equipment has been produced by the Institution of Electrical Engineers (IEE).[4] This document gives guidance both for those with management responsibility for electrical maintenance, but who may have little technical knowledge, and for those who actually carry out the inspections and tests. The IEE document gives advice and makes recommendations on what may be considered to be 'pass' or 'fail' conditions. In the past there has been an unnecessarily high failure rate for certain types of equipment, often due to insufficient information or knowledge.

Duties under the law

9 There are legal duties on manufacturers and suppliers covering the initial integrity (safety) of new work equipment. There are general duties covering the use and maintenance of work equipment, designed to ensure that it remains in a safe condition. Further details are contained in Appendix 1.

10 The particular legal requirements relating to the use and maintenance of electrical equipment are contained in the Electricity at Work Regulations 1989 (EAW). These Regulations apply to all work activities involving electrical equipment. They place duties on employers, the self-employed and employees (subsequently referred to as duty holders). These duties are intended to control risks arising from the use of electricity.

11 The Regulations are goal-setting, describing safety objectives to be achieved, without prescribing the measures to be taken. This allows the duty holder to select precautions appropriate to the risk rather than having precautions imposed that may not be relevant to a particular work activity.
For further information see the Memorandum of Guidance on the Electricity at Work Regulations 1989 (EAW Memorandum).[5]



12 EAW Regulation 4(2) requires that all systems be maintained, so far as reasonably practicable, to prevent danger. This requirement covers all items of electrical equipment including fixed, portable and transportable equipment. Particular actions that can be taken in order to maintain portable and transportable equipment, and thereby prevent danger, are described in paragraph 34 of this book onwards. The Memorandum also gives guidance on the meaning of 'reasonably practicable'.

Explanation of terms used

Hazard

13 A simple definition of a hazard is anything that can cause harm if things go wrong (eg a fault on equipment).

Risk

14 A simple definition of risk is the chance (large or small) of harm actually being done when things go wrong (eg risk of electric shock from faulty equipment).

Portable and transportable

15 There is no universally accepted definition of what is meant by portable or transportable electrical equipment. However, in this guidance it means equipment that is not part of a fixed installation, but is intended to be connected to a fixed installation, or a generator, by means of a flexible cable and either a plug and socket, or a spur box, or similar means. This includes equipment that is either hand-held or hand-operated while connected to the supply, intended to be moved while connected to the supply, or likely to be moved while connected to the supply. The electrical supply to the equipment is assumed to be at a voltage that can give a fatal electrical shock to a person, ie more than 50 V ac or 120 V dc.

16 Examples of portable equipment include: tools and extension leads in the construction industry (high-risk); grinders and handlamps in general manufacturing (medium-risk); and floor cleaners and metal-bodied kettles in offices (medium-risk). Extension leads, plugs and sockets, and cord sets that supply portable equipment, are classified as portable equipment because they operate in the same environment and are subject to the same use as the equipment they serve.

Note: The word 'portable' is used subsequently to mean both portable and transportable.

Controlling the risk

A pressure washer

17 Failure to maintain the equipment is a major cause of accidents involving portable equipment. The likelihood of accidents occurring and their severity will vary, depending on the type of electrical equipment, the way in which it is used and the environment in which it is used.

18 An example of a high-risk activity is the use of a pressure water cleaner, powered by a 230 V electrical supply, with the cable trailing on the ground where it can be damaged by vehicles and other equipment, and where water is present. Damage to the cable or other parts is likely to expose the operator or others to electric shock.

19 Similar risks result when electrical equipment such as drills or portable grinders are used in a harsh and sometimes wet environment such as at a construction site, where there is a high probability of mechanical damage.

20 Lower risks result from floor cleaners or kettles that are generally used in a more benign environment, eg offices and hotels. But such equipment can still be subject to intensive use and wear. This can eventually lead to faults that can also result in a shock, burns or, more rarely, a fire.

21 Control of risks arising from the use of portable electrical equipment should be based on a risk assessment. Guidance on carrying out a risk assessment is given in paragraphs 56-59. Risks can be managed and controlled by setting up an appropriate maintenance system including the measures referred to in paragraphs 36-53.

22 An electrical accident can lead to a potentially fatal electric shock, or fire affecting the whole premises. The maintenance system should therefore be designed to be proactive, ie planned to prevent incidents arising, rather than reactive, where action is taken following an incident/accident. The measures taken should be appropriate to the risk. Procedures will need to be carried out more frequently where the risk is high, eg on construction sites, and less frequently where the risk is lower, eg in offices.

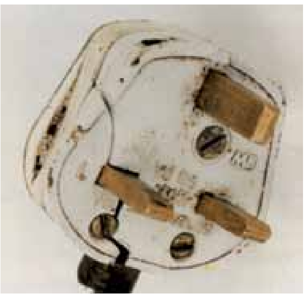
23 Much 'unauthorised' equipment is brought to work by employees (eg electric heaters, kettles, coffee percolators, electric fans). Use of such equipment should be controlled and it may need to be included in the maintenance regime (particularly the formal visual inspection described in paragraphs 41-46) if its use if permitted. Equipment that fails a user check (paragraphs 39-40) or a formal visual inspection should not be used until it is properly repaired.

24 If you are setting up a maintenance regime for the first time, see Table 1 (after paragraph 59) for suggested initial intervals between both formal visual inspections and combined inspections and tests. Duty holders may use the suggested intervals as a starting point, but every situation has to be considered in relation to the type of equipment, its use and its environment. Duty holders may therefore choose intervals that they consider to be appropriate. (The suggested frequencies for inspection and testing given in Table 1 are recommendations and are not legal requirements.)

25 With practical maintenance experience, it may be possible to extend maintenance intervals if few faults are found. However, if faults are common it may be necessary to reduce intervals, or take other action to improve maintenance and reduce risk.

Cable damage

Use of the equipment

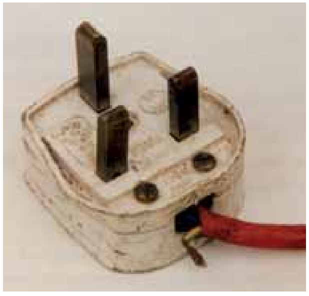


Damaged plug casing

26 Portable equipment and the electrical connections to it (eg the plug and flexible cable and its terminations) are likely to be subjected to, and more vulnerable to, physical damage and wear or harsh treatment in use than equipment which forms part of the fixed installation. The fixed installation is usually provided with a significant degree of protection against damage by the fabric of the building or fixed enclosure. (But the same legal requirements apply to both portable and fixed equipment.)

27 Equipment that is held by hand or handled when switched on will present a greater degree of risk because, if it does develop a dangerous fault, the person holding it will almost certainly receive an electric shock.

Construction of the equipment



Lost earth connection

28 For safety reasons some electrical equipment relies on the metallic (exposed conducting) parts of the equipment being effectively earthed. This type of equipment is known as 'Class I'. If this earth connection is lost there is a possibility of the exterior of the equipment becoming live, with a potentially fatal result. Anyone touching live metal will be in contact with electricity.

29 Another category of electrical equipment, known as 'Class II' (which includes double-insulated equipment marked ⧈), is constructed with high-integrity insulation and does not have or need an earth connection in order to maintain safety.

Cables

Damaged cable

Damaged cable grip

30 The most vulnerable item is often the cable (sometimes called cord or lead) that supplies the equipment. Most portable equipment is supplied by a flexible cable, which is made up of thin, flexible wires covered in insulation and then enclosed in an overall sheath. The cable may deteriorate due to ageing or environmental effects, fail because of repeated flexing, or suffer mechanical damage. The most obvious examples of mechanical damage are being struck or penetrated by objects.

31 Repeated or excessive flexing will eventually cause the conductor to fracture and the sheath to crack. Damage usually occurs first at the cord grip or gland where the cable enters the equipment or its plug. The damage is usually apparent at the user check (see paragraphs 39-40) and should be reported. The cable should be replaced before a dangerous fault develops, such as exposure of conductors, or possibly arcing between broken conductor ends.

32 Some portable equipment (such as floor-polishers, hedge-trimmers, saws and soldering irons) is capable of causing damage to the sheath, or even to the insulation, of its own flexible cable. The cable should be secured in such a way that it does not come into contact with parts that are moving or hot. The users of such equipment should always be on the alert to avoid such damage. If damage does occur they should stop using the equipment and report it.

Environment

33 The risk of receiving an electric shock will be greater when the user of portable electrical equipment is standing on a surface that is a good electrical conductor (such as the ground outside, a concrete floor or on scaffolding) than if they are standing on a wooden floor or dry carpet and not in contact with earthed metal work.

Maintenance

Cracked casing and damaged cable sheath

34 Although a good initial level of safety can be achieved by correct selection and use of equipment and its connectors and cables, lasting safety can only be attained by ongoing and effective maintenance (see paragraphs 36-37). Users should treat their equipment reasonably, including stopping it if defects occur and reporting them.

35 In many cases (eg Class I equipment), the safety of portable electrical equipment depends on the continued integrity of the earthing, and correct connections, of the fixed electrical installation up to and including the socket supplying the equipment. So you should also correctly select, use and maintain the fixed installation, although this is outside the scope of this book - see *Inspection and testing* (Guidance Note 3) from the Institution of Electrical Engineers (IEE)[6] for guidance on inspection and testing of the fixed electrical installation.

36 Maintenance can include visual inspection, testing, repair and replacement. Maintenance will determine whether equipment is fully serviceable or remedial action is necessary. Routine inspection and appropriate testing, where necessary, are normally part of any overall strategy for ensuring that work equipment is maintained in a safe condition.

37 Cost-effective maintenance of portable electric equipment can be achieved by a combination of:

- checks by the user;
- formal visual inspections by a person trained and appointed to carry them out;
- combined inspection and tests by an electrically competent person or by a contractor.

38 Management should follow up these procedures by monitoring the effectiveness of the system and taking action where faults are found, particularly when faults are frequent.

User checks (visual)

Cable damage covered with tape

39 The person using the equipment should be encouraged to look at it critically and check for signs that it may not be in sound condition, for example:

- damage (apart from light scuffing) to the cable sheath;
- damage to the plug, for example the casing is cracking or the pins are bent;
- inadequate joints, including taped joints in the cable;
- the outer sheath of the cable is not effectively secured where it enters the plug or the equipment. Obvious evidence would be if the coloured insulation of the internal cable cores were showing;
- the equipment has been subjected to conditions for which it is not suitable, eg it is wet or excessively contaminated;

- damage to the external casing of the equipment or there are some loose parts or screws;
- evidence of overheating (burn marks or discoloration).

40 These checks also apply to extension leads and associated plugs and sockets. The user should make visual checks when the equipment is taken into use and during use. Any faults should be reported to management and the equipment taken out of use immediately. Management should take effective steps to ensure that the equipment is not used again until it is repaired by a person competent to carry out the task (eg the defective equipment could be labelled as ‘faulty’ and its associated plug removed).

Formal visual inspections

41 The most important component of a maintenance regime is usually the formal visual inspection, carried out routinely by a trained person. Such inspections can pick up most potentially dangerous faults and the maintenance regime should always include this component.

Homemade fuse

Missing screw on earth connection

42 To control the risks and to monitor the user checks, a competent person should carry out regular inspections that include visual checks similar to those in paragraphs 39-40 but undertaken in a more formal and systematic manner. Additional checks could include:

- removing the plug cover and ensuring that a fuse is being used (eg it is a fuse not a piece of wire or a nail etc);
- checking that the cord grip is effective;
- checking that the cable terminations are secure and correct, including an earth where appropriate, and there is no sign of internal damage, overheating or ingress of liquid or foreign matter.

43 The formal visual inspection should not include taking the equipment apart. This should be confined, where necessary, to the combined inspection and testing.

44 The trained person can normally be a member of staff who has sufficient information and knowledge of what to look for, and what is acceptable, and who has been given the task of carrying out the inspection. To avoid danger, trained people should know when the limit of their knowledge and experience has been reached. Simple, written guidance relating to the visual inspection can be produced that summarises what to look for and which procedures to follow when faults are found or when unauthorised equipment is found in use. This guidance can also help equipment users.

45 The formal visual inspections should be carried out at regular intervals. The period between inspections can vary considerably, depending on the type of equipment, the conditions of use and the environment. For example, equipment used on a construction site or in a heavy steel fabrication workshop will need much more frequent inspection than equipment such as floor cleaners in an office. In all cases, however, the period between inspections should be reviewed in the light of experience. Faulty equipment should be taken out of service and not used again until properly repaired. If necessary, it should be tested.

46 The pattern of faults can help management decide what action to take, depending on whether the faults show:

- the wrong equipment is being selected for the job;
- further protection may be necessary in a harsh environment;
- the equipment is being misused.

Combined inspection and tests

47 The checks and inspections outlined in the previous paragraphs will, if carried out properly, reveal most (but not all) potentially dangerous faults. However, some deterioration of the cable, its terminals and the equipment itself can be expected after significant use. Additionally, the equipment itself may be misused or abused to the extent that it can give rise to danger. Some of these faults, such as loss of earth integrity (eg broken earth wire within a flexible cable), or deterioration of insulation integrity, or contamination of internal and external surfaces, cannot be detected by visual inspection alone. Periodic combined inspection and testing is the only reliable way of detecting such faults, and should be carried out to back up the checks and inspection regime. Testing is likely to be justified:

- whenever there is reason to suppose the equipment may be defective (but this cannot be confirmed by visual inspection);
- after any repair, modification or similar work;
- at periods appropriate to the equipment, the manner and frequency of use and the environment.

48 The inspection carried out in conjunction with testing should usually include checking:

- the correct polarity of supply cables;
- correct fusing;
- effective termination of cables and cores;
- that the equipment is suitable for its environment.

49 Such combined inspection and testing requires a greater degree of competence than that required for inspection alone, because the results of the tests may require interpretation and appropriate electrical knowledge will be needed. However, it can often be carried out by a competent employee.

Portable appliance tester (PAT)

50 People carrying out testing of portable electrical equipment should be appropriately trained for this work. It is the employer's duty to ensure that they are competent for the work they are to carry out. Basically, there are two levels of competency.

- The first level is where a person not skilled in electrical work routinely uses a simple 'pass/fail' type of portable appliance tester (PAT), where no interpretation of readings is necessary. The person would need to know how to use the PAT correctly. Providing the appropriate test procedures are rigorously followed and acceptance criteria are clearly defined, this routine can be straightforward.
- The second level is where a person with appropriate electrical skills uses a more sophisticated instrument that gives actual readings requiring interpretation. Such a person would need to be competent through technical knowledge or experience related to the type of work.

51 Some combination of the actions in paragraphs 39-46 should provide the most cost-effective way of ensuring, so far as is reasonably practicable, that equipment will be maintained in a safe condition wherever it is used. The actions in paragraphs 39-43 are relatively simple. The more extensive inspection and testing described in paragraphs 48-50 can be carried out less frequently if the maintenance system includes formal visual inspections and monitoring of the user checks described in paragraphs 39-43.

52 Testing can be carried out at minimal cost where an employee has been trained to a suitable level of competence and provided with appropriate equipment.

Maintenance and test records

53 Although there is no requirement in the EAW Regulations to keep maintenance logs for portable and transportable electrical equipment, the EAW Memorandum[5] does refer to the benefits of recording maintenance, including test results. A suitable log is useful as a management tool for monitoring and reviewing the effectiveness of the maintenance scheme and also to demonstrate that a scheme exists. It can also be used as an inventory of equipment and a check on the use of unauthorised equipment (eg domestic kettles or electric heaters brought to work by employees).

54 The log can include faults found during inspection, which may be a useful indicator of places of use, or types of equipment, that are subject to a higher than average level of wear or damage. This will help monitor whether suitable equipment has been selected. Entries in a test log can also highlight any adverse trends in test readings that may affect the safety of the equipment, thus enabling remedial action to be taken. Be careful when interpreting trends where a subsequent test may be done with a different instrument to that used for an earlier test, as differences in the results may be due to difference in the instruments rather than deterioration in the equipment being tested.

55 Records do not necessarily have to be on a paper system. Test instruments are available that store the data electronically, which can then be downloaded directly onto a computer database. Duty holders with large amounts of equipment will find it useful to label equipment to indicate that the equipment has been tested satisfactorily, ie has been passed as safe, and when the date for the next test is due. Otherwise, individual items may be missed on consecutive occasions.

Frequency of inspection and combined inspection and testing

56 Deciding on the frequency of inspection and testing is a matter of judgement by the duty holder, and should be based on an assessment of risk. This can be undertaken as part of the assessment of risks under the Management of Health and Safety at Work Regulations 1999.[7]

57 Paragraph 59 and Table 1 can help any duty holder decide how often to carry out a formal visual inspection as well as combined inspection and testing, particularly where a maintenance regime has not previously existed. Alternatively, seek advice from a competent person who has the knowledge and experience to make the necessary judgement, eg manufacturers or suppliers of equipment, or relevant trade associations.

58 Factors to consider when making the assessment include the following:

- type of equipment and whether it is hand-held or not;
- manufacturer's recommendations;
- initial integrity and soundness of equipment;
- age of the equipment;
- working environment in which the equipment is used (eg wet or dusty) or likelihood of mechanical damage;
- frequency of use and the duty cycle
- of the equipment;
- foreseeable abuse of the equipment;
- effects of any modifications or repairs to the equipment;
- analysis of previous records of maintenance, including both formal inspection and combined inspection and testing.

59 Table 1 sets out the suggested frequency of formal visual inspections and combined inspections and electrical tests for portable and transportable electrical equipment. It gives suggested starting intervals when implementing a maintenance programme. Where one figure is given, this is a guide for anticipated average use conditions; more demanding conditions of use will require more frequent formal visual inspections, and/or combined inspections and tests. Where a range is shown, the small interval is for more demanding conditions of use and the longer interval is for less demanding ones. It is up to the duty holder, with appropriate advice where necessary, to assess the conditions affecting equipment, which may lead to potential damage and/or deterioration and should determine the maintenance regime.

Table 1 Suggested initial maintenance intervals

Type of business	**User checks**	**Formal visual inspection**	**Combined inspection and test**
Equipment hire	N/A	Before issue/after return	Before issue
Construction (For indication only. See *Electrical safety on construction sites*[3] for more detail)	110 V – Weekly 230 V mains – Daily/every shift	110 V – Monthly 230 V mains – Weekly	110 V – Before first use on site then 3-monthly 230 V mains – Before first use on site then monthly
Light industrial	Yes	Before initial use then 6-monthly	6 – 12 months
Heavy industrial/high risk of equipment damage	Daily	Weekly	6 – 12 months
Office information technology, eg desktop computers, photocopiers, fax machines	No	1 – 2 years	None if double-insulated, otherwise up to 5 years
Double-insulated equipment ***not*** hand-held, eg fans, table lamps	No	2 – 3 years	No
Hand-held, double-insulated (Class II) equipment, eg some floor cleaners, kitchen equipment and irons	Yes	6 months – 1 year	No
Earthed (Class I) equipment, eg electric kettles, some floor cleaners	Yes	6 months – 1 year	1 – 2 years
Equipment used by the public, eg in hotels	By member of staff	3 months	1 year
Cables and plugs, extension leads	Yes	1 year	2 years

60 In premises where portable electrical equipment is used by the public, and where a duty holder does not have direct control over the way it is used, formal visual inspection may need to be done much more frequently. This should be determined by knowledge of the likely risks, and subsequently modified in the light of experience.

61 In many premises, eg in the health service, or in education, hotels and offices, more than one inspection and test regime may apply to different types of equipment. Some transportable electrical equipment may be less susceptible to mechanical damage, eg a table lamp in an office, which is supplied from a plug and socket and is rarely handled or moved. In a relatively benign environment, these conditions can be described as similar to those for fixed installations and the need

for examination and test set accordingly, for example in their guidance[6] the IEE recommend every five years for business and commercial premises.

62 However, these conditions do not apply to all office equipment. Some frequently used items (floor cleaners, kettles, free-standing electric heaters etc), which may be likely to suffer abuse and damage, would need to be inspected and tested more frequently, until results can be studied and failure rates analysed.

63 After the first few formal visual inspections, the information obtained can be used to give an indication as to the intervals before further inspections are carried out. The same is true for combined inspection/testing. A low failure rate would indicate that the interval can be increased and a high failure rate that the interval should be shortened; see paragraphs 53-55 on record keeping.

Repair and replacement

64 The repair of most portable electrical equipment requires specialist knowledge and expertise if the faulty or damaged equipment is to be restored to the necessary safe condition. It is often more cost-effective to replace cheaper items than to repair them. Similarly, it is better to replace than to repair faulty or damaged plugs, connectors and flexible cables.

65 Where flexible cables have been in use for a long time, it is better to replace rather than repair them because conductor wires, insulation and sheathing materials deteriorate. Replacement of relatively short lengths of unsatisfactory cable is usually cheaper than carrying out repairs.

66 Where longer lengths of cable are involved, if the damaged part is close to one end, cut it off. If the damage is not near one end, after removing the damaged section, you can join the healthy sections by using a proprietary cable coupler. If a coupler is used, the socket part should be on the section fed from the electricity supply side and the plug part should be on the cable connected to the equipment.

Appendix 1

Legal requirements

1 The initial integrity (safety) of new work equipment when first supplied is covered by:

- section 6 of the Health and Safety at Work etc Act 1974,[8] which requires *'any person who designs, manufactures, imports or supplies any article for use at work or any article of fairground equipment:*
  (i) to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health at all times when it is being set, used cleaned or maintained by a person at work;
  (ii) to take such steps as are necessary to secure that persons supplied by that person with the article are provided with adequate information about the use for which the article is designed or has been tested and about any conditions necessary to ensure that it will be safe and without risks to health at all such times as are mentioned in paragraph (i) above and when it is being dismantled or disposed of …';
- the Electrical Equipment (Safety) Regulations 1994,[9] which require certain safety objectives to be met, including design and construction to assure protection against hazards arising from the electrical equipment, and protection against hazards that may be caused by external influences on the electrical equipment;
- the Supply of Machinery (Safety) (Amendment) Regulations 1994,[10] which contain a general requirement for protection against electrical hazards.

2 The general duties covering the use and maintenance of work equipment in addition to the Electricity at Work Regulations 1989[5] are contained in:

- section 2 of the Health and Safety at Work etc Act 1974, which requires *'the provision and maintenance of plant … so far as is reasonably practicable safe…';*
- the Management of Health and Safety at Work Regulations 1999,[7] which require an employer to make *'a suitable and sufficient assessment of the risks to health and safety of employees … for the purposes of identifying the measures he needs to take to comply with the requirements … imposed upon him … under other relevant law'.* Such a risk assessment should include risks arising from the use of electrical equipment;
- the Provision and Use of Work Equipment Regulations 1998,[11] which require the employer (person in control) to select suitable work equipment (regulation 5) and to *'ensure that work equipment is maintained in an efficient state, in efficient working order and in good repair'.*

Appendix 2

Summary

You can use this summary to check whether you are managing the risks from portable electrical equipment effectively.

- Set up a system of maintenance for portable (and transportable) electrical equipment.

- Identify which portable electrical equipment needs to be maintained and find out where it is used and how. Decide what to do about 'unauthorised equipment' brought in by employees.

- Provide straightforward training and information for all users (including yourself) to help carry out user checks.

- Set up a formal visual inspection system and train someone to carry this out.

- Consider producing brief, written guidance on the formal visual inspection, what to look for and procedures to follow when faults are found and when unauthorised equipment is in use.

- Decide on the appropriate frequency for formal visual inspection. If records of formal visual inspections are kept, the findings can be reviewed and the records used to help you decide how frequently these inspections should be carried out.

- Assign someone to test equipment that:
  - is suspected of being defective (but this cannot be determined by visual examination), has been repaired or modified;
  - is due for a combined inspection and test (or has never had one at the start of a maintenance regime).

- Ensure that the person carrying out combined inspection and testing has sufficient knowledge, training and experience as well as access to further information and advice where necessary.

- Decide on an appropriate frequency for combined inspection and testing where this is necessary.

- Review records of test results and use these to decide on how frequently you should carry out combined inspections and tests.

- Monitor all the arrangements and ensure that follow-up action is carried out, including a review of the frequency of formal visual inspection.

References

1 *Maintaining portable electrical equipment in hotels and tourist accommodation* Leaflet INDG237 HSE Books 1996 (single copy free or priced packs of 10 ISBN 0 7176 1273 2)

2 *Maintaining portable electrical equipment in offices and other low-risk environments* Leaflet INDG236 HSE Books 1996 (single copy free or priced packs of 10 ISBN 0 7176 1272 4)

3 *Electrical safety on construction sites* HSG141 HSE Books 1995 ISBN 0 7176 1000 4

4 *Code of practice for the in-service inspection and testing of electrical equipment* Institution of Electrical Engineers (IEE) 2001 ISBN 0 85 296776 4

5 *Memorandum of guidance on the Electricity at Work Regulations 1989* HSR25 HSE Books 1989 ISBN 0 7176 1602 9

6 *Inspection and testing* Guidance Note 3 Institution of Electrical Engineers (IEE) 2002 ISBN 0 85 296991 0

7 *Management of health and safety at work. Management of Health and Safety at Work Regulations 1999. Approved Code of Practice and guidance* L21 (Second edition) HSE Books 2000 ISBN 0 7176 2488 9

8 *Health and Safety at Work etc Act 1974 Ch37* The Stationery Office 1974 ISBN 0 10 543774 3

9 *Electrical Equipment (Safety) Regulations 1994* SI 1994/3260 The Stationery Office 1994 ISBN 0 11 043917 1

10 *Supply of Machinery (Safety) (Amendment) Regulations 1994* SI 1994/2063 The Stationery Office 1994 ISBN 0 11 045063 9

11 *Safe use of work equipment. Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and guidance* L22 (Second edition) HSE Books 1998 ISBN 0 7176 1626 6

Further information

IEE publications

These are available from
The Institution of Electrical Engineers (IEE),
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E-mail: sales@iee.org.uk

The Stationery Office publications

The Stationery Office publications are available from The Stationery Office, PO Box 29, Norwich NR3 1GN Tel: 0870 600 5522 Fax: 0870 600 5533 e-mail: customer.services@tso.co.uk Website: www.tso.co.uk (They are also available from bookshops.) Statutory Instruments can be viewed free of charge at www.opsi.gov.uk.

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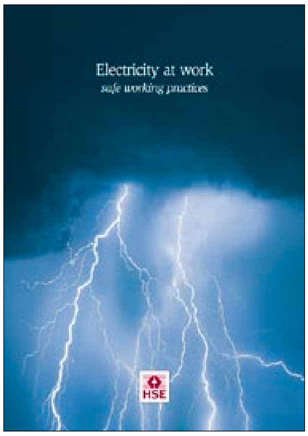
Health and Safety
Executive

Electricity at work

Safe working practices



This is a free-to-download, web-friendly version of HSG85 (Second edition, published 2007). This version has been adapted for online use from HSE's current printed version.

You can buy the book at www.hsebooks.co.uk and most good bookshops.

ISBN 978 0 7176 2164 4
Price £7.95

This second edition of HSG85 gives guidance on the key elements that need to be considered when devising safe working practices for people who carry out work on or near electrical equipment. It includes advice that is relevant to managers and supervisors who control or influence the design, specification, selection, installation, commissioning, maintenance or operation of electrical equipment. The first edition was published in 1993 and this new version updates the guidance and provides sources of further information.

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This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Contents

Introduction

1 This book gives guidance on devising safe working practices for people who carry out work on or near electrical equipment. It includes advice that is relevant to managers and supervisors who control or influence the design, specification, selection, installation, commissioning, maintenance or operation of electrical equipment. Some organisations will already have industry-specific rules or guidance for safe working practices but they should ensure that all aspects addressed in this book are adequately covered. Other organisations will have no such internal guidance and will need to apply the principles contained in this book and devise safe working practices relating to their own specific circumstances and activities.

2 The *Electricity at Work Regulations 1989* (EAW Regulations)[1] apply to almost all places of work. The Memorandum of guidance on the Electricity at Work Regulations 1989[2] (the Memorandum) is intended to help duty holders meet the requirements of the Regulations. This guidance supplements the Memorandum with further advice on safe working practices. Where regulation numbers are quoted, they refer to the EAW Regulations. Regulations 17 to 28 and Schedule 1 apply specific duties in relation to mines. There are also two Approved Codes of Practice covering the use of electricity at mines and quarries that provide additional guidance relevant to those industries.[3, 4] Other legislation can also apply to electrical work and this is listed in the 'References' or 'Further reading' sections, as are all other publications referred to in the book.

Definitions

3 In this book, unless the context otherwise requires, the following words and terms have meanings as given below:

charged: the item has acquired a charge either because it is live or because it has become charged by other means such as by static or induction charging, or has retained or regained a charge due to capacitance effects even though it may be disconnected from the rest of the system;

dead: not electrically 'live' or 'charged';

designated competent person: a person appointed by the employer, preferably in writing, to undertake certain specific responsibilities and duties, which may include the issue of permits-to-work. The person must be competent by way of training and qualifications and/or experience;

disconnected: equipment (or a part of an electrical system) that is not connected to any source of electrical energy;

equipment: for this book this means 'electrical equipment' and includes anything used, intended to be used or installed for use, to generate, provide, transmit, transform, rectify, convert, conduct, distribute, control, store, measure or use electrical energy (as defined in the EAW Regulations);

high voltage: this is defined in national and international standards as being in excess of 1000 V ac or 1500 V dc. However, historically, certain precautions have been applied in the UK to systems energised at more than 650 V ac. To maintain the same degree of safety this guidance uses the term 'high voltage' where the voltage exceeds 650 V ac;

isolated: equipment (or part of an electrical system) which is disconnected and separated by a safe distance (the isolating gap) from all sources of electrical energy in such a way that the disconnection is secure, ie it cannot be re-energised accidentally or inadvertently;

live: equipment that is at a voltage by being connected to a source of electricity. This implies that, unless otherwise stated, the live parts are exposed so that they can be touched either directly or indirectly by means of some conducting object and that they are either live at a dangerous energy level or dangerous potential, ie over 50 V ac or 120 V dc in dry conditions - see BSI publication PD 6519;[5]

live work: work on or near conductors that are accessible and 'live' or 'charged'.

Hazards

4 Each year about 20 people die from electric shock or electric burns at work and about 30 die from electrical accidents in the home. Most of these accidents are preventable and this book is intended to help you avoid such accidents. Many people have had an electric shock at some time or another without lasting injury but this does not demonstrate an immunity, merely the unpredictable nature of the risk. Slightly different circumstances could have resulted in death. If the victims of electric shock do not die, they usually recover very quickly unless there are other injuries (such as burns) or consequential injuries such as strained muscles from sudden contraction during the shock or injuries from, for example, falling as a result of the shock.

5 Electric shock is not the only hazard. Where electrical arcing occurs, perhaps as a result of accidental short circuit, the heat generated can be intense and, even if it persists for only a very short time, it can cause deep-seated and slow-healing burns. Engineers and craftsmen often fail to appreciate the very real risk of injury that can arise from arcing. As a result, there are several hundred serious burn accidents each year arising from unsafe working practices. The intense ultraviolet radiation from an electric arc can also cause damage to the eyes.

6 Arcing, overheating and, in some cases, electrical leakage currents can cause fire or explosion by igniting flammable materials. This can cause death, injury and considerable financial loss.

7 Most electrical accidents occur because people are working on or near equipment that is:

- thought to be dead but which is live;
- known to be live but those involved do not have adequate training or appropriate equipment, or they have not taken adequate precautions.

Equipment

8 In general, equipment that has been properly designed, constructed, installed and maintained does not present a risk of electric shock or burn injury when properly used. BS 7671 *Requirements for electrical installations*,[6] although non-statutory, is a code of good engineering practice and makes requirements for

systems and equipment to be designed, constructed and installed so that they can be used safely. The standard mainly covers systems and equipment that operate at low voltage (up to 1000 V ac). Installations that comply with this Standard are likely to achieve conformity with the relevant parts of the EAW Regulations.

9 Some equipment, not designed to prevent injury from shock or burn, relies on the user having sufficient knowledge and experience to recognise the danger and avoid it. This equipment (including open-type switchboards and fuseboards used by electricity suppliers and steelworks etc for distribution) should be located in a secure room or area, with access available only to those who have specific authority and are competent in relation to the danger. Even then, the open-type board will need to be further protected to prevent accidental contact when competent persons are near the equipment. (See paragraph 14 for the need to insulate parts of control panels.) Regulation 14 specifies the requirements when working on or near live parts and regulation 15 and Appendix 3 of the Memorandum relate to working space, access and lighting requirements.

10 Some equipment operates at voltages that are so low that they cannot give an electric shock but, even at these extra-low voltages, an arc can occur or burns can result from overheated conductors. A good example of this is a short-circuited car battery that may cause the conductors to overheat or even explode. The following advice is also applicable to self-contained sources of electrical energy, whether the risk is from electric shock, burn or arcing.

11 Equipment should be suitable for the environment in which it is used, for example cables and equipment in heavy industries such as sheet metal works need to be protected against mechanical damage (regulation 6). Adverse environmental factors should always be considered when work is to be carried out on equipment. For example, excessively damp or humid conditions will increase the risk of injury because of a reduction in the effectiveness of insulation and may also undermine the effectiveness of devices used for isolation. Such conditions would also increase the severity should an electrical shock occur. Equipment that has corroded may not function as intended.

12 There may be a need for certified explosion-protected equipment in locations where there could be potentially explosive atmospheres, for example if there has been a leakage of flammable gas that could be ignited by an electric spark. This shows the need for careful assessment of the situation before work is carried out on or near equipment. It must be remembered that the act of working on equipment may result in removal of components and parts that provide protection for people against electric shock when the equipment is in normal use.

13 Much can be done to improve operational safety by the careful design and selection of electrical equipment. For example, switch disconnectors must have a locking off facility or other means of securing them in the OFF position to meet the requirements of regulation 12. Circuits and equipment should be installed so that all sections of the system can be isolated as necessary. Switch disconnectors should be suitably located and arranged so that circuits and equipment can be isolated without disconnecting other circuits that are required to continue in service.

14 Control panels should be designed with insulated conductors and shrouded terminals (regulation 7) so that commissioning tests, fault-finding, calibration etc can be carried out with a minimum of risk. The Engineering Equipment and Materials Users Association (EEMUA) have produced a design guide for electrical safety7 in this respect. The use of interlocking is recommended to reduce the risk of injury from contact with live parts. Equipment in which power and control circuits are segregated is preferred.

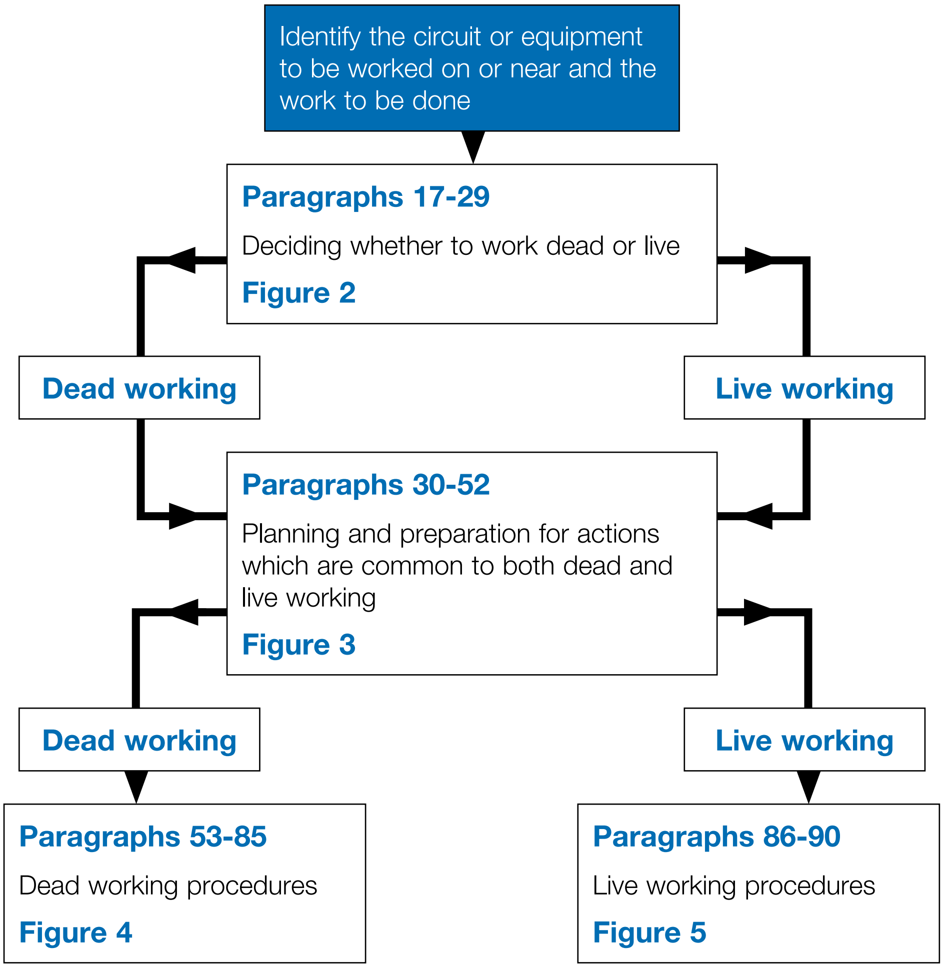
15 Sometimes live working during commissioning and fault-finding can be avoided if suitably designed equipment having in-built test facilities and diagnostic aids is provided. Regulation 15 requires that there should be adequate space, access and lighting to work safely. Temporary systems and equipment should be designed, constructed, installed and maintained to comply with the Regulations and with suitable Standards including, where appropriate, BS 7671 *Requirements for electrical installations*. The Institution of Electrical Engineers (IEE) produce a series of guidance notes that provide advice in addition to that given in BS 7671, some of which relates to electrical safety. (See 'Sources of further information' for IEE's address and telephone number.)

Assessing safe working practices

16 Figure 1 illustrates the sequence of the planning steps. The procedure can be divided into four stages as follows:

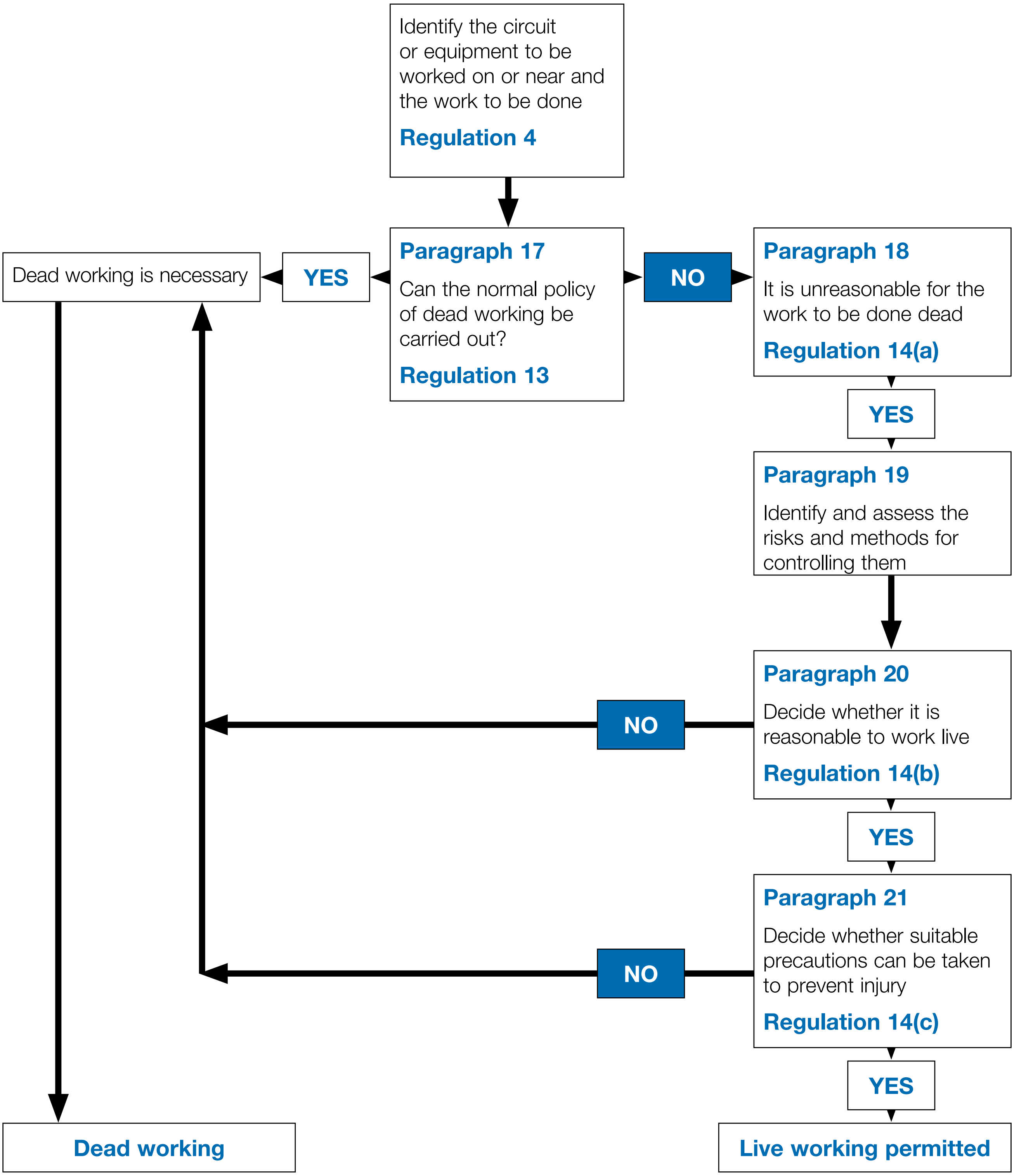
- deciding whether to work dead or work live (coloured yellow);
- planning and preparation for actions which are common to both dead and live working (coloured blue);
- procedures for working dead (coloured green);
- procedures for working live (coloured red).

Figure 1 Basic flow chart for assessing safe working practices



Deciding whether to work dead or live

Figure 2 Deciding to work dead or live



Can the normal policy of dead working be carried out?

17 Work on or near live conductors should rarely be permitted (regulation 14). Many accidents to electricians, technicians and electrical engineers occur when they are working on equipment that could have been isolated. In most cases, adequate planning and work programming will allow such jobs to be carried out as the Regulations require, ie with the equipment dead. Regulation 14 requires that three conditions are met for live working to be permitted where danger may arise. It is stressed that if just one of those conditions cannot be met, live working cannot be permitted and dead working is necessary. The assessment procedure illustrates this. The conditions are:

- it is unreasonable in all the circumstances for the conductor to be dead; and
- it is reasonable in all the circumstances for the person to be at work on or near that conductor while it is live; and
- suitable precautions (including, where necessary, the provision of personal protective equipment) have been taken to prevent injury.

It is unreasonable for the work to be done dead

18 There are some circumstances where it is unreasonable to make equipment dead because of the difficulties it would cause (regulation 14(a)). For example, it may be difficult, if not impossible, to commission a complex control cabinet without having it energised at some time with parts live (but not exposed so that they may be easily touched). Also it may not be realistic to monitor the operation and performance of a control system or to trace a malfunction of such equipment with it dead, ie fault-finding. Another example is the situation of a Distribution Network Operator (DNO) (formerly known as a Regional Electricity Company (REC)) who needs to connect a new low-voltage service to an existing main, but it might be unreasonable to disconnect many other customers. In recognition of the dangers associated with live working, the DNO needs to have a very strict code of safety rules and procedures to prevent injury.

Identify and assess the risks and methods for controlling them

19 At this stage some form of risk assessment is necessary. This will usually be qualitative but it should be applied to the specific equipment to be worked on or near. The assessment indicated in this box on Figure 2 pre-empts to some extent the requirements of other boxes in Figures 3, 4 and 5, particularly those dealing with regulations 4(3), 4(4), 14(c) and 16. The person carrying out the assessment etc should have extensive knowledge and experience of the factors to consider and of the competence of the people who will be carrying out the work and of their ability to avoid danger.

Decide whether it is reasonable to work live

20 On completion of the preceding stage it is now appropriate for managers and supervisors to judge whether it is reasonable in all circumstances to work live (regulation 14(b)). The decision should not be taken lightly. At this stage the economic and operational factors should be evaluated against the risks involved before making a decision, bearing in mind that the shock or burn risks associated with working live can be very serious.

Decide whether suitable precautions can be taken to prevent injury

21 Providing the other requirements of regulation 14 have been met, live working can still only be justified if suitable precautions are taken to prevent injury arising from risks identified in the assessment (regulation 14(c)). All of the factors covered in paragraphs 22-29 should be taken into account.

22 The possibility of anyone touching parts at dangerously different potentials at the same time should be avoided by installing temporary insulation or protective barriers. This may mean putting temporary insulating screens over live parts and/or applying insulation to parts that are at earth potential. Temporary screens etc can also help to prevent the risk of accidental short circuit from tools, components, conductors etc.

23 When work is to be carried out 'near' rather than 'on' live equipment (eg near an overhead line), the essential precautions will often be directed towards ensuring that appropriate and adequate safety clearances are established and maintained. For more detailed advice, see HSE Guidance Note GS6 *Avoidance of danger from overhead electric powerlines*.[8]

24 The people doing the work must be adequately trained and experienced in the type of live work being undertaken (regulation 16). They should understand the task and be able to recognise any deterioration in the state of equipment or departures from agreed procedures. They should have the self-discipline to recognise their own limitations and should be encouraged to seek assistance with work that may be outside their area of competence.

25 There must be adequate working space and adequate lighting (regulation 15). There should be adequate headroom, no tripping hazards and no obstructions that could restrict a person's movements. Where there are exposed parts live at 400 V ac the recommended minimum clear working space should not be less than 3 ft or 915 mm measured from the live part. If there are live parts exposed on each side of the working space the minimum recommended clearance should not be less than 4 ft 6 ins or 1375 mm, although this situation should be avoided whenever possible, eg by screening.

26 Only properly insulated tools should be used (see BS EN 60900[9]). They should have insulation that is robust enough to be proof against mechanical damage (regulation 14(c)). These tools should be inspected frequently by a suitably competent person. They should be destroyed if the insulation is damaged. Test instruments should have insulated probes and fused leads (see HSE Guidance Note GS38 *Electrical test equipment for use by electricians*[10]).

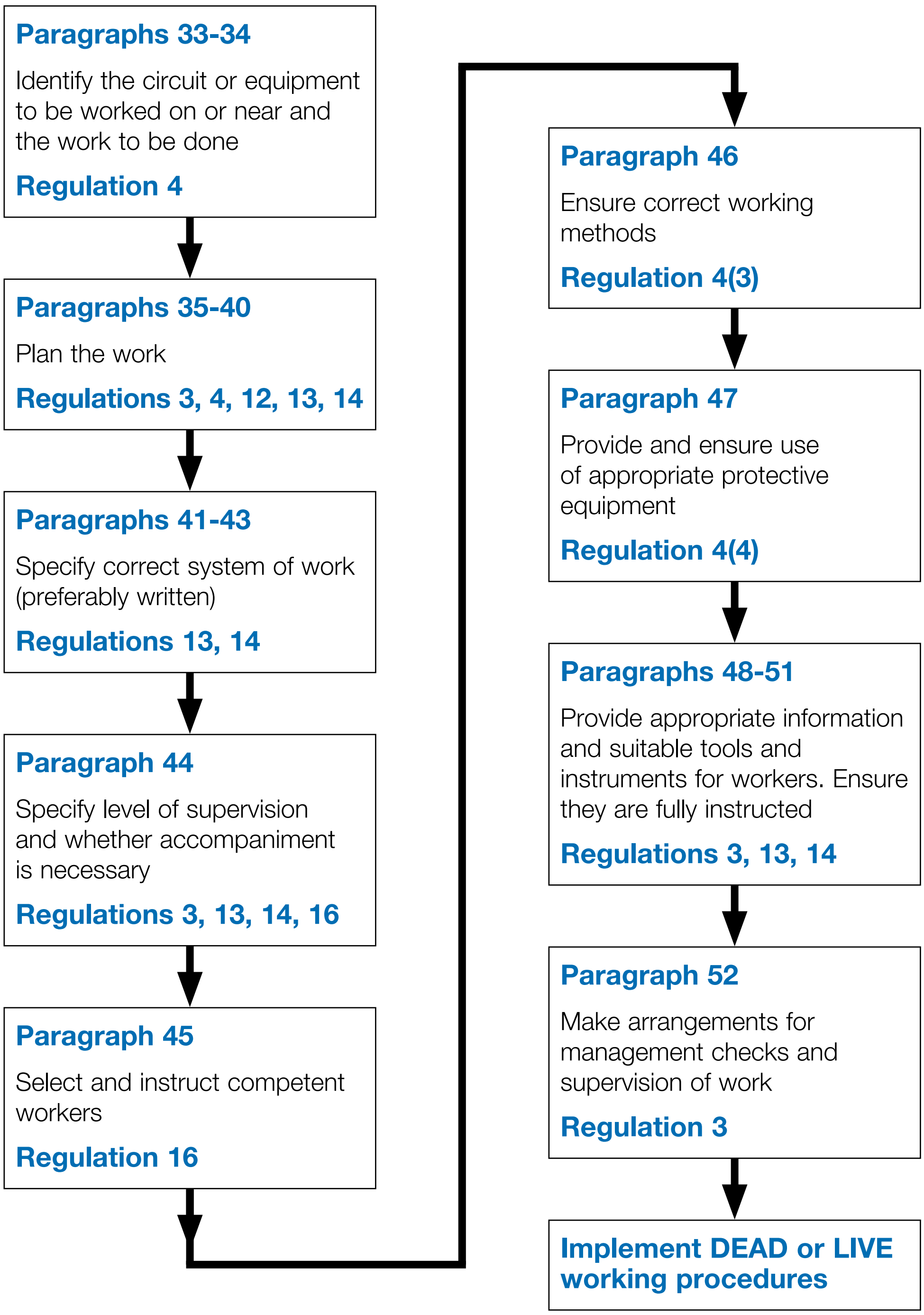
27 Protective clothing and equipment should be provided and used as required by regulation 4(4) where this would reduce the risk of contact with live parts or earth. For example, a cable joiner will need insulating gloves and insulating rubber matting to BS 921.[11] Such equipment should be inspected frequently by a person who is competent to assess its condition.

28 Horizontal surfaces and projections inside control cabinets etc should not be used for temporary storage of tools and other equipment.

29 Experience has shown that rapid action can save life in the event of electric shock. A person working on live parts should normally be accompanied by someone who is in a safe position, who has the necessary competence to avoid injury, who can help by disconnecting the supply and who can render first aid or obtain assistance in the event of an emergency.

Actions common to both dead and live working

Figure 3 Planning and preparation for actions which are common to both dead and live working



Actions for managers and supervisors

30 Both managers and supervisors should be involved at the first stage since this is where, in most cases, major responsibility for safe working practices lies. In some cases management and supervision may be carried out by the same person and there may be cases where the worker has to carry out these two functions. There may be some routine jobs covered by a management policy, but the details may not be discussed before each job is done. Where a business employs a contractor, the division of responsibilities requires careful definition, in advance of the work being done.

31 The supervision of electrical work must be appropriate to the danger and the technical knowledge or experience of the people doing the work (regulation 16). Supervisors should be knowledgeable about the general principles of electrical safety and their duties and responsibilities should be defined in writing by their employers. The supervisor should discuss the intended work with the participants, ensuring that they clearly understand the precautions that are to be taken.

32 If there is more than one group at work, the supervisor should co-ordinate the activities of the various groups and there should be a recognised procedure for referring any problems that may arise to the supervisor. Everyone involved should also be clear about what is to be done if something goes wrong. It is essential that for group activities one person should be given overall supervisory responsibility and everyone involved should know who that person is.

Identify the circuit or equipment to be worked on or near and the work that needs to be done

33 Much time and trouble can be saved by carrying out these actions in advance of the work being done. Factors that may affect the safe system of work should also be taken into account. In many cases actual physical identification will be necessary and this may be aided by the use of appropriate drawings, diagrams and other written information. The features of equipment mentioned in paragraphs 8 to 15 should be taken into account.

34 When the equipment and work to be done has been identified, it is necessary to decide whether to work dead or work live, although it must be stressed that working dead should be the norm because the three conditions which have to be met to permit working live, as set out in regulation 14, are very strict. This procedure is discussed in more detail in paragraphs 17 to 29. Irrespective of whether it has been decided to work dead or live, the common steps in paragraphs 35 to 52 should always be followed.

Plan the work

35 Many electrical accidents are due to failure to plan ahead. Safe working practices rely on clearly thought-out systems of work, carried through by adequately competent and trained personnel who are self-disciplined and aware of their own limitations. Recklessness with electricity can lead to injury, death and criminal charges.

36 To plan and execute electrical work safely, there should be adequate information available about the electrical system and the work to be done. In the case of a newly constructed electrical system (or newly installed equipment), there should be drawings and schedules relating to the design and these should have been updated, if necessary, by the people carrying out the installation.

37 Records in the form of drawings and/or schedules should be kept for all but the most basic of installations. In the case of old installations where records may be poor, some measures should be taken to improve the records for the installation. Such measures would involve a combination of surveying, testing and labelling of the installation. However, when checking records before working on an installation it is unwise to rely solely on one source of information, eg a label. All equipment should be labelled as necessary for it, and its function, to be properly identified.

38 Planning should include the management, supervision and execution of the work and should lead to a formal system of work, as is discussed further in paragraphs 41-43. It is necessary to plan work, even for seemingly simple jobs, both in advance and while the work progresses. Planning is most important since it requires a disciplined way of thinking by the person in charge of the work and demands that five important factors are considered:

- the work to be done;
- the hazards of the system or equipment to be worked on;
- the people doing the work and the level of supervision necessary;
- the precautions to be taken; and
- the system of work to be employed.

39 A job may have been planned but the nature of the work may change as the job progresses. When planning work properly it should be recognised that some decisions may not be possible until part-way through the job, eg a testing job may turn into a fault-finding situation. The plan should recognise this and cover the possibilities. The worker should then be in a position to recognise the changed circumstances and that it may be necessary to stop and review the situation with the person in charge of the work.

40 Some electrical accidents occur during fault-finding after a plant breakdown, when pressure for continued operation or production could result in electricians taking risks. To anticipate this, a plan should be established for proper fault-finding procedures that are always implemented during breakdown maintenance.

Specify correct system of work

41 There should be a system of rules and procedures wherever electrical work is to be carried out. These should be in written form so that everybody involved is made aware of them. The amount of detail depends on the circumstances; the simplest form may be a brief policy statement (perhaps reflecting a policy of always switching off, working dead and never working on live equipment) backed up by a set of simple instructions to reflect that policy. Where there are extensive or complex electrical systems this will be reflected in the safety rules, which should embody a methodical approach so that the safety principles involved can be clearly understood and avoid ambiguity.

42 Safety rules should set out the principles and general practices clearly and in a format that is compact enough for the people involved to carry around with them. Detailed procedures for safe working on particular items of equipment, or under particular circumstances, should be the subject of separate documents, which should be readily available when required (even in out-of-hours emergencies). This book does not contain a sample set of safety rules because they should be devised to reflect, among other things, the relevant organisation, personnel and working environment. However, guidance can be obtained from three British Standards – BS 6423,[12] BS 6626[13] and BS 6867.[14]

43 If something totally unforeseen occurs during the working procedure, there should be a review of the work. Even a properly trained, competent worker may not always be aware of what to do when things go wrong. The worker should have been trained to recognise that there may be a need to change to a new system of work. It will normally be necessary for the worker to know how to refer a changed situation to the correct people, by communicating both up and down the management structure in the organisation.

Specify level of supervision and whether accompaniment is necessary

44 The system of work (paragraphs 41-43) will give an indication of the level of supervision required. An important factor to consider at this stage is the amount of training and experience workers have had to do the specific jobs. There will be a greater need for supervision when working live as opposed to working dead. The need for accompaniment is also greater for live work, although it may still be necessary for some cases of working dead, especially if there are adjacent live parts. See also paragraphs 29 and 90.

Select and instruct competent workers

45 It is important to remember that the degree of competence of individual workers should be judged against the specific type of work to be done and related to their knowledge, training and experience. The instructions should also be specific to each job and in many cases will require emphasis on and elaboration of the safe system of work. Where workers are expected to carry out a broad range of work, which may involve additional responsibilities, additional training should be given. The need for training to make a person competent is very important. Even the most highly qualified people may not be competent to carry out specific types of work without suitable training. It is usually necessary to accompany people during training.

Ensure correct working methods

46 Workers should understand the correct working methods, again related to the specific work in hand. It is necessary for the people doing the work to be aware of the limits of the work they are to do and the constraints put upon them in how they carry out the work. This includes knowing how to deal with any contingencies that may arise.

Provide and ensure use of appropriate protective equipment

47 It is an absolute requirement of regulation 4(4) that any protective equipment provided for people at work on or near electrical equipment must meet the following three requirements, these duties being placed on managers, supervisors and workers as necessary. It must be:

- suitable for the use for which it is provided;
- maintained in a condition suitable for that use; and
- used properly.

Provide information, tools and instruments and ensure workers are fully instructed

48 If a job has been planned properly, the worker will be supplied with and will use correct and appropriate information, tools, instruments, safety equipment and instructions. Appropriate information includes drawings and diagrams of the equipment or circuit, as well as manufacturer's and installer's information and instructions. Appropriate tools may include suitably insulated tools which have been maintained in good condition and which have been regularly inspected and tested.

49 Before working on equipment made dead (regulation 13), the conductors should be proved dead. The instrument to do this should be properly constructed to protect against electric shock and designed to prevent short circuits occurring during use. Adequate insulation and fusing or energy limitation are essential. Proprietary voltage detectors should be used. It will be necessary to test the instrument before and after use. This may be done by means of a proving unit with a low power output. If live circuits are used to prove instruments, adequate precautions against electric shock and short circuits should be taken (see paragraphs 18 and 21-29).

50 Training in the correct use of voltage detectors is essential to avoid risk in the event of unexpected use on a live conductor. Where underground cables cannot be positively identified at the point of work, it may be necessary to spike the cable using a properly designed, cartridge-operated spiking gun. For low voltages, detectors, such as two-pole voltage detectors, proprietary test lamps, or voltmeters with insulated probes and fused leads can be used (see HSE Guidance Note GS38 *Electrical test equipment for use by electricians*). The use of multimeters, which can be set to the wrong function, is not recommended for proving dead. All instruments used for checking circuits should be maintained and inspected frequently.

51 This is usually the stage at which the worker is about to approach the equipment or circuit to be worked on, or to start switching operations, so a final check that the worker understands the system of work and work to be done should be made. If there is more than one worker, the understanding of the team leader should be checked and the team members should understand that only the work given them by the team leader should be undertaken. On no account should team members carry out work on their own initiative.

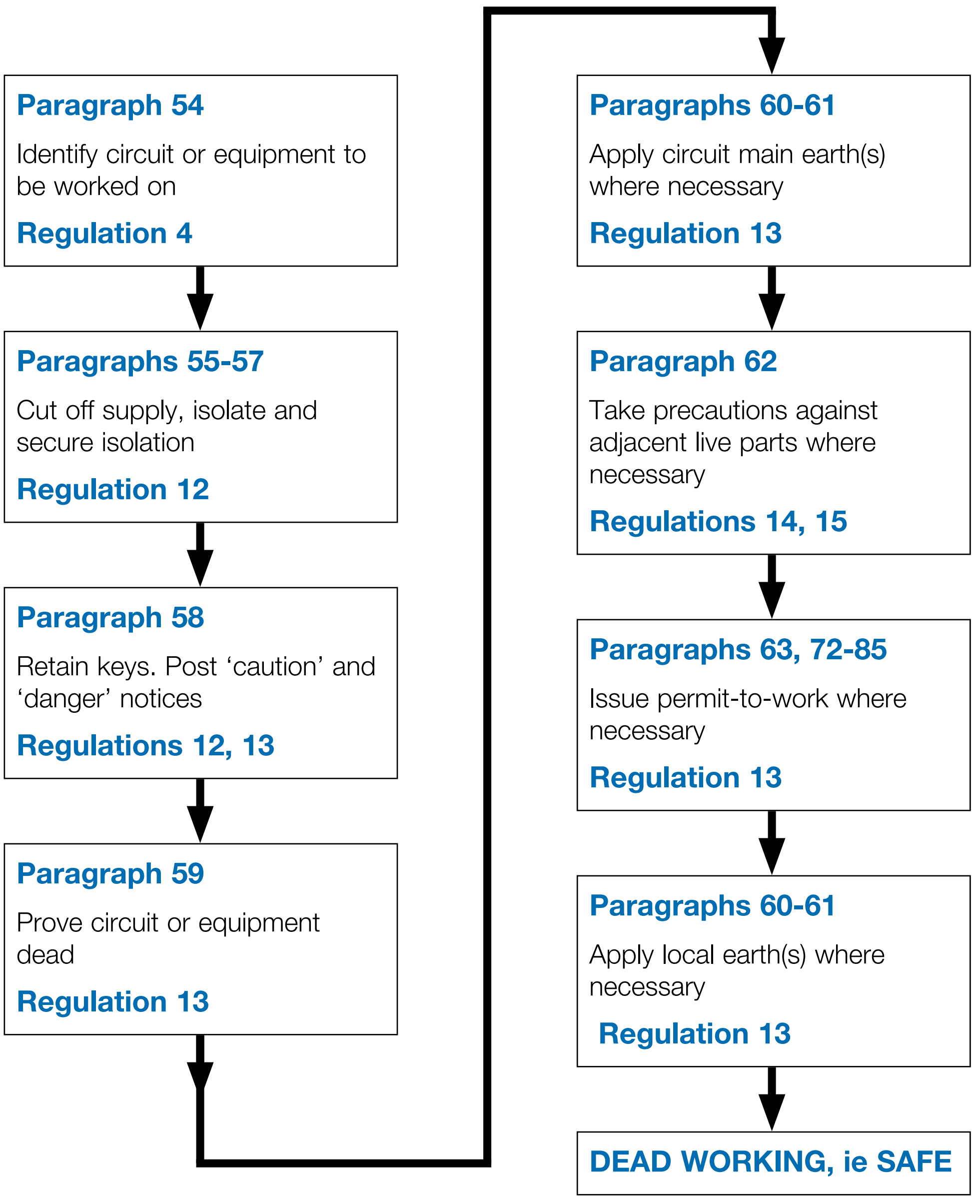
Make arrangements for management checks and supervision of work

52 Regulation 3(1) requires that employers comply with the Regulations in so far as they relate to matters within their control, and regulation 3(2) places similar duties on employees. The only effective way of management knowing that the Regulations are being complied with is by carrying out regular checks of the work. Sometimes, some or all of these checks may be delegated to the supervisor of the work. Even in organisations with effective, written safety rules and safe systems of work, regular and systematic management checks of the work are necessary. This is particularly important if the work is being done in the field, on another occupier's premises or by peripatetic workers.

Working dead

53 While it is not always possible to rigidly follow a set procedure in every situation, the following sequence is recommended as a guide.

Figure 4 Dead working procedures



Identification

54 Adequate information should be supplied for this step as mentioned in paragraphs 33-34. For most circuits and equipment correct labelling is important, but it should never be assumed that labelling is correct and that work can be started without having first proved that the equipment or circuit is dead. In some special cases, eg underground cables, cable-locating techniques using specialised instruments may be necessary and it may also be necessary to identify the cable both before and after switching operations and cable spiking.

Disconnection

55 Disconnect the equipment from every source of electrical energy before working on, or near, any part which has been live or is likely to be live (regulation 12). To ensure safety after disconnection the procedure in paragraphs 56-62 should be followed.

Secure isolation

56 To ensure adequate isolation, the disconnecting device should have an isolating gap sufficient for the voltage levels present or likely to occur. Make sure that any switch disconnector or other means of disconnection is secure (regulation 13). Switches should preferably be locked in the OFF position using a 'safety' lock, ie a lock having a unique key. If a plug has been withdrawn, make sure that it cannot be reconnected to the electrical supply while work is taking place on the circuits or apparatus. If a fuse is removed, make sure that it or a similar one cannot be reinserted by taking it away or by locking the box or enclosure until work is completed.

57 Some manufacturers produce insulating blanks that can be inserted in an empty fuseway and are capable of being locked. This prevents inadvertent insertion of a fuse while the associated circuit is being worked on. If reliance is placed on locking off where a number of people are working, the use of a multiple locking hasp attachment may be appropriate to ensure that all the locks are removed before the equipment can be re-energised.

Post notices

58 Put a notice or label at the place of disconnection so everyone else knows that work is being done. A good system is to use a 'caution' notice to indicate that someone is working on the apparatus and may be injured if it is re-energised. This should be supplemented by 'danger' notices adjacent to the place of work indicating nearby apparatus that is still energised. Notices or labels should be easily understandable to anyone in the area. It is also important to remove labels or notices when they no longer apply so that the system does not fall into disrepute. It is often useful for the 'caution' and 'danger' notices to have a space for the name of the person working or in charge and for the date. All keys should be retained in a secure place.

Proving dead

59 Having isolated the circuit or equipment, check at the point of work that the parts to be worked on or near really are dead, even if the isolation has been achieved automatically through an interlocking system. If it is a three-phase system or equipment with more than one supply, prove that all supply conductors are dead. The device used for proving dead should itself be proved immediately before and after testing. See paragraphs 49-50 for information on suitable devices.

Earthing

60 To ensure that the risk to personnel is minimised, even if the above precautions fail, it is preferable that all the conductors are earthed using properly designed earthing devices or earthing leads, usually applied to all points where the circuit or equipment is isolated from the supply. Additional local earths at the point of work may also be necessary if this is remote from the point of isolation, but these should be applied only after proving dead at the point of work. This procedure is essential

for high-voltage apparatus (see paragraphs 66-67) and stored energy equipment (eg capacitors). The earthing conductors and their connections should be suitable for the energy that may flow in the event of a failure of the above precautions.

61 Earthing low-voltage equipment is particularly desirable if there is a risk of re-energisation, eg from a generator under someone else's control (regulation 13). In other low-voltage equipment, however, it may be physically impractical to apply earths, or the risk of short circuit from introducing an earth near adjacent live parts may outweigh the benefit of earthing the apparatus being worked on.

Adjacent parts

62 When the circuit or equipment to be worked on has been made dead or where the work is non-electrical, it may still be necessary to protect against inadvertent contact with other live parts nearby (regulation 14). This should preferably be done by erecting physical barriers and/or the use of temporary insulation. The requirements of regulation 15 regarding adequate working space, access and lighting should also be met.

Additional procedures

63 On the high-voltage systems (and often on high-energy systems) a permit-to-work should be issued but only after all the actions described in paragraphs 54-62 have been carried out. (See paragraphs 72-85 for more information on permit-to-work systems.)

Extra precautions for high-voltage work

64 The following paragraphs (relating to regulations 12 and 13) apply particularly to equipment and circuits operating at high voltage. However, there are many installations where the same procedures should be used at lower voltages, for example if the available short-circuit power is such as to give rise to a risk of serious burn injuries. Conversely, there are a few exceptional circumstances where high voltages will not give rise to danger, for example if the maximum possible current is reliably limited to a safe level (see PD 6519 Parts 1 and 2).

65 High-voltage equipment should be designed and installed so that it is not necessary to work on exposed live parts. However, allowance has to be made for carrying out potential checks or tests, and also for observation from safe distances such as when phasing out.

66 Because high voltages can arc across an air gap, it is not necessary to touch live voltage parts to suffer a shock or burns. The procedure outlined in paragraphs 54-63 should be strictly applied. The isolation should be by means of a device that has a safe isolating gap between live parts and those that have been made dead for work to be carried out (see relevant British Standards). Earthing of conductors at the point of disconnection of the supply is essential and additional earths may be necessary at the place of work.

67 The system of locking OFF while work is in progress should use safety locks which have unique keys so that the apparatus cannot be inadvertently re-energised. The keys should be retained in a key safe or other suitable place available only to the person in charge of the activity. The precautions should be backed up with a disciplined documentation system; the permit-to-work is an established system that has proved to work well in practice and is detailed in paragraphs 72-85.

68 There are some situations where additional procedures will be necessary to cover adequately shift changes or work extending over long periods. It may also be necessary to have special rules or procedures for particular items of equipment and for particular working practices such as testing (eg it may be necessary to remove earths to facilitate testing under a clearly defined sanction-to-test procedure).

69 Precautions must be taken to prevent people approaching dangerously close to high-voltage conductors. This will normally mean that any work on high-voltage equipment is undertaken only after all the precautions set out in paragraphs 64-68 have been taken. There are, however, some special situations where, by the use of appropriate tools, apparatus and precautions, work on live, high-voltage conductors may be permissible while the people involved are at a safe distance. Two examples are work on overhead conductors by DNOs or work on railways using long, specially designed, insulated tools.

70 A more recent development is live, hands-on working on both electricity transmission and distribution overhead conductors. For this latter work, special vehicles, work equipment, tools, clothing etc, together with exacting working methods, are necessary to ensure safe working. For all the special situations referred to, work procedures need to be specially devised and a very high degree of training and discipline are essential for everyone involved. These special situations are not within the scope of this document.

71 Similar procedures may also be necessary if high-voltage apparatus is to be tested. In every case, the objective is to prevent anyone coming near to live, high-voltage conductors and the procedure should reflect this.

Permits-to-work

72 A typical example of a permit-to-work form is given in Appendix 1. Further information is available in BS 6626 and BS 6867. An electrical permit-to-work is primarily a statement that a circuit or item of equipment is safe to work on. A permit should never be issued on equipment that is still live. The information given in the permit should be precise, detailed and accurate. It should state which equipment etc has been made safe, the steps by which this safety has been achieved and exactly what work is to be done.

73 In no circumstances should anyone be allowed to work on equipment that is not specified in the permit as having been made safe. This restriction should be understood to apply to everyone in the premises, including directors and senior staff. No one is too important to comply with safety rules and no one should do any work that is not specified in the permit.

74 If it is found that a programme of work must be changed, no variation of any kind should be introduced until after the existing permit has been cancelled and a new one issued. The only person who has the authority to agree the change in programme and issue the new permit-to-work is either the person who issued the original permit or the person nominated by management to take over the responsibility, eg at the end of a shift or during absence on leave.

75 A permit-to-work should be issued by only a designated competent person (see paragraph 3) who is deemed to be so by means of technical knowledge and/or experience and who is familiar with the system and equipment. The person should be authorised, in writing, by the employer to issue permits relating to specified equipment or systems. Before issuing the permit, this person should work out, in detail and in writing, what the various steps are to disconnect, isolate, prove

dead, lock OFF and earth the equipment, post warning notices and identify the equipment to be worked on and adjacent equipment which will still be live.

76 The permit-to-work should state clearly:

- the person the permit is addressed to, ie the leader of the group or working party, who will be present throughout the work;
- the exact equipment which has been made dead and its precise location;
- the points of isolation;
- where the conductors are earthed;
- where warning notices are posted and special safety locks fitted;
- the nature of the work to be carried out;
- the presence of any other source of hazard, with cross-reference to other relevant permits;
- further precautions to be taken during the course of the work.

77 In most cases it is preferable to include a diagram on, or attached to, the permit confirming the above information and showing the zone for work.

78 It is strongly recommended that the permit is issued at the place where the work is being done. The designated competent person issuing the permit should explain the work and agree the accuracy and completeness of the details with the person doing the work before they both sign the permit. The person issuing the permit should be sure that all necessary action has been taken to make the equipment safe. As a general rule, a personal inspection should be made but in geographically very large undertakings, such as the electricity supply industry, it may occasionally be necessary to make an exception to this.

79 In cases where some degree of divided responsibility may arise, for instance between the DNO and the duty holder at the customer's premises, the permit-to-work form should be countersigned by a person nominated in the joint ownership schedule and by the duty holder for the premises. Another example is where contractors may need to work on an occupier's system or equipment. In this case the duty holder at the premises needs to take particular care to define responsibilities, in advance of the work being done and any permit-to-work being issued, to ensure that there is no confusion over divided responsibilities.

80 The person who accepts the permit (ie the person who is in immediate charge of the operation) becomes, from that moment, responsible for ensuring that all the specified safety precautions are adhered to, that only permitted work is done and that this is confined to the area defined in the permit. If the permit is issued to the leader of a group, the leader accepts responsibility for people in the group.

81 If the person issuing the permit will also be doing the work, it is strongly recommended that another person should make an independent check of the precautions taken. The person doing the work should then issue a permit to himself/herself. This routine helps to ensure that the full safety procedure is applied. The self-discipline is vitally important.

82 The recipient of a permit-to-work should keep it for reference while the work is in progress and to prevent inadvertent cancellation and re-energisation of the equipment.

83 When the work is complete, whoever the permit clearance was issued to should sign it to declare that any additional earths and tools have been removed and people in the group have been withdrawn and instructed not to approach the equipment again. The person clearing the permit should also indicate whether or not the equipment is fit for service. The permit is then returned, preferably to the

designated competent person who originally issued it, for cancellation before the equipment is re-energised.

84 To reduce the scope for misunderstanding when work is suspended, it is always preferable that the original permit is cancelled and a new one is issued when required. The suspension of permits-to-work is not generally recommended. Where, however, the practice is essential it will be necessary to have a written procedure to ensure that tools and additional local earths are withdrawn and everyone is aware that the permit has been suspended.

85 Any permit-to-work system should also have an additional procedure for monitoring (audit) to ensure that the safety rules are followed and the documents are completed accurately. The monitoring should preferably be carried out by someone with managerial responsibilities, who is not involved in the day-to-day issuing of permits and should be random and ongoing so that bad habits and inaccuracies can be identified and eliminated quickly.

Working live

Figure 5 Live working procedures

Identify the circuit or equipment to be worked on or near and the work to be done

Regulation 4

↓

Paragraph 88

Ensure suitable precautions are taken and that suitable protective equipment is used

Regulations 4(4), 14(c)

↓

Paragraph 89

Ensure adequate working space, access and lighting. Restrict access to area of live work

Regulations 14, 15

↓

Paragraph 90

Ensure accompaniment is provided if necessary. Accompaniment to be trained to give assistance

Regulations 3, 14, 16

↓

LIVE WORKING, ie
INJURY TO BE PREVENTED

86 For the purposes of this guidance live working is generally restricted to:

- work on live, high-voltage equipment that is, for all practical purposes, limited to diagnostic testing (apart from certain specialised work by DNOs);
- work on live, low-voltage conductors that is for all practical industrial purposes limited to diagnostic testing, eg voltage measurement (apart from certain specialised work by DNOs);
- work near live, low- or high-voltage conductors that requires the rigorous precautions described in this guidance.

87 While it is not always possible to follow rigidly a set procedure to cover all situations, the following criteria should be met.

Take precautions and use protective equipment

88 The requirements of regulation 4(4) and regulation 14(c) have to be met and these have already been mentioned in paragraphs 22-29. The use of suitably insulated tools has been covered in paragraphs 26 and 48. Instruments and voltage detectors have been covered in paragraphs 49 and 50 and further information can be found in HSE Guidance Note GS38 *Electrical test equipment for use by electricians*. Some of the precautions necessary for live, high-voltage work have been covered in paragraphs 69-71. Advice on work near overhead lines is given in Guidance Note GS6 and on avoiding danger from underground cables in guidance booklet HSG47 *Avoiding danger from underground services*.[15]

Provide adequate working space, access and lighting and restrict other access

89 The requirements of regulation 15 are mentioned in paragraph 25 and Appendix 3 of the Memorandum should be referred to for more detailed information on working space. Further details on lighting at work can be found in guidance booklet HSG38 *Lighting at work*.[16] When working live, it is important to prevent non-authorised personnel from encroaching on the area of live work. To ensure control of the area, it is often necessary to provide some form of effective enclosures or barriers to prevent access to the live work area by people not involved with the work. Warning notices should be fixed to the enclosures or barriers.

Accompaniment

90 This is often necessary for working live, especially if an accompanying person can substantially contribute towards the implementation of safe working practice. If the risk is one of electric shock, evidence shows that prompt first aid is a significant factor in survival. The accompanying person should be trained to recognise danger, how to switch off and, if necessary, to give assistance in the event of an emergency. Help can also be given in restricting access to non-authorised personnel. In addition, a less experienced worker may need to be supervised to enable the work to be carried out safely.

Appendix 1:

Typical example of a permit-to-work

1 Issue:

To ______________________________________ in charge of this work.

I hereby declare that the following high-voltage apparatus in the area specified is dead, isolated from all live conductors and is connected to earth:

____
____
____

Treat all other apparatus and areas as dangerous

The apparatus is efficiently connected to EARTH at the following points:

____
____
____

The points of isolation are:

____
____
____

CAUTION NOTICES have been posted at the following points:

____
____
____

SAFETY LOCKS have been fitted at the following points:

____
____
____

The following work is to be carried out:

____
____
____

Diagram

Signed ________________________________ Time _______ Date ________

Permit-to-work (front)

2 Receipt:

I accept responsibility for carrying out the work on the apparatus detailed on this permit-to-work and no attempt will be made by me or by people under my charge to work on any other apparatus or in any other area.

Signed ____________________________________ Time _______ Date _________

Note: After signing the receipt, this permit-to-work should be retained by the person in charge at the place where the work is being carried out until work is complete and the clearance section is signed.

3 Clearance

The work for which this permit-to-work was issued is now suspended*/completed* and all people under my charge have been withdrawn and warned that it is no longer safe to work on the apparatus detailed on this permit-to-work.

All work equipment, tools, test instruments etc have been removed.

Additional earths have been removed.

*Delete words not applicable and where appropriate state:

The work is complete*/incomplete* as follows:

____

____

____

Signed ____________________________________ Time _______ Date _________

4 Cancellation

This permit-to-work is cancelled.

Signed ____________________________________ Time _______ Date _________

Permit-to-work (back)

References

1 *Electricity at Work Regulations 1989* SI 1989/635 The Stationery Office 1989

2 *Memorandum of guidance on the Electricity at Work Regulations 1989. Guidance on Regulations* HSR25 (Second edition) HSE Books 2007 ISBN 978 0 7176 6228 9

3 *The use of electricity in mines. Electricity at Work Regulations 1989. Approved Code of Practice* L128 HSE Books 2001 ISBN 978 0 7176 2074 6

4 *The use of electricity at quarries. Electricity at Work Regulations 1989. Approved Code of Practice* COP35 HSE Books 1989 ISBN 978 0 11 885484 9 (Withdrawn)

5 PD 6519-2:1988 *Guide to effects of current on human beings and livestock. Special aspects relating to human beings* British Standards Institution (IEC 60479 Part 2)

DD IEC/TS 60479-1:2005 *Effects of current on human beings and livestock. General aspects* British Standards Institution

6 BS 7671:2001 *Requirements for electrical installations. IEE Wiring Regulations. Sixteenth edition* British Standards Institution Available from the Institution of Electrical Engineers (IEE)

7 *A design guide for the electrical safety of instruments, instrument/control panels and control systems* Engineering Equipment and Materials Users Association (EEMUA) 1994 ISBN 0 85931 080 9

8 *Avoidance of danger from overhead electric powerlines* General Guidance Note GS6 (Third edition) HSE Books 1997 ISBN 978 0 7176 1348 9

9 BS EN 60900:2004 *Liveworking. Hand tools for use up to 1000 V ac and 1500 V dc* British Standards Institution

10 *Electrical test equipment for use by electricians* General Guidance Note GS38 (Third edition) HSE Books 1995 ISBN 978 0 7176 0845 4

11 BS 921:1976 *Specification. Rubber mats for electrical purposes* British Standards Institution

12 BS 6423:1983 *Code of practice for maintenance of electrical switchgear and controlgear for voltages up to and including 1 kV* British Standards Institution

13 BS 6626:1985 *Code of practice for maintenance of electrical switchgear and controlgear for voltages above 1 kV and up to and including 36 kV*

14 BS 6867:1987 *Code of practice for maintenance of electrical switchgear for voltages above 36 kV*

15 *Avoiding danger from underground services* HSG47 (Second edition) HSE Books 2000 ISBN 978 0 7176 1744 9

16 *Lighting at work* HSG38 (Second edition) HSE Books 1997 ISBN 978 0 7176 1232 1

Further reading

HSE publications

Management of health and safety at work. Management of Health and Safety at Work Regulations 1999. Approved Code of Practice and guidance L21 (Second edition) HSE Books 2000 ISBN 978 0 7176 2488 1

Safe use of work equipment. Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and guidance L22 (Second edition) HSE Books 1998 ISBN 978 0 7176 1626 8

Personal protective equipment at work. Personal Protective Equipment at Work Regulations 1992 (as amended). Guidance on Regulations L25 HSE Books 2005 ISBN 978 0 7176 6139 8

Electrical safety on construction sites HSG141 HSE Books 1995 ISBN 978 0 7176 1000 6

Electrical safety at places of entertainment General Guidance Note GS50 (Second editon) HSE Books 1997 ISBN 978 0 7176 1387 8

Electrical risks from steam/water pressure cleaners Plant and Machinery Guidance Note PM29 (Second edition) HSE Books 1995 ISBN 978 0 7176 0813 3

Maintaining portable and transportable electrical equipment HSG107 (Second edition) HSE Books 2004 ISBN 978 0 7176 2805 6

Selection and use of electric handlamps Plant and Machinery Guidance Note PM38 (Second edition) HSE Books 1992 ISBN 978 0 11 886360 5

Electrical safety in arc welding HSG118 HSE Books 1994 ISBN 978 0 7176 0704 4

British Standards

BS EN 50281 Parts 1, 2 and 3 *Electrical apparatus for use in the presence of combustible dust* British Standards Institution

BS EN 60079 Parts 10, 14, 17, 19 *Electrical apparatus for explosive gas atmospheres* British Standards Institution

BS EN 60903:2003 *Liveworking. Gloves of insulating material* British Standards Institution

BS 7375:1996 *Code of practice for distribution of electricity on construction and building sites* British Standards Institution

Further information

Engineering Equipment and Materials Users Association (EEMUA)
10-12 Lovat Lane, London EC3R 8DN
Tel: 020 7621 0011 Fax: 020 7621 0022

The Institution of Engineering and Technology
Michael Faraday House, Stevenage, Herts SG1 2AY
Tel: 01438 313 311 Fax: 01438 765 526

For information about health and safety ring HSE's Infoline Tel: 0845 345 0055 Fax: 0845 408 9566 Textphone: 0845 408 9577 e-mail: hse.infoline@natbrit.com or write to HSE Information Services, Caerphilly Business Park, Caerphilly CF83 3GG.

HSE priced and free publications can be viewed online or ordered from www.hse.gov.uk or contact HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA Tel: 01787 881165 Fax: 01787 313995. HSE priced publications are also available from bookshops.

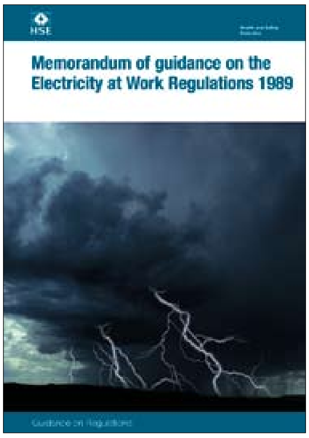
British Standards can be obtained in PDF or hard copy formats from the BSI online shop: www.bsigroup.com/Shop or by contacting BSI Customer Services for hard copies only Tel: 020 8996 9001 e-mail: cservices@bsigroup.com.

The Stationery Office publications are available from The Stationery Office, PO Box 29, Norwich NR3 1GN Tel: 0870 600 5522 Fax: 0870 600 5533 e-mail: customer.services@tso.co.uk Website: www.tso.co.uk (They are also available from bookshops.) Statutory Instruments can be viewed free of charge at www.opsi.gov.uk.

Published by HSE 09/09

Memorandum of guidance on the Electricity at Work Regulations 1989

Guidance on Regulations



This is a free-to-download, web-friendly version of HSR25, (Second edition, published 2007). This version has been adapted for online use from HSE's current printed version.

You can buy the book at www.hsebooks.co.uk and most good bookshops.

ISBN 978 0 7176 6228 9
Price £11.95

This new edition of HSR25 is intended to help dutyholders meet the requirements of the Electricity at Work Regulations 1989. It will be of interest and practical help to all dutyholders, particularly engineers (including those involved in the design, construction, operation or maintenance of electrical systems), technicians and their managers. It sets out the Regulations and gives technical and legal guidance on them except as they apply to mines and quarries (there is separate guidance for this). The purpose of this Memorandum is to highlight the nature of the precautions in general terms to help in the achievement of high standards of electrical safety in compliance with the duties imposed. The book also contains references to HSE guidance and advice and codes of practice from other standards-making bodies and trade associations.

First published 1989
Second edition 2007
Reprinted 2009

ISBN 978 0 7176 6228 9

This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Contents

Foreword

This book is one of two that set out the Electricity at Work Regulations 1989 and give guidance on them. The other book relates specifically to mines.

This book is relevant to all work activities and premises except mines and quarries, certain offshore installations and certain ships.

This second edition updates references to relevant regulations, standards and publications. It replaces references to the Institution of Electrical Engineers' (IEE) Wiring Regulations with British Standard BS 7671.

After the *Introduction*, the text of each regulation is given in italics followed by guidance on that regulation. Regulations 17 to 28 (which apply to mines only) are omitted as are parts of regulation 2 which interpret terms found only in regulations 17 to 28.

Introduction

1 The Electricity at Work Regulations 1989 (SI 1989/635) (as amended) (the Regulations)* came into force on 1 April 1990. The purpose of the Regulations is to require precautions to be taken against the risk of death or personal injury from electricity in work activities. The text of the Regulations, which includes those parts relevant to the mining industries, is available from The Stationery Office.

2 The Regulations are made under the Health and Safety at Work etc Act 1974 (HSW Act). The HSW Act imposes duties principally on employers, the self-employed and on employees, including certain classes of trainees. The Regulations impose duties on people (referred to in this Memorandum as 'dutyholders') in respect of **systems**, **electrical equipment** and **conductors**, and in respect of work activities on or near electrical equipment. (The words in **bold** are defined in regulation 2.) The duties are in addition to those imposed by the HSW Act.

3 The guidance is intended to assist these dutyholders in meeting the requirements of the Regulations. It will be of interest and practical help primarily to engineers (including those involved in the design, construction, operation or maintenance of electrical systems and equipment), technicians and their managers. It sets out the Regulations and gives technical and legal guidance on the Regulations except as they apply to mines or quarries. While it reflects the Health and Safety Executive's (HSE's) view of the meaning of terms used in the Regulations only the Courts can provide a binding interpretation. The purpose of this Memorandum is to amplify the nature of the precautions in general terms so as to help in the achievement of high standards of electrical safety in compliance with the duties imposed. However, for detailed advice reference must be made elsewhere and some relevant sources of information available at the time of writing are made throughout the Memorandum.

4 When those who design, construct, operate or maintain electrical installations and equipment need advice they should refer to appropriate guidance, such as may be found in national, international, reputable foreign and harmonised or industry standards and codes of practice or HSE guidance, or they should seek expert advice. Only those who have both the knowledge and the experience to make the right judgements and decisions and the necessary skill and ability to carry them into effect should undertake work subject to these Regulations. A little knowledge is often sufficient to make electrical equipment function but a much higher level of knowledge and experience is usually needed to ensure safety.

5 Because the Regulations state principles of electrical safety in a form which may be applied to any electrical equipment and any work activity having a bearing on electrical safety, they apply to all *electrical systems* and equipment (as defined) whenever manufactured, purchased, installed or taken into use even if its manufacture or installation pre-dates the Regulations. Where electrical equipment pre-dates the Regulations this does not of itself mean that the continued use of the equipment would be in contravention of the Regulations. For example, much of the equipment to which the Regulations apply may have been made to a standard, such as a British Standard, which has since been modified or superseded. It is likely to be reasonably practicable to replace it with equipment made to a more recent standard when, but only when, it becomes unsafe or falls due for replacement for other than safety reasons, whichever occurs sooner. Equally, fixed installations to which BS 7671 is relevant may have been installed in accordance with an earlier edition, now superseded but then current; that, in itself, does not mean that the installation does not comply with the 1989 Regulations.

* *As they apply to places of work other than mines and quarries.*

6 Advice on the application of the Regulations in particular circumstances can be obtained from local offices of the appropriate Inspectorate.

British Standard BS 7671 Requirements for Electrical Installations (also known as the IEE Wiring Regulations)

7 The British Standard BS 7671 *Requirements for Electrical Installations* is also known as the IEE Wiring Regulations* – they are non-statutory regulations. They 'relate principally to the design, selection, erection, inspection and testing of electrical installations, whether permanent or temporary, in and about buildings generally and to agricultural and horticultural premises, construction sites and caravans and their sites'. BS 7671 is a code of practice which is widely recognised and accepted in the UK and compliance with it is likely to achieve compliance with relevant aspects of the 1989 Regulations.

8 There are however many types of system, equipment and hazard to which BS 7671 is not applicable; for example, certain installations at mines and quarries, equipment on vehicles, systems for public electricity supply and explosion protection. Furthermore, BS 7671 applies only to installations operating at up to 1000 volts ac or 1500 volts dc.

9 Installations to which BS 7671 is relevant may have been installed in accordance with an earlier edition, now superseded but then current. That, in itself, would not mean that the installation would fail to comply with the 1989 Regulations.

* *Obtainable from the Institution of Engineering and Technology, Michael Faraday House, 6 Hills Way, Stevenage, Herts, SG1 2AY.*

Other, Statutory Regulations

10 The Electricity Safety, Quality and Continuity Regulations 2002 (SI 2002/2665) (as amended) impose requirements regarding the installation and use of electric lines and apparatus of suppliers of electricity, including provisions for connections with earth. The safety aspects of these Regulations are administered by HSE; the remainder are administered by the Department of Energy and Climate Change. The Electricity Safety, Quality and Continuity Regulations may impose requirements which are in addition to those of the Electricity at Work Regulations.

Other sources of guidance

11 Guidance notes and other publications issued by HSE from time to time give detailed advice on such matters as design of certain equipment, safe working practices, maintenance and repair of equipment, and installation practice for particular environments. A list of some of these is given in Appendix 1.

12 There exist many codes of practice written by standards-making authorities, trade associations and other bodies setting out standards and procedures applicable to particular industries, processes or hazards. Such codes may provide useful, detailed expansion of the guidance given in this book but it must be borne in mind how and by whom these codes have been drawn up. A list of some of these is given in Appendix 2.

European Directives

13 Purchasers and users of electrical equipment should be aware that Member States of the EU, and enforcing authorities such as HSE within Member States, are obliged* to accept for health and safety purposes equipment which conforms to certain Directives made under Article 100 of the Treaty of Rome. Further information about these Directives can be obtained from HSE.

* *Subject to a procedure for appeal.*

Regulation

1

Regulation 1 Citation and commencement

These Regulations may be cited as the Electricity at Work Regulations 1989 and shall come into force on 1st April 1990.

Regulation

2

Regulation 2 Interpretation

(1) In these Regulations, unless the context otherwise requires -

*"circuit conductor" means any **conductor** in a **system** which is intended to carry electric current in normal conditions, or to be energised in normal conditions, and includes a combined neutral and earth **conductor**, but does not include a conductor provided solely to perform a protective function by connection to earth or other reference point;*

*"conductor" means a **conductor** of electrical energy;*

*"danger" means risk of **injury**;*

"electrical equipment" includes anything used, intended to be used or installed for use, to generate, provide, transmit, transform, rectify, convert, conduct, distribute, control, store, measure or use electrical energy;

"injury" means death or personal injury from electric shock, electric burn, electrical explosion or arcing, or from fire or explosion initiated by electrical energy, where any such death or injury is associated with the generation, provision, transmission, transformation, rectification, conversion, conduction, distribution, control, storage, measurement or use of electrical energy;

*"system" means an electrical system in which all the **electrical equipment** is, or may be, electrically connected to a common source of electrical energy, and includes such source and such equipment.*

Guidance

2

14 Words and phrases which are in **bold** type in the text of the regulation preceding the guidance on each regulation are those which have been assigned a special meaning by being defined in regulation 2.

Systems

15 The term 'system' includes all the constituent parts of a system, eg conductors and electrical equipment in it, and is not a reference solely to the functional circuit as a whole. It follows that something required of a system is required both of the system as a whole and of the equipment and conductors in it.

16 The definition refers to electrical systems. In the case of each system this will include all of the electrical equipment connected together and the various electrical energy sources in that system. In the case of transformers, even though there may be galvanic separation between the various windings of the transformers, where the energy is transmitted through these from one part of the electrical system to another, the transformer and all of its windings are part of the same system.

Guidance

17 The definition of 'system' includes equipment which, although not energised, may be electrically connected to a common source of electrical energy. Equipment which is readily capable of being made live by a system is therefore considered to be part of that system. For example, a lighting circuit which has been disconnected from its source of electrical energy by means of removable links or fuses is still part of that system and so is such a circuit which has been switched off even though the switch might be a double pole switch.

18 Equipment which is in any way connected to a source of electrical energy, eg a test instrument containing a source and the equipment containing or connected to that source becomes part of a system and the Regulations apply to that system. Electrical equipment which is not connected, and cannot be readily connected, to a source of electrical energy is not part of a system. Protective conductors, if they are connected to a source, are part of that system.

19 The reference in the definition to a common source of electrical energy does not exclude systems fed by several generators or transformers. The word 'common' is included in the definition so that completely independent electrical installations are regarded as separate systems. If however they are electrically connected in any way they are part of the same system for the purposes of the Regulations, even though this may mean that in some cases the system may be an extensive electrical network covering large geographical areas over which several or even many people have control of various parts. In such cases the Regulations place duties on these people only in respect of those provisions of the Regulations which relate to matters which are within their control (see regulation 3).

20 Self-contained portable systems such as portable generating sets are electrical systems for the purpose of the Regulations as are transportable systems and systems on vehicles etc.

Electrical equipment

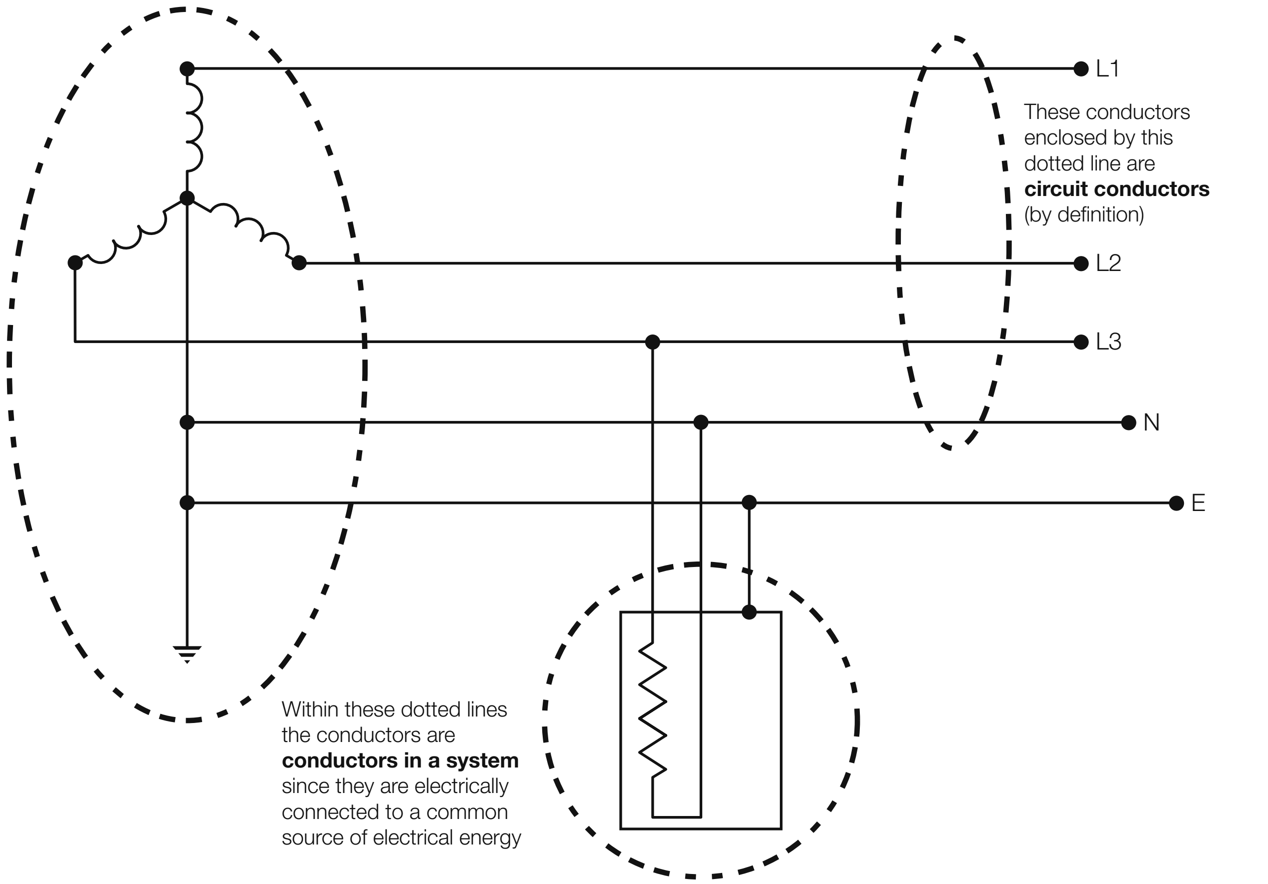
21 'Electrical equipment' as defined in the Regulations includes every type of electrical equipment from for example a 400 kV overhead line to a battery-powered hand lamp. It is appropriate for the Regulations to apply even at the very lowest end of the voltage or power spectrum because the Regulations are concerned with for example explosion risks which may be caused by very low levels of energy igniting flammable gases even though there may be no risk of electric shock or burn. Therefore no voltage limits appear in the Regulations. The criteria of application is the test as to whether 'danger' (as defined) may arise.

22 Electrical equipment (as defined) includes conductors used to distribute electrical energy such as cables, wires and leads and those used in the transmission at high voltage of bulk electrical energy, as in the national grid.

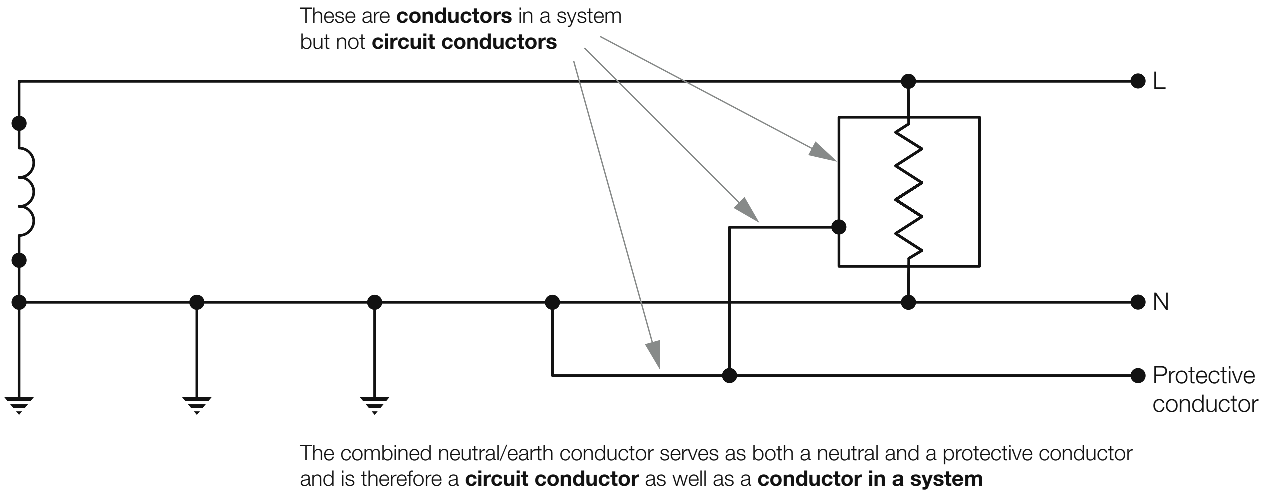
Conductors

23 Regulation 2 defines a conductor as 'a conductor of electrical energy'. This means any material which is capable of conducting electricity (electricity is synonymous with electrical energy) and therefore includes both metals and all other conducting materials. The definition is not limited to conductors intended to carry current and so includes, for example, metal structures, salt water, ionised gases and conducting particles. The conductance of most materials varies with parameters such as temperature; eg glass is conducting when molten (and is then a conductor as defined) whereas in its normal, solid, state it is a good insulator and finds many applications as such. For the purposes of the Regulations, while such materials conduct electricity, they are 'conductors'.

2



3 Phase system - separate neutral and earth



System including both combined and separate neutral and earth conductors (single phase only shown)

Figure 1 Types of conductor

Guidance

Circuit conductor

24 This definition is used in regulations 8 and 9 only. It distinguishes from all other conductors those conductors whose normal function is to carry load current or to be energised. (See Figure 1.)

Danger

25 The Regulations use the two defined terms, 'danger' and 'injury'. 'Danger' is defined as 'risk of *injury*'. 'Injury' is defined in terms of certain classes of potential harm to people.

26 Where the term 'prevent danger' is used it should therefore be read as 'prevent the risk of *injury*'.

27 The Regulations make requirements to 'prevent danger' or 'prevent injury' – or in the case of regulation 16 – 'to prevent danger or, where appropriate, injury'. The purpose of the distinction between 'injury' and 'danger' is to accommodate those circumstances when people must work on or so near live equipment that there is a risk of 'injury', ie where 'danger' is present and cannot be prevented. In these circumstances under regulation 14, danger may be present but injury must be prevented.

28 The type of injuries with which the Regulations are concerned are detailed in the definition of 'injury' in the regulation (see paragraphs 30 and 31). The scope of the Regulations does not include consequential dangers such as crushing injuries caused by a machine going out of control following an electrical malfunction. Such other dangers are subject to other legal requirements under for example the HSW Act, the Factories Act 1961 and the Offices Shops and Railway Premises Act 1963.

29 If no danger arises from a particular system, item of electrical equipment or conductor and will not arise, then the Regulations, although applying to it, do not require any precautions to be taken. However, in order for there to be no danger, there would have to be no risk of electric shock, electric burn, fire, arcing or explosion.

Injury

30 The purpose of the Regulations is to prevent death or personal injury to any person from electrical causes in connection with work activities.

31 'Injury' means death or injury to people from:

(a) electric shock;
(b) electric burn;
(c) fires of electrical origin;
(d) electric arcing; or
(e) explosions initiated or caused by electricity.

(a) Electric shock

32 The human body responds in several ways to electrical current flowing through it. The sensation of shock is only one such effect and this can be extremely painful. When a shock is received, the electric current may take multiple paths through the body and its intensity at any one point is difficult or impossible to predict. The passage of electric current may cause muscular contractions, respiratory failure, fibrillation of the heart, cardiac arrest or injury from internal burns. Any of these can be fatal.

Guidance

33 The nature and severity of injury depends upon the magnitude, duration and path of the current through the body and, in the case of alternating current, on its frequency. It is not possible to identify precise thresholds for the existence of hazard because a judgement has to be made in each case taking all the circumstances into account such as body weight, physical condition of the victim and so forth. Nevertheless, a guide to the sort of current magnitudes which mark the occurrence of various dangerous effects is given in the International Electrotechnical Commission's publication IEC TS/60479. Quite low currents, of the order of only a few milliamps (mA), can cause fatal electric shock.

34 Factors which mainly influence the likely effect of shock current are its voltage, frequency and duration and any impedance in the current path. The effects of electric shock are most acute at about the public electricity supply frequency of 50 hertz. Susceptibility to electric shock is increased if a person is in good electrical contact with earth, such as in damp or wet conditions or in conducting locations such as inside a metal tank. Hot environments where people may become damp due to perspiration or humidity, thus reducing the insulation protection offered by clothing, may present an increased risk from electric shock.

35 The variability of conditions makes it impossible to specify a voltage which is guaranteed to be safe in all situations. The risk of injury from electric shock in any situation must be considered against the background of the various national and international standards and technical publications giving guidance as to the voltages and other factors which have been found by extensive experience to be safe. These documents must be interpreted carefully and with a view to the limitation of their various scopes and assumptions. However, the conventional public electricity supply voltage of 230 volts ac should always be considered as potentially fatally dangerous. Many fatal electric shock accidents have occurred from contact with conductors live at this voltage and possibly the most dangerous situation is where contact is made with conductors by each hand, current then flowing 'hand to hand' across the heart region.

36 The following documents give some guidance:

(a) IEC Publication TS/60479 *Effects of current on human beings and livestock*;
(b) BS 7671 *Requirements for Electrical Installations*;
(c) IEC Guide 105 *Principles concerning the safety of equipment electrically connected to a telecommunications network*.

(b) Electric burn

37 Electric burns are different from burns due to fire (see paragraphs 40–41), arcing (see paragraphs 42–44) or explosion (see paragraphs 45–47).

38 Electric burns are due to the heating effect caused by the passage of electric current through body tissues. They are most commonly associated with electric shock and often occur in and on the skin layers at the point of contact with the electrical conductors which gave rise to the electric shock.

39 At high frequencies, eg radio frequencies (RF), which include microwaves, it may not even be necessary for contact to be made with live conductors for an electric burn to be received. In the case of RF, the heating is by absorption of the electromagnetic wave energy by a dielectric loss process in the body of the victim. RF burns can thus be extremely deep within the body. RF burning can occur without the sensation of shock, particularly if no contact is made with the RF conductors, and can therefore cause severe injury before the victim is aware of their occurrence. Electric burns are usually painful and very slow to heal. Permanent scarring is common.

Guidance

(c) Fires of an electrical origin

40 Fires may be started by electricity in a number of ways. The principal mechanisms are:

(a) overheating of cables and electrical equipment due to overloading of conductors;
(b) leakage currents due to poor or inadequate insulation;
(c) overheating of flammable materials placed too close to electrical equipment which is otherwise operating normally; and
(d) the ignition of flammable materials by arcing or sparking of electrical equipment, including the scattering of hot particles from electrical equipment.

41 The injuries associated with fire are usually burns but may include other injuries such as smoke inhalation.

(d) Arcing

42 Arcing causes a particular type of burn injury which is distinct from other types. Arcing generates ultra violet radiation which causes damage akin to severe sunburn. Molten metal particles from the arc itself can penetrate, burn and lodge in the flesh. These effects are additional to any radiated heat damage caused by the arc.

43 On its own, ultra violet radiation can cause damage; sensitive skin and eyes are especially vulnerable to arc flash. ('Arc eye' is commonly encountered with electric arc welding if the proper precautions are not adopted.)

44 Arcing faults can occur if the energy available at a piece of electrical equipment is sufficient to maintain a conductive path through the air or insulation between two conductors which are at different potentials. Under fault flashover conditions, currents many times the nominal rating or setting of a protective device may flow before those devices operate to clear the fault. Much energy is dissipated in the arc and depending on the electrical protection, may continue long enough to inflict very serious arcing burns or to initiate a fire in periods for example as short as 0.25 second, which is not an untypical minimum time for fault clearance. Arc flashovers caused during work on live circuit conductors are likely to be particularly hazardous because the worker is likely to be very near to or even enveloped by the arc. Such cases often lead to very serious, sometimes fatal, burn injuries.

(e) Explosion

45 In this category are those injuries caused by explosions either of an electrical nature or those whose source of ignition is electrical.

46 Electrical explosions include the violent and catastrophic rupture of any electrical equipment. Switchgear, motors and power cables are liable to explode if they are subjected to excessive currents, which release violent electromagnetic forces and dissipate heat energy, or if they suffer prolonged internal arcing faults.

47 Explosions whose source of ignition is electrical include ignition of flammable vapours, gases, liquids and dusts by electric sparks, arcs or the high surface temperature of electrical equipment.

2

Guidance

Other words used in the Regulations

Charged/live (as used in regulations 8, 13 and 14)

48 The terms 'charged' and 'live' have different meanings; they are not defined in the Regulations so they take their ordinary meaning. 'Live' means that the item in question is at a voltage, by being connected to a source of electricity for example as in normal use. 'Charged' means that the item has acquired a charge either because it is live or because it has become charged by other means such as by static or induction charging, or has retained or regained a charge due to capacitance effects even though it may be disconnected from the rest of the system.

Dead (as used in regulations 13, 14)

49 The term 'dead' is not defined in the Regulations so it takes its ordinary meaning. Thus, in the context of the Regulations, for a conductor to be 'dead' means that it is neither 'live' nor 'charged'.

2

Regulation

Regulation 3 Persons on whom duties are imposed by these Regulations

(1) Except where otherwise expressly provided in these Regulations, it shall be the duty of every -

(a) employer and self-employed person to comply with the provisions of these Regulations in so far as they relate to matters which are within his control; and
(b) (i) manager, in relation to a mine within the meaning of section 180 of the Mines and Quarries Act 1954, and
(ii) operator, in relation to a quarry within the meaning of regulation 3 of the Quarries Regulations 1999,

to ensure that all requirements or prohibitions imposed by or under these Regulations are complied with in so far as they relate to the mine of which he is the manager or quarry of which he is the operator and to matters which are within his control.

(2) It shall be the duty of every employee while at work -

(a) to co-operate with his employer so far as is necessary to enable any duty placed on that employer by the provisions of these Regulations to be complied with; and
(b) to comply with the provisions of these Regulations in so far as they relate to matters which are within his control.

3

Guidance

Employer

50 For the purposes of the Regulations, an employer is any person or body who (a) employs one or more individuals under a contract of employment or apprenticeship; or (b) provides training under the schemes to which the HSW Act applies through the Health and Safety (Training for Employment) Regulations 1990 (SI 1990/1380).

3

Guidance

Self-employed

51 A self-employed person is an individual who works for gain or reward otherwise than under a contract of employment, whether or not they employ others.

Employee

52 Regulation 3(2)(a) reiterates the duty placed on employees by section 7(b) of the HSW Act.

53 Regulation 3(2)(b) places duties on employees equivalent to those placed on employers and self-employed people where these are matters within their control. This will include those trainees who will be considered as employees under the Regulations described in paragraph 50.

54 This arrangement recognises the level of responsibility which many employees in the electrical trades and professions are expected to take on as part of their job. The 'control' which they exercise over the electrical safety in any particular circumstances will determine to what extent they hold responsibilities under the Regulations to ensure that the Regulations are complied with.

55 A person may find himself responsible for causing danger to arise elsewhere in an electrical system, at a point beyond his own installation. This situation may arise, for example, due to unauthorised or unscheduled back feeding from his installation onto the system, or to raising the fault power level on the system above rated and agreed maximum levels due to connecting extra generation capacity, etc. Because such circumstances are 'within his control', the effect of regulation 3 is to bring responsibilities for compliance with the rest of the Regulations to that person, thus making him a dutyholder.

Absolute/reasonably practicable

56 Duties in some of the regulations are subject to the qualifying term 'reasonably practicable'. Where qualifying terms are absent the requirement in the regulation is said to be absolute. The meaning of reasonably practicable has been well established in law. The interpretations in paragraphs 58–60 are given only as a guide to dutyholders.

Absolute

57 If the requirement in a regulation is 'absolute', for example if the requirement is not qualified by the words 'so far as is reasonably practicable', the requirement must be met regardless of cost or any other consideration. Certain of the regulations making such absolute requirements are subject to the Defence provision of regulation 29.

Reasonably practicable

58 Someone who is required to do something 'so far as is reasonably practicable' must assess, on the one hand, the magnitude of the risks of a particular work activity or environment and, on the other hand, the costs in terms of the physical difficulty, time, trouble and expense which would be involved in taking steps to eliminate or minimise those risks. If, for example, the risks to health and safety of a particular work process are very low, and the cost or technical difficulties of taking certain steps to prevent those risks are very high, it might not be reasonably practicable to take those steps. The greater the degree of risk, the less weight that can be given to the cost of measures needed to prevent that risk.

3

Guidance 3

59 In the context of the Regulations, where the risk is very often that of death, for example, from electrocution and where the nature of the precautions which can be taken are so often very simple and cheap, eg insulation, the level of duty to prevent that danger approaches that of an absolute duty.

60 The comparison does not include the financial standing of the dutyholder. Furthermore, where someone is prosecuted for failing to comply with a duty 'so far as is reasonably practicable', it would be for the accused to show the court that it was not reasonably practicable for him to do more than he had in fact done to comply with the duty (section 40 of the HSW Act).

Regulation 4

Regulation 4 Systems, work activities and protective equipment

*(1) All **systems** shall at all times be of such construction as to prevent, so far as is reasonably practicable, **danger**.*

*(2) As may be necessary to prevent **danger**, **all systems** shall be maintained so as to prevent, so far as is reasonably practicable, such **danger**.*

*(3) Every work activity, including operation, use and maintenance of a **system** and work near a **system**, shall be carried out in such a manner as not to give rise, so far as is reasonably practicable, to **danger**.*

*(4) Any equipment provided under these Regulations for the purpose of protecting persons at work on or near **electrical equipment** shall be suitable for the use for which it is provided, be maintained in a condition suitable for that use, and be properly used.*

Guidance 4

61 Regulation 4 covers, in a general way, those aspects of electrical systems and equipment, and work on or near these, which are fundamental to electrical safety.

Regulation 4(1)

62 The word 'construction' in the regulation has a wide application. It may be considered to cover the physical condition and arrangement of the components of a system at any time during its life. It will include aspects such as the design of the system and the equipment comprising that system.

63 In assessing the suitability of the construction of electrical systems, consideration should be given to all likely or reasonably foreseeable conditions of actual application or use of the electrical equipment in the system. This will include the testing, commissioning, operation and maintenance of the equipment throughout the life of the system.

64 In particular, consideration should be given to:

(a) the manufacturer's assigned or other certified rating of the equipment;
(b) the likely load and fault conditions;
(c) the need for suitable electrical protective devices;
(d) the fault level at the point of supply and the ability of the equipment and the protective devices to handle likely fault conditions;
(e) any contribution to the fault level from the connected loads such as from motors;
(f) the environmental conditions which will have a bearing on the mechanical strength and protection required of the equipment;

Guidance

(g) the user's requirements of the installation;
(h) the manner in which commissioning, testing and subsequent maintenance or other work may need to be carried out.

65 The safety of a system depends upon the proper selection of all the electrical equipment in the system and the proper consideration of the inter-relationship between the individual items of equipment. For example, electrical protection against overloads and earth faults etc may need to be provided in one part of a system to protect another, possibly remote part of the system. Also, where electrical energy is transformed or converted from one voltage to another, precautions should be taken to prevent danger arising from the lower voltage conductors becoming charged above their normal voltage.

Regulation 4(2)

66 Regulation 4(2) is concerned with the need for maintenance to be done to ensure safety of the system, rather than with the activity of doing the maintenance in a safe manner (which is required by regulation 4(3)).

67 The obligation to maintain arises only if danger would otherwise result. The quality and frequency of maintenance should be sufficient to prevent danger so far as is reasonably practicable.

68 Regular inspection of equipment is an essential part of any preventive maintenance programme. Practical experience of use may indicate an adjustment to the frequency at which preventive maintenance needs to be carried out. This is a matter for the judgement of the dutyholder who should seek all the information he needs to make this judgement including reference to the equipment manufacturer's guidance.

69 Records of maintenance, including test results, preferably kept throughout the working life of an electrical system will enable the condition of the equipment and the effectiveness of maintenance policies to be monitored. Without effective monitoring, dutyholders cannot be certain that the requirement for maintenance has been complied with.

70 British Standard Codes of Practice offering guidance on maintenance are referred to in Appendix 2. Advice on inspection and testing of some fixed installations is given in BS 7671 (see *Introduction* and Appendix 2).

Regulation 4(3)

71 Regulation 4(3) requires that work activities of any sort, whether directly or indirectly associated with an electrical system, should be carried out in a way which, as far as is reasonably practicable, does not give rise to danger. Regulations 12 to 16 provide more specific requirements in connection with work of an electrical nature on or near electrical systems.

Work activities associated with electrical systems

72 In the case of work of an electrical nature it is preferable that the conductors be made dead before work starts. (See regulations 12, 13 and 14.) In such cases it is essential that the equipment be isolated (note that 'isolation' is defined in regulation 12(2) which will include securing by locking off etc; see also paragraph 75) and the conductors proved dead at the point of work before the work starts. Where a test instrument or voltage indicator is used for this purpose this device should itself be proved preferably immediately before and immediately after testing the conductors.

4

Guidance

73 Proper safe systems of work incorporating safety isolation procedures are important for work upon equipment which is to be made dead before work starts. These are also discussed under regulations 12 and 13. Some work, such as fault finding and testing, or live jointing by the electricity supply industry, may require electrical equipment to remain energised during the work. In these cases if there may be danger from live conductors, regulation 14 makes particular requirements and regulation 4(4) is also likely to be relevant in terms of the protective equipment which may need to be provided.

74 The operation, maintenance and testing of electrical systems and equipment should be carried out only by those people who are competent for the particular class of work. (See also regulation 16.)

Disused electrical equipment and systems

75 Before electrical equipment is decommissioned or abandoned for any reason it should be disconnected from all sources of supply and isolated. Isolation (as defined in regulation 12(2)) requires taking effective steps to ensure that it is dead and cannot become inadvertently re-energised or charged by induction or capacitance effects. (Regulations 12, 13 and 14 are also likely to be relevant.) Suitable labels or notices to bring people's attention to the state of the equipment are likely to be necessary in preventing inadvertent re-energisation.

Other work near electrical systems

76 Regulation 4(3) is wide in its application and includes work of a non-electrical nature where there is a risk of electrical injury. A common example is excavation near to live electric power cables and work near live overhead power lines, where the risks can be severe. Advice on these matters is given in HSE guidance notes which are listed in Appendix 1. The requirements of regulation 14 must also be taken into consideration.

Regulation 4(4)

77 The defence (regulation 29) is available in any proceedings for an offence under this part of regulation 4.

78 The term 'protective equipment' can be of wide application but typically includes those special tools, protective clothing and insulating screening materials etc necessary to undertake work safely on live electrical equipment. The requirement for suitable precautions to prevent injury may arise under regulation 14. The regulation makes three particular requirements of the protective equipment, that it be (a) suitable for use, (b) maintained in that condition and (c) properly used.

79 Regulation 4(4) is not qualified by 'so far as is reasonably practicable', nor does the regulation refer either to injury or the risk of injury, ie electrical danger. The impact of the regulation is that where protective equipment is provided in pursuance of compliance with any of the other regulations, that the equipment must conform to the requirements of regulation 4(4). Advice on safe working practices is given in HSE guidance notes (see Appendix 1). Specifications for certain types of protective equipment such as insulating gloves and floor mats are listed in Appendix 2.

4

Regulation

5

Regulation 5 Strength and capability of electrical equipment

*No **electrical equipment** shall be put into use where its strength and capability may be exceeded in such a way as may give rise to **danger**.*

Guidance

80 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

81 The regulation requires that before equipment is energised, the characteristics of the system to which the equipment is connected be taken into account, including those pertaining under normal conditions, possible transient conditions and prospective fault conditions, so that the equipment is not subjected to stress which it is not capable of handling without giving rise to danger. The effects to be considered include voltage stress and the heating and electromagnetic effects of current.

Strength and capability

82 The term 'strength and capability' of electrical equipment refers to the ability of the equipment to withstand the thermal, electromagnetic, electro-chemical or other effects of the electrical currents which might be expected to flow when the equipment is part of a system. These currents include, for example, load currents, transient overloads, fault currents, pulses of current and, for alternating current circuits, currents at various power factors and frequencies. Insulation must be effective to enable the equipment to withstand the applied voltage and any likely transient over-voltages.

83 A knowledge of the electrical specification and the tests, usually based on the requirements of national or international standards, which have been carried out either by the manufacturer or by an accredited testing organisation, will assist the user in identifying the withstand properties of the equipment so that it may be selected and installed to comply with this regulation.

Rating

84 The strength and capability of electrical equipment is not necessarily the same as its rating. Usually the rating is that which has been assigned by the manufacturer following a number of agreed tests.

85 It is recommended that electrical equipment be used within the manufacturer's rating (continuous, intermittent or fault rating as appropriate) and in accordance with any instructions supplied with the equipment.

Fault conditions

86 In order that equipment may remain safe under prospective fault conditions, it is necessary when selecting equipment to take account of the fault levels and the characteristics of the electrical protection which has been provided for the purpose of interrupting or reducing fault current (excess current protection is required by regulation 11). Most electrical equipment will be able to withstand short-circuit currents safely for limited periods only. The considerations extend also to conductors and equipment provided solely for protective purposes, eg earthing conductors must be adequately rated to survive beyond fault clearance times to ensure satisfactory protective gear operation and fault clearance.

5

Regulation

6

Regulation 6 Adverse or hazardous environments

Electrical equipment *which may reasonably foreseeably be exposed to -*

(a) mechanical damage;
(b) the effects of the weather, natural hazards, temperature or pressure;
(c) the effects of wet, dirty, dusty or corrosive conditions; or
(d) any flammable or explosive substance, including dusts, vapours or gases,

shall be of such construction or as necessary protected as to prevent, so far as is reasonably practicable, ***danger*** *arising from such exposure.*

Guidance

6

87 The regulation draws attention to the kinds of adverse conditions where danger could arise if equipment is not constructed and protected to withstand such exposure. The regulation requires that electrical equipment should be suitable for the environment and conditions of use to which it may reasonably foreseeably be exposed so that danger which may arise from such exposure will be prevented so far as is reasonably practicable. The following paragraphs detail some of the conditions which electrical equipment may be subjected to. Guidance is given in these paragraphs and additional guidance may be found in the documents listed in Appendices 1 and 2. Particular attention should be paid to the IP rating (Index of Protection) of equipment (see paragraph 108). Guidance is also given under regulation 8 on the use of reduced voltage systems on construction sites and elsewhere where particularly arduous or conducting locations may exist (see paragraphs 143–145).

Effects

88 The conditions at which the regulation is directed are those occurring naturally as well as those resulting from human activities, including the following:

(a) mechanical damage including impact, stress, strain, abrasion, wear, vibration and hydraulic and pneumatic pressure;
(b) effects of the weather, which include both short-term (eg wind, ice and snow, lightning) and long-term (eg temperature cycling) effects;
(c) natural hazards, which are those resulting from other than man's activities and include animals, trees and plants, tides and solar radiation etc;
(d) temperature and pressure;
(e) liquids which include water and other liquids and their effects, including humidity, condensation, flooding, splashing, or immersion in these, cleaning with liquids, hosing down and solvent and solvent vapour action (electrically conducting and non-conducting liquids may present different aspects of electrical danger);
(f) dirty conditions which include all contamination as a result of liquids or solids (electrically conducting and non-conducting dusts may present different aspects of electrical danger);
(g) corrosive conditions which include all chemical action and reactions and electrochemical effects;
(h) flammable substances including flammable dusts and flammable vapours;
(i) explosive substances which include both any mixture of solids, liquids or gases which is capable of exploding and substances intended to be explosive (ie explosives).

89 In gauging the suitability of equipment for particular environments or conditions of use it is necessary to consider only those effects or exposure which are reasonably foreseeable.

Guidance

Mechanical damage

90 The mechanical damage to which electrical equipment may be subjected varies considerably from one environment to another. For example, equipment designed for use in an office is unlikely to be suitable, without further protection or careful siting, in a workshop or farm environment.

91 The effects covered by regulation 6(b), (c) and (d) may also impose mechanical stresses on electrical equipment. For example, ice and wind loading, or loss of mechanical strength due to expansion and contraction resulting from temperature changes, can give rise to mechanical damage.

92 This regulation requires the mechanical protection, if necessary, of the insulation which is required under regulation 7(a). Further suitable protection in addition to basic insulation may be necessary to form the physical protection necessary to ensure the continuing integrity of basic insulation, eg conduits or a trunking for single insulated conductors or the armouring or tough external sheathing of composite or multi-core electric cable.

Weather, natural hazards and extreme conditions

93 Precautions which are taken to protect a site, structure or building from natural hazards and extreme weather conditions may give some protection to the associated electrical installation, but additional protection or precautions may be necessary.

94 Extremes of temperature, pressure or humidity may result either from climatic conditions or from adjacent plant or from the use of the electrical equipment itself. Standards frequently quote the range of service conditions for electrical equipment, including temperature limits, and users should consider these when selecting equipment.

95 Guidance on assessing the need for lightning protection of structures and buildings etc, the design and provision of systems and their inspection, testing and maintenance is given in publications listed in Appendix 2.

Corrosive effects

96 If substances are present in the environment which either alone, in combination, or in the presence of moisture can cause accelerated corrosion of metallic enclosures or fittings, special materials or surface treatments may be necessary. In these cases it would be recommended that much of the electrical equipment, eg motors, be of a type which is totally enclosed by an appropriate corrosion-resistant housing, ie not ventilated to the atmosphere.

97 Insulating materials and other materials used in electrical equipment may be affected by chemical agents or solvents. Cubicles housing electrical control equipment in hostile environments may need to be kept purged or pressurised with clean air or, in special cases, inert gas. See Appendix 2 for standards.

6

Guidance

Dirt and dusts

98 Most industrial enclosures for electrical equipment do not resist the entry of fine dusts. Equipment should be constructed so as to resist the entry of dust and dirt where this may give rise to electrical and mechanical failures. Regular inspection and cleaning as necessary is recommended where dirt and dusts are likely to accumulate. A particular example is that of portable motor-driven equipment incorporating ventilation slots which can give rise to the accumulation of potentially hazardous layers of dirt and dust.

Combustible dusts

99 In cloud form, some dusts create an explosion hazard, while layers of combustible dust on electrical equipment can give rise to fire hazards. The selection, construction or installation of the equipment so exposed to combustible dust should be such as to guard against the possibility of ignition. The maximum temperature attainable on the surface of any electrical equipment where these dusts may be deposited should be considered in the selection of the equipment. The temperature of such surfaces should always be below the temperature at which any charring or smoking of dust takes place. However, appropriate dust control measures and general cleanliness which minimise the problem at source are to be preferred. See Appendix 2 for standards.

Potentially explosive atmospheres

100 If electrical equipment is used where a flammable or explosive atmosphere is likely to occur the equipment shall be so constructed that it is not liable to ignite that atmosphere.

101 The selection and installation of equipment for use in potentially explosive atmospheres should be guided by the recommendations contained in the HSE guidance and British Standards on the subject (see Appendices 1 and 2). Existing installations complying with the recommendations of earlier standards should be acceptable for continuing service, subject to proper maintenance.

102 It is recommended that the choice of electrical equipment be from that which has been certified as being in conformity with an appropriate standard.

103 Uncertified electrical equipment should not be used unless it will provide at least an equivalent level of safety to that provided by appropriately certified equipment.

104 Some manufacturing processes, for example electrostatic paint spraying, make use of the characteristics of static electricity and the design of electrical equipment needs to be such that the ignition of solvents, vapours or particulate substances is prevented. See Appendix 2 for standards.

105 The maintenance and repair of explosion-protected equipment is a specialised field of work and should be undertaken only by those who have the necessary training and experience. See Appendix 2 for standards.

Other flammable substances

106 Much electrical equipment generates heat or produces sparks and this equipment should not be placed where either the heat emitted or the occurrence of sparking is likely to lead to the uncontrolled ignition of any substance.

6

Guidance

6

107 The construction of the equipment should either exclude the substances from any part of the equipment which may be a source of ignition (eg by suitable enclosure) or should ensure that the equipment operates at sufficiently low temperature and energy levels as not to be a source of ignition under likely conditions of use and fault.

Classification system of ingress protection (IP rating)

108 There is an internationally recognised system of classifying the degree of protection provided by enclosures against the ingress of solid objects and moisture, and the protection afforded against contact with any live parts within the enclosure for all types of electrical equipment. The system is commonly known as the IP rating system (IP = Index of Protection) and is detailed in a number of standards which are listed in Appendix 2.

Regulation

7

Regulation 7 Insulation, protection and placing of conductors

*All **conductors** in a **system** which may give rise to **danger** shall either -*

(a) *be suitably covered with insulating material and as necessary protected so as to prevent, so far as is reasonably practicable, **danger**; or*
(b) *have such precautions taken in respect of them (including, where appropriate, their being suitably placed) as will prevent, so far as is reasonably practicable, **danger**.*

Guidance

7

109 The regulation requires that danger be prevented, so far as is reasonably practicable, by the means detailed in either part (a) or (b).

110 The danger to be protected against generally arises from differences in electrical potential (voltage) between circuit conductors or between such conductors and other conductors in a system – usually conductors at earth potential. The conventional approach is either to insulate the conductors or to so place them that people are unable to receive an electric shock or burn from them.

111 Some form of basic insulation, or physical separation, of conductors in a system is necessary for the system to function. That functional minimum, however, may not be sufficient to comply with the requirements of regulation 7. Factors which must be taken into account are:

(a) the nature and severity of the probable danger;
(b) the functions to be performed by the equipment;
(c) the location of the equipment, its environment and the conditions to which it will be subjected;
(d) any work which is likely to be performed upon, with or near the equipment.

Guidance

Insulation

112 Regulation 7(a) states the requirement that conductors are to be insulated. Suitable insulation of the conductors in an electrical system is, in the majority of cases, the primary and necessary safeguard to prevent danger from electric shock, either between live conductors or between a live conductor and earth. It will also prevent danger from fire and explosion arising from contact of conductors either with each other or with earth. Energy from quite low levels of voltage (and levels insufficient to create a shock risk) can ignite a flammable atmosphere. The quality and effectiveness of insulation therefore needs to be commensurate with the voltages applied to the conductors and the conditions of use.

113 BS 7671 gives some advice on these matters for fixed electrical installations up to 1000 volts ac or 1500 volts dc. See Appendix 2.

114 The regulation then requires that the insulation be protected as necessary, so that danger may be prevented so far as is reasonably practicable. Mainly, the protection required is to prevent mechanical damage to the insulation but may include any of the effects detailed under regulation 6. Examples of such protection would be the use of steel trunking and conduits or the use of steel armoured cables.

Other precautions including placing

115 Regulation 7(b) permits the alternative of having such precautions taken in respect of the conductors. These precautions may include the suitable placing of conductors. The precautions may comprise strictly controlled working practices reinforced by measures such as written instructions, training and warning notices etc. The precautions must prevent danger so far as is reasonably practicable. Examples where bare conductors are used in conjunction with suitable precautions are to be found in many applications including overhead electric power lines, down-shop conductors for overhead travelling cranes in factories etc, railway electrification using either separate conductor and running rails or overhead pick-up wires, and certain large electrolytic and electrothermal plants.

116 The design and construction of overhead electric power lines is specified in statutory regulations which are administered by the Department of Energy and Climate Change. (See *Introduction*.)

117 Electric railway and tramway operators, in conjunction with the Office of the Rail Regulator (HM Railway Inspectorate), have developed standards and safety specifications for the construction of those parts of their systems which use bare conductors at overhead and at track level, together with safe systems of work.

118 Safety is ensured in electrochemical plants which use high current by such means as the separation of conductors which are at different potentials, the use of insulating working platforms and unearthed or isolated electrical supplies. (See paragraphs 122–124.)

119 Suitable placing of the conductors may alone go a considerable way towards preventing danger, for example where the conductors are within a secure enclosure or where they are placed overhead at such a height that contact with these conductors is not reasonably foreseeable. Guidance on the security and protection of enclosures and the measure of their accessibility as determined by standard (finger) tests is given in standards listed in Appendix 2.

7

Guidance

120 However, if the placing of the conductors cannot alone be relied upon to prevent danger, then additional precautions need to be taken and rigorously applied. For example, in the case of live railway conductor rails the precautions may include warning notices, barriers and special training for railway staff. Electrolytic and electrothermal processes are further examples and these are the subject of paragraph 122.

121 Dutyholders should carefully consider the inherent risks that may exist if bare conductors are merely placed where they cannot normally be touched. Firstly, the protection of the equipment is required under regulation 6 for a range of reasonably foreseeable effects and secondly, there may be occasions when people will require access to the area or enclosure where such conductors are located, eg substations and test areas. Where work is to be done with the conductors live, regulation 14 is relevant and the guidance under that regulation also applies.

Electrolytic and electrothermal processes

122 It is often necessary, in connection with industrial electrolytic and electrothermal processes, including large secondary battery installations, to adopt a range of precautions. As the work activity is likely to be near the live and uninsulated conductors the precautions adopted will go towards satisfying both part (b) of regulation 7 and regulation 14.

123 Precautions may include:

(a) segregating the process area and limiting access to those people who are trained and experienced in the process and to people who are supervised so that injuries are prevented;
(b) ensuring a separation of conductors appropriate to the difference in potentials;
(c) use of insulating work platforms;
(d) use of electrical supplies which are isolated from earth together with protective devices to ensure this isolation;
(e) exclusion of unnecessary conducting materials and implements from the process area;
(f) use of protective clothing, eg in electric arc welding processes, protective clothing offers protection against both the hot welding process and against the electric shock risk.

7

124 Details of advice on the safe use of electric induction furnaces and electric arc welding is given in Appendix 1.

Regulation

Regulation 8 Earthing or other suitable precautions

*Precautions shall be taken, either by earthing or by other suitable means, to prevent **danger** arising when any **conductor** (other than a **circuit conductor**) which may reasonably foreseeably become charged as a result of either the use of a **system**, or a fault in a **system**, becomes so charged; and, for the purposes of ensuring compliance with this regulation, a **conductor** shall be regarded as earthed when it is connected to the general mass of earth by **conductors** of sufficient strength and current-carrying capability to discharge electrical energy to earth.*

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Guidance 8

125 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

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126 The regulation applies to any conductor, other than a circuit conductor, which is liable to become charged either as a result of the use of a system or a fault in a system. The regulation requires that precautions be taken to prevent danger resulting from that conductor becoming charged.

127 Because the regulation applies to any conductor (other than circuit conductors), this may include the conductive parts of equipment, such as outer metallic casings, which can be touched, which although not live, may become live under fault conditions.

128 Conductors which, although not part of a system, are within electrostatic or electromagnetic fields created by a system may be subject to this regulation. Appropriate precautions are necessary if the induced voltages or currents are large enough to give rise to danger.

Dangers

129 Dangers which may arise as a result of failure to take the necessary precautions include:

(a) risk of shock from such conductors which are or may be exposed so that they may be touched and which become charged at dangerous voltage relative to earth or to other exposed conductors;
(b) risk of burns, fire, arcing or explosion due to currents of excessive magnitude and/or duration in such conductors.

130 The requirements of the regulation may be responded to in several different ways, depending on the circumstances, including:

(a) ensuring that such conductors do not become charged. This has the effect of excluding the conductors from the scope of this regulation;
(b) ensuring that if such conductors do become charged the values of voltage and current and the duration are such that danger will not arise;
(c) ensuring that if such conductors do become charged the environment is such that danger will not arise.

131 Techniques employed for achieving the above include:

(a) double insulation;
(b) earthing;
(c) connection to a common voltage reference point on the system;
(d) equipotential bonding;
(e) use of safe voltages;
(f) earth-free non-conducting environments;
(g) current/energy limitation; and
(h) separated or isolated systems.

The above techniques may be employed singly or in combination.

(a) Double insulation

132 The principle of 'double insulation' is that the live conductors of the electrical equipment are covered by two discrete layers or components of insulation each of which would adequately insulate the conductor but which together ensure an improbability of danger arising from insulation failure. This arrangement avoids the need for any external metalwork of the equipment to be connected to a protective conductor or to earth. Double insulation has been found to be particularly suitable for certain types of portable equipment, eg electric motor-driven tools etc, and the

Guidance

need for an earthing protective conductor is eliminated. See Appendix 2 for relevant standards. However, the integrity of this protective provision for safety depends upon the layers of insulation remaining in sound condition and this in turn requires that the equipment be properly constructed, used and maintained.

(b) Earthing

133 It is the practice in the UK for the public electricity supply system at the usual distribution pressures of 230 volts single phase, 400 volts three phase, to be referenced to earth by a deliberate electrical connection made at the distribution substations or power transformers. It is the existence of this system earthing which enables earth faults on electrical equipment to be detected and the electrical supply to faulty equipment to be cut off automatically.

134 Many 230/400 volt power installations are so designed that the automatic interruption of the supply upon the occurrence of an earth fault is performed by fuses or automatic circuit breakers (MCBs etc). In most cases these devices will have been selected to provide the additional protective function of interrupting excess current required under regulation 11. In these circumstances it is essential that the earth fault current be large enough to rupture the fuse quickly. The magnitude of the fault current under full earth fault conditions is governed mainly by the combined impedance of the fault loop which will include the impedance of the fault itself, that of the earthing or protective conductors, the circuit conductors and that of the source. Tests should therefore be carried out on new installations and at appropriate intervals thereafter to ascertain that the earth fault (loop) impedances are low enough to ensure that the electrical protective devices such as fuses, circuit breakers etc will operate in the event of a breakdown of insulation leading to an 'earth fault'.

135 Acceptable parameters of earth loop impedance and interruption times etc for final installations up to 1000 volts may be found in BS 7671 (see Appendix 2). It is rarely sufficient to rely on an earth rod or rods to provide sufficient conductance for return fault currents. Separate protective earth cables or conductors connected to the neutral point of the supply are usually necessary unless other measures such as the use of sensitive residual current protection equipment is used to detect earth fault currents.

136 For the duration of the fault, the electrical bonding of exposed conductive parts and their connection to earth serves to limit the shock risk from the transient voltages appearing between metallic enclosures of equipment in the system or between a metallic enclosure and earth. Equipment earthing therefore includes the bonding of metallic enclosures, cable armouring, conduits and trunking etc, so that these conductors are electrically continuous and securely connected to the general mass of earth at one or more points.

137 Earthing and bonding conductors must be suitable for the maximum current which they may carry under fault conditions and be capable of surviving the worst-case fault (see paragraph 82). Their construction and strength must be adequate to withstand likely wear and tear. Where it might otherwise be difficult to ensure the continued effectiveness of earthing and bonding arrangements, it may be necessary to provide supplementary protection such as protective earth conductor monitoring.

138 Many accidents have been caused by the metalwork of portable or transportable equipment becoming live as a result of the combined effects of a fault and high impedance protective conductor connections. The danger may be reduced by the use of a residual current device (RCD) designed to operate rapidly at small leakage currents (typically not exceeding 30 mA), although these devices

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do not eliminate the risk of electric shock. RCDs should be considered only as providing a second line of defence. They should be operated regularly using the test trip button. This test trip procedure is important in maintaining the effectiveness of most types of RCD.

139 Electric arc welding brings special problems associated with earthing practices. Stray currents from electrical arc welding can damage the protective earthing conductors of electrical installations.

140 Information on earthing practice is available in a number of publications, some of which are listed in Appendix 2.

(c) Connection to a common voltage reference point on the system

141 In the case of UK public electricity supply systems where transformer neutral points are connected to earth, the voltage reference point is the general mass of earth. Other reference points, to which systems may be referenced and to which bonding conductors are connected, may be chosen to suit particular circumstances.

(d) Equipotential bonding

142 Equipotential bonding is the electrical interconnection of all exposed and extraneous conductors, which may become electrically charged, in such a way that dangerous voltages between any of the conductors which may be simultaneously touched are limited.

(e) Use of safe voltages

143 Reduced voltage systems are particularly appropriate for portable and transportable equipment, in highly conducting locations such as boilers and tunnels where the risk of mechanical damage to equipment and trailing cables is high, where the body may be damp and have large areas of contact with the conducting location and on construction sites.

144 One example is that of building or construction site supply systems operating at 55-0-55 V ac single phase, or at 110 V three phase with a phase-earth voltage of 64 V ac. Another example is that of an extra low voltage system operating at or below 50 V ac or 120 V dc as recommended internationally. Supply systems like these are referenced to earth and are therefore a special case of systems operating at reduced voltage for which bonding and earthing of all metallic enclosures are still recommended.

145 Further advice on reduced voltage systems may be found in HSE guidance notes listed in Appendix 1 and in BS 7671 (see Appendix 2).

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(f) Earth-free, non-conducting environments

146 If a system is supplied from a source which is earth-referenced, the path for fault current and the existence of dangerous potentials to earth can be eliminated in a defined area by ensuring that the area is 'earth-free'. This does not necessarily mean that metallic components or fittings need to be prohibited but rather that no part of the defined area is earthed. It is easier to ensure the integrity of an 'earth-free' area by constructing it from non-metallic components in which case it is more appropriately known as a non-conducting location or area. 'Earth-free' and 'non-conducting' areas are of rather specialised application and are used mainly in certain types of testing of electrical equipment, advice on which is available in the publications on electrical testing listed in Appendices 1 and 2.

(g) Current limitation

147 If fault currents which could cause electric shock are inherently limited by appropriate passive devices, eg high integrity resistors, then protection by earthing or other means may not be required. In the conventional dry, working environment, for example, if the current is limited preferably to 1 mA but certainly to no more than 5 mA this will not usually present a risk of injury from electric shock to people in good health who may be subjected to it only occasionally and for a short time only. However, even this low level of current may give perceptible shock which although by itself is unlikely to be physiologically dangerous, may give rise to a consequential injury such as from a fall induced by the shock (but see paragraph 31 on 'injury' under regulation 2, especially IEC publication TS/60479 (see Appendix 2)).

(h) Separated or isolated systems

148 If safety depends on the supply system not being referenced to its immediate environment, whether true earth or surrounding metalwork, no potential should normally exist between live conductors and earth or exposed metallic parts. However, all systems are to some extent referenced to their environment by capacitive or inductive coupling or by leakage. For this reason, reliance cannot necessarily be placed on the circuit conductors of separated or isolated* systems being at zero potential relative to their environment. Unless the isolated system is a very small and localised one, the leakage current may be large enough to provide a path for a fatal electric shock. Any difference in potential is likely to be greatest on extensive systems but, in all cases when the voltages or currents could be dangerous, precautions are needed. Examples of isolated systems are those supplied from the secondary winding of an isolating transformer or the winding of an alternator where there is no connection between them and any other source of electrical energy.

149 The isolation of a power system from earth may reduce the risks associated with a single fault. However, if this first fault has the effect of referencing the system to earth or other exposed conductor, subsequent faults may lead to very destructive and hazardous short circuits so extra precautions will be necessary to prevent this danger. These may include the bonding of metallic enclosures; earth fault detection; insulation monitoring or the use of an earth-free non-conducting environment. Regular inspection and testing to ensure that system isolation integrity is maintained will also be necessary.

* *'Isolated' in this context means separate from all other systems and does not imply 'isolation' as defined specifically for the purpose of regulation 12.*

Regulation

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Regulation 9 Integrity of referenced conductors

If a ***circuit conductor*** *is connected to earth or to any other reference point, nothing which might reasonably be expected to give rise to* ***danger*** *by breaking the electrical continuity or introducing high impedance shall be placed in that conductor unless suitable precautions are taken to prevent that* ***danger****.*

Guidance

150 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

151 In many circumstances the reference point is earthed because the majority of power distribution installations are so referenced by a deliberate connection to earth at the generators or distribution transformers.

152 The object of the regulation is to prevent referenced circuit conductors which should be at or about the same potential as the reference point from reaching significantly different potentials thereby giving rise to possible danger.

153 The most common situation in which this regulation is relevant is in systems having a neutral point which is earthed. Such systems can be subdivided:

(a) systems, or parts of systems, in which the neutral and protective conductor are combined (eg TN-C and the combined parts of TN-C-S systems);*
(b) systems or parts of systems in which the neutral and protective conductors are separate (eg TN-S and the separate parts of TN-C-S systems).

* *This terminology is explained in BS 7671.*

Devices placed in the conductor

154 The regulation does not prohibit all electrical devices from being placed in referenced conductors. For example, a proper joint or a bolted link or a bar primary current transformer can be arranged to ensure the integrity of the conductor.

155 The regulation would also permit the inclusion of other devices such as a removable link, or even a manually-operated knife switch, provided that suitable precautions are adopted to ensure that these devices are not removed or operated in such a way as to give rise to danger. However, a number of other devices such as fuses, thyristors, transistors etc generally cannot be relied upon not to give rise to danger by becoming open circuit or introducing high impedance into the conductor. The regulation prohibits such applications.

Combined neutral and protective conductors

156 Open circuit of, or high impedance in, combined neutral and protective conductors will almost certainly result in the exposed and extraneous conductors which are connected to the protective conductors, eg metal enclosures of switchgear, being at a significant potential (up to phase-neutral volts) relative to earth. This could lead to a risk of electric shock or burn, thus the integrity of the combined neutral and earth conductor is very important. However, where the protective conductor is combined with the neutral conductor over some part of their length, precautions to prevent people coming into simultaneous contact with the protective conductors and earth (or conductors at earth potential) should be taken. Equipotential bonding of all metalwork within a building and the connection of this to the protective conductor or neutral is a commonly used approach. Generally, however, CNE systems should be confined to the public electricity supply network up to the point of supply to consumers.

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Guidance

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Separate neutral and protective conductors

157 When deciding whether danger may result where there are separate neutral and protective conductors it is necessary to consider not only the normal operation of the system but also the situations that may arise when work is being carried out on or near the system. If voltage rises on the neutral conductor could result in danger during the work then the above restrictions on devices in the neutral should be observed. For example, a fuse should not be placed in a neutral of a fixed power distribution installation (typically 230 volts) because this places people working on the installation at risk of electric shock and burn should that fuse operate or otherwise become open circuit. Double pole fusing (fuses in both the phase and neutral) is acceptable, however, if these are fitted within self-contained electrical equipment which itself is not part of the fixed electrical installation, and is connected to the fixed installation by a plug and socket by means of which the equipment may be readily isolated from the system prior to work being done on that equipment.

158 In general, if a neutral conductor is to be switched, a multipole switch or circuit breaker should be used which also switches all of the related phase conductors, the neutral breaking last and making first. Such switching should not interrupt the protective conductor.

Regulation

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Regulation 10 Connections

*Where necessary to prevent **danger**, every joint and connection in a **system** shall be mechanically and electrically suitable for use.*

Guidance

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159 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

Suitability of connections

160 The regulation requires that all connections in circuit and protective conductors, including connections to terminals, plugs and sockets, and any other means of joining or connecting conductors, should be suitable for the purposes for which they are used. This requirement applies equally to temporary and permanent connections.

161 The insulation and conductance of the connections should be suitable, having regard to the conditions of use including likely fault conditions.

162 The mechanical protection and strength should be such as to ensure the integrity of the insulation and conductance under all conditions of use including likely fault conditions, subject to the need for any maintenance which may be required by regulation 4(2).

163 Joints and connections in protective conductors should be made at least as carefully as those in circuit conductors and they should be of sufficient strength and conductance to allow for the passage of fault currents. Such connections may need to be treated so as to prevent corrosion. It is recommended that combinations of metals liable to produce damaging electrolytic action be avoided.

Guidance

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Plugs and sockets

164 Plug and socket connections and their use should be so arranged that accidental contact with conductors live at dangerous voltages is prevented. Mainly this should be achieved by selection of appropriate equipment but may involve some degree of operator skill and/or training depending on the circumstances.

165 In most applications, where a plug and socket type connector conveys a protective conductor as well as the circuit conductors, the protective conductor should be the first to be made and the last to be separated. The use of equipment made to appropriate standards should ensure that the principle is adhered to.

166 Where plug and socket connections are not rated for making or breaking the maximum load current, effective arrangements should be made, for example, by mechanical interlocking with the switch that controls the power, to ensure that the connections are made or broken only under no-load conditions.

Portable equipment

167 Special attention should be given to joints and connections in cables and equipment which will be handled, for example flexible cables for portable equipment. Plugs and sockets for portable equipment should be constructed in accordance with appropriate standards and arranged that, where necessary, earthing of any metal casing of the equipment is automatically effected by the insertion of the plug. HSE guidance notes and British Standards give further guidance on portable equipment (see Appendices 1 and 2).

Regulation

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Regulation 11 Means for protecting from excess of current

*Efficient means, suitably located, shall be provided for protecting from excess of current every part of a **system** as may be necessary to prevent **danger**.*

Guidance

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168 The defence (regulation 29) is available in any proceedings for an offence under this regulation. (See paragraphs 178 to 180.)

169 It is recognised that faults and overloads may occur on electrical systems. The regulation requires that systems and parts of systems be protected against the effects of short circuits and overloads if these would result in currents which would otherwise result in danger.

170 The means of protection is likely to be in the form of fuses or circuit breakers controlled by relays etc or it may be provided by some other means capable of interrupting the current or reducing it to a safe value.

The need to anticipate abnormal conditions

171 The regulation requires the means of preventing danger to be provided in anticipation of excess current; a fault or overload need not have occurred. Fault currents arise as a result of short circuits between conductors caused either by inherent failure of the electrical equipment or some outside influence, eg mechanical damage to a cable. Overload currents can arise as a result of the inadequacy of a system to supply the load and may be caused by an increased demand created by outside influence on the electrical equipment, eg mechanical overloading of an electric motor.

Guidance

The selection of excess current protection

172 In principle, every main circuit should be protected at its origin, ie at the source end of the circuit. Where the rating of the conductors forming a branch circuit is less than that of the conductors from which it is drawing power, it is conventional for protection to be placed at this point. In practice, however, there are exceptions to this principle and, depending on the nature of the system, a technical judgement must be made as to where the protection should be placed. Guidance on some aspects of this subject is given in BS 7671 (see Appendix 2).

173 When selecting the means of protection, consideration must be given to a number of factors among the more important of which are:

(a) the nature of the circuits and type of equipment to be protected;
(b) the short-circuit energy available in the supply (the fault level);
(c) the nature of the environment;
(d) whether the system is earthed or not.

(a) The nature of the circuits and type of equipment to be protected

174 The circuits to be dealt with may vary from high-power high-voltage circuits, for example for the inter-connection of substations or for the supply to large motors, down to the smallest final circuit supplying a few low-power lamps at say 6 volts. Over this range lies a great diversity of equipment each item of which will possess characteristics which must be carefully considered in the selection of appropriate devices to protect against excess current.

(b) Fault level

175 Due regard must be paid to the maximum short-circuit current with which the protective device may have to deal. (The ability of circuit breakers and fuses to operate successfully and without dangerous effects, serious arcing or, in the case of oil-filled equipment, the liberation of oil, is implicit in the requirements of regulations 4 and 5.) The design of the protective arrangement must also provide for sufficient current to be available to operate the protective devices correctly in respect of all likely faults.

(c) The nature of the environment

176 The nature of the environment may have a bearing on the choice of protective devices and their settings, for example where the possibility of a fire being started may be considerable. In all cases, however, the protection against excess current must be effective so that short circuits and earth faults are cleared promptly to minimise destructive arcing and heating. Protective devices, whether they be circuit breakers or fuses, should therefore be set or selected for the minimum tripping currents and times consistent with ensuring the reliable operation of the device and for the need for discrimination between successive stages of protection.

(d) Earthed system

177 Where a system is earthed, the nature and efficiency of the earthing system is important in relation to the design and reliability of the protective devices. In earthed systems, ie where some part of the windings of the machine or transformer from which the supply is derived is connected to earth, operation in the event of an earth fault of the protective device, whether circuit breaker or fuse, is dependent on sufficient current passing to operate the excess current or earth leakage tripping device or to blow the fuse. In many systems, the device provided in pursuance of the requirements of this regulation in respect of excess of current (very often a fuse)

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Guidance

may also provide protection against earth faults – and thus be in pursuance of the requirements of regulation 8.

Defence in criminal proceedings

178 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

179 In some circumstances it will be technically impossible to achieve total compliance with the absolute requirement to prevent danger. If an excess of current is drawn due to a fault or overload, for example due to an arcing fault, then whatever form of electrical protection is provided, there will be some danger at the point of the fault during the finite time taken for the detection and interruption of the fault current. Nevertheless, the choice of electrical protection, be it by means of a simple fuse or whatever, must be properly chosen and installed in accordance with good electrical engineering practice. The protection must be efficient and effective.

180 In some circumstances it is undesirable to interrupt the current in a circuit because this may itself lead to a hazard. Examples of such circumstances include the excitation field current of direct current motors, trip coil circuits, lifting electromagnets and the secondary circuits of current transformers. In such cases, however, the circuit should be so rated or arranged not to give rise to danger from excess of current.

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Regulation

Regulation 12 Means for cutting off the supply and for isolation

(1) Subject to paragraph (3), where necessary to prevent ***danger****, suitable means (including, where appropriate, methods of identifying circuits) shall be available for -*

(a) cutting off the supply of electrical energy to any ***electrical equipment****; and*
(b) the isolation of any ***electrical equipment****.*

(2) In paragraph (1), "isolation" means the disconnection and separation of the ***electrical equipment*** *from every source of electrical energy in such a way that this disconnection and separation is secure.*

(3) Paragraph (1) shall not apply to ***electrical equipment*** *which is itself a source of electrical energy but, in such a case as is necessary, precautions shall be taken to prevent, so far as is reasonably practicable,* ***danger****.*

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Guidance

181 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

Regulation 12(1)(a)

182 The objective of this part of the regulation is to ensure that, where necessary to prevent danger, suitable means are available by which the electricity supply to any piece of equipment can be switched off. Switching can be, for example, by direct manual operation or by indirect operation via 'stop' buttons in the control circuits of contactors or circuit breakers. There may be a need to switch off electrical equipment for reasons other than preventing electrical danger but these considerations are outside the scope of the Regulations.

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Guidance

Regulation 12(1)(b)

183 Whereas regulation 12(1)(a) requires means to be provided whereby the supply of electrical energy can be switched off, 12(1)(b) requires that there will be available suitable means of ensuring that the supply will remain switched off and inadvertent reconnection prevented. This is isolation. This provision, in conjunction with safe working practices, will enable work to be carried out on electrical equipment without risk of it becoming live during the course of that work, for example if the work is to be done under the terms of regulation 13.

184 In some cases the equipment used to perform the requirement under regulation 12(1)(a) may also serve to perform the requirement under 12(1)(b). It must be understood that the two functions of ***switching*** off and ***isolation*** are not the same, even though in some circumstances they are performed by the same action or by the same equipment.

Regulation 12(3)

185 Regulation 12(3) recognises the impracticability in some cases of switching off or of isolating that equipment which is itself an integral part of a source of electrical energy, for example the terminals of accumulators, large capacitors and the windings of generators. The regulation requires precautions to be taken in these circumstances so that danger is prevented so far as is reasonably practicable. See Appendix 1 for guidance on working practices.

"Where necessary to prevent danger"

186 The need for means to cut off the supply and effect isolation depends on factors such as likely danger in normal and abnormal conditions. This assessment may be influenced by environmental conditions and provisions to be made in case of emergencies, such as a fire in a premises. It includes consideration of which electrical equipment could be a source of danger if such means were not provided and of the installation, commissioning, operational and maintenance requirements over the life of the equipment.

Suitable means for cutting off the supply

187 The suitable means for cutting off the supply (regulation 12(1)(a)) should:

(a) be capable of cutting off the supply under all likely conditions having regard to the equipment, its normal operation conditions, any abnormal operating or fault conditions, and the characteristics of the source(s) of electrical energy;
(b) be in a suitable location having regard to the nature of the risks, the availability of people to operate the means and the speed at which operation may be necessary. Access to switches etc should be kept clear and unobstructed, free of tripping and slipping hazards etc;
(c) be clearly marked so as to show its relationship to the equipment which it controls, unless there could be no doubt that this would be obvious to any person who may need to operate it; and
(d) only be common to several items of electric equipment where it is appropriate for these to be energised and de-energised as a group.

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Guidance

Suitable means of isolation

188 The suitable means of isolation of equipment (regulation 12(1)(b)) should:

(a) have the capability to positively establish an air gap or other effective dielectric, which together with adequate creepage and clearance distances, will ensure that there is no likely way in which the isolation gap can fail electrically;
(b) include, where necessary, means directed at preventing unauthorised interference with or improper operation of the equipment, for example means of locking off;
(c) be located so that the accessibility and ease with which it may be employed is appropriate for the application. The time and effort which must be expended to effect isolation should be reasonable having regard to the nature of the equipment and the circumstances under which isolation may be required, eg a very remote means of isolation may be acceptable if isolation is only needed infrequently and any additional time taken to effect isolation does not result in danger;
(d) be clearly marked so as to show to which equipment it relates, unless there could be no doubt that this would be obvious to any person who may need to operate it;
(e) only be common to several items of electrical equipment where it is appropriate for these to be isolated as a group.

Selection of isolator switches

189 Isolator switches (or disconnectors) will often be employed as the means of effecting disconnection and secure separation from the supply. In selecting appropriate equipment to perform this function particular regard should be given to:

(a) the isolating distances between contacts or other means of isolation which should be in accordance with an appropriate Standard or be otherwise equally effective;
(b) the position of the contacts or other means of isolation which should either be externally visible or clearly and reliably indicated. An indication of the isolated position, other than by direct observation of the isolating gap, should occur when the specified isolating distance has been achieved in each pole;
(c) provision to enable the prevention of unauthorised, improper or unintentional energisation, eg locking-off facilities.

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190 For further information on the selection of isolators/disconnectors reference should be made to appropriate standards, see Appendix 2.

Regulation

Regulation 13 Precautions for work on equipment made dead

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*Adequate precautions shall be taken to prevent **electrical equipment**, which has been made dead in order to prevent **danger** while work is carried out on or near that equipment, from becoming electrically charged during that work if **danger** may thereby arise.*

Guidance 13

191 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

Guidance

192 Regulation 13 relates to situations in which electrical equipment has been made dead so that work either on it or near it may be carried out without danger. The regulation may apply during any work, be it electrical or non-electrical. The regulation requires adequate precautions to be taken to prevent the electrical equipment from becoming electrically charged, from whatever source, if this charging would give rise to danger. 'Charged' is discussed under regulation 2.

193 The regulation uses the term 'electrical equipment' which is defined by regulation 2. This will include any cables, conductors, wires, connectors etc which may have been arranged to connect together the various other items of electrical plant or equipment such as motors, transformers, switch gear etc. The regulation may therefore apply to any or all of these.

The precautions

194 The precautions should be effective in preventing the electrical equipment from becoming charged in any way which would give rise to danger.

195 In the first place, the procedures for making the equipment dead will probably involve use of the means required by regulation 12(1)(a) for cutting off the supply of electrical energy. Isolation of the electrical equipment will be necessary and the means required by regulation 12(1)(b) will facilitate this. Ideally a means of locking off an isolator can be used. Where such facilities are not available, the removal of fuses or links and their being held in safe keeping can provide a secure arrangement if proper control procedures are used.

196 These precautions will prevent the equipment from becoming charged by connection to its own or normal sources of electrical energy but may not alone be sufficient to prevent charging. The presence of electrical energy as a result of electromagnetic induction, mutual capacitance or stored electrical energy may have to be guarded against, for example by applying earthing connections for the duration of the work (temporary earths). The precautions may need to include means of preventing further accumulation of electrical charge, following initial discharge, because latent energy may be stored in the system, for example in the dielectric of high voltage cables. In the case of work upon high voltage power distribution circuits, isolation procedures should include the back-up measure of applying circuit main earths (primary earths) at points of isolation by means of purpose-built facilities.

197 Where work is to be done on or near conductors that have been isolated, the conductors should be proved dead at the point of work before the work starts. Where a test instrument or voltage indicator is used for this purpose this should itself be proved, preferably immediately before and immediately after testing the conductor. (See also regulation 4(3).)

198 The regulation does not preclude the application of a test voltage to equipment provided that this does not give rise to danger.

Written procedures

199 It may also be appropriate for the safety isolation procedures to be formalised in written instructions or house rules. 'Permits-to-work' may form part of the written procedures and their use is considered essential to ensuring a safe system of work where this involves work on the conductors or equipment of high voltage power distribution systems (typically where the working voltage exceeds 1000 volts) or where the system is very complex. Properly formulated and regulated 'permit-to work' procedures focus the minds both of those issuing and of those receiving the permits both on the manner in which the work is to be done and on how the

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equipment has been made safe. Further advice on these procedures and precautions may be found in the guidance listed in Appendices 1 and 2.

Decommissioned equipment

200 Before electrical equipment is decommissioned, dismantled or abandoned for any reason, it should be disconnected from all sources of supply and effective steps taken to ensure that it is dead and cannot inadvertently become re-energised or dangerously charged. It may be necessary to securely mark or otherwise suitably label equipment, circuits, switches etc to guard against inadvertent re-energisation. (See also the requirement for identifying circuits under regulation 12(1).)

13

Regulation

Regulation 14 Work on or near live conductors

No person shall be engaged in any work activity on or so near any live ***conductor*** *(other than one suitably covered with insulating material so as to prevent* ***danger****) that* ***danger*** *may arise unless -*

- *(a) it is unreasonable in* ***all*** *the circumstances for it to be dead; and*
- *(b) it is reasonable in all the circumstances for him to be at work on or near it while it is live; and*
- *(c) suitable precautions (including where necessary the provision of suitable protective equipment) are taken to prevent* ***injury****.*

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Guidance

201 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

202 Regulation 14 addresses the situation where, either permanently or temporarily, danger from conductors is not prevented by the precautions specified in regulation 7(a).

203 The regulation is concerned only with those situations where people are at work on or near live electrical conductors which may foreseeably give rise to danger. Such work is permitted only if conditions (a) and (b) and (c) are satisfied. ‘Work’ is not confined to electrical work but includes any work activity

(a) The need for the conductor to be live

204 If danger may otherwise arise it is always preferable from the point of view of safety that work on or near such electrical equipment should be carried out when that equipment is dead. (See regulation 13 and guidance.) Regulation 14 recognises that there are circumstances, however, in which it is unreasonable, having regard to all relevant factors, for the equipment to be dead while work proceeds. An example of this might be where it was found necessary to undertake some maintenance, checking or repair on a busy section of electric railway track where it would be disproportionately disruptive and costly in many ways for the live conductors to be isolated for the period of the work. Other examples are to be found in the electrical supply industry, particularly live cable jointing, and in much of the work done on telephone network connections.

205 Equipment users should bear in mind at the time of ordering, purchase and installation of plant, the manner of operation, maintenance and repair of the electrical equipment which will be necessary during the life of the plant.

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Guidance

206 It is recommended that the design of electrical equipment and of the installation should eliminate the need for live work which puts people at risk of injury. This can often be done by careful thought at the design stage of installations, for example by the provision of alternative power infeeds, properly laid out distribution systems to allow parts to be isolated for work to proceed and by designing equipment housings etc to give segregation of parts to be worked on and protect people from other parts which may be live.

207 It is recommended that equipment which combines power and control circuitry should be arranged so that the power circuits are physically separate and segregated from logic and control circuits or so placed, recessed or otherwise arranged that the risk of accidental contact is eliminated. Diagnostic work on the low power/voltage circuits may then proceed with less risk to personnel. Where regular measurements of say voltage, current etc are to be made, consideration should be given to appropriate test and measuring equipment, eg voltmeters, ammeters, etc or test points being built into the equipment.

208 Live work includes live testing, for example the use of a potential indicator on mains power and control logic circuits (but see paragraph 220).

209 The factors which would be considered in deciding whether it was justifiable for work to proceed with the conductors live would include the following:

(a) when it is not practicable to carry out the work with the conductors dead, eg where for the purposes of testing it is necessary for the conductors to be live;
(b) the creation of other hazards, by making the conductors dead, such as to other users of the system, or for continuously operating process plants etc;
(c) the need to comply with other statutory requirements;
(d) the level of risk involved in working live and the effectiveness of the precautions available set against economic need to perform that work.

(b) The need to be near uninsulated live conductors

210 People at work are permitted to be near live conductors only if this is reasonable in all the circumstances. If, for example, it would be reasonable for the work to be carried out at a safe distance from the conductors then it would be prohibited for that work to be done near the conductors.

211 People whose presence near the live conductors is not necessary should not be so near the conductors that they are at risk of injury.

(c) The need to take precautions to prevent injury

212 The precautions necessary to comply with regulation 14(c) need to be commensurate with the risk.

213 The system of work should: allow only people who are competent to do so to work on or near exposed, live conductors (competence for these and other purposes is further dealt with at regulation 16); indicate within what limits the work is to be attempted; indicate what levels of competence apply to each category of such work; and incorporate procedures under which the person attempting the work will report back if the limits specified in the system are likely to be exceeded. This usually requires detailed planning before the work is started.

Guidance

214 Suitable precautions should include as appropriate:

(a) the use of people who are properly trained and competent to work on live equipment safely (see also regulation 16);
(b) the provision of adequate information to the person carrying out the work about the live conductors involved, the associated electrical system and the foreseeable risks;
(c) the use of suitable tools, including insulated tools, equipment and protective clothing (see also regulation 4(4));
(d) the use of suitable insulated barriers or screens (see also regulation 4(4));
(e) the use of suitable instruments and test probes;
(f) accompaniment by another person or people if the presence of such person or people could contribute significantly to ensuring that injury is prevented;
(g) the restriction of routine live test work (for example product testing) to specific areas and the use of special precautions within those areas such as isolated power supplies, non-conducting locations etc;
(h) effective control of any area where there is danger from live conductors.

Accompaniment

215 A dutyholder's judgement as to whether someone carrying out work subject to regulation 14 should be accompanied should be based on considerations of how injury is to be prevented. If an accompanying person can substantially contribute towards the implementation of safe working practice, then they should be present. They should be trained to recognise danger and, if necessary, to render assistance in the event of an emergency.

216 Some examples of electrical work where it is likely that the person carrying out the work should be accompanied are:

(a) electrical work involving manipulation of live, uninsulated power conductors at say, 230 volts using insulated tools; and
(b) other work on or near bare live conductors where someone working on their own would not be capable of undertaking the work safely without assistance in, for example, keeping other people from the work area.

Control of the area

217 Effective control of an area where there is danger from live conductors means ensuring that those who are not competent to prevent the occurrence of injury and those whose presence is unnecessary are not permitted into the area. If the person undertaking the work is continuously present while danger exists from the live conductors, and the area is small enough to be under their constant supervision and control, then further precautions to control access may not be necessary. If, however, the area is too large for them to exercise effective surveillance, or they are not continuously present, then effective control will need to be secured by other means such as the provision of lockable enclosures or barriers, and warning notices indicating the presence of live conductors.

(The above examples are given without prejudice to the requirements of regulation 14, the criteria of which must be followed in each case before live work is undertaken.)

14

Guidance

Testing

218 Regulation 14 will often apply to electrical testing. Testing to establish whether electrical conductors are live or dead should always be done on the assumption that they may be live and therefore it should be assumed that this regulation is applicable until such time as the conductors have been proved dead.

219 When testing for confirmation of a 'dead' circuit, the test instrument or voltage indicator used for this purpose should itself be proved, preferably immediately before and immediately after testing the conductors.

220 Although live testing may be justifiable it does not follow that there will necessarily be justification for subsequent repair work to be carried out live.

Protective equipment

221 Examples of protection of someone from the effects of electricity are suitable clothing including insulating helmets, goggles and gloves, insulating materials used as fixed or temporary screening to prevent electric shock and to prevent short circuit between live conductors or between live conductors and earth, insulating mats and stands to prevent electric shock current via the feet and insulated tools and insulated test probes.

222 There should be procedures for the periodic examination and where necessary testing of this protective equipment and replacement as necessary. See also the requirements of regulation 4(4). See Appendices 1 and 2 for further guidance on working procedures, standards etc.

Emergency resuscitation and first aid

223 It may be helpful to place notices or placards giving details of emergency resuscitation procedures in the event of electric shock at those locations where people may be at greater risk of electric shock than most. Such places might include electrical test areas, substations and laboratories but for resuscitation techniques to be effective, those required to exercise them must receive proper training and regular practice. The Health and Safety (First Aid) Regulations 1981 make various requirements for the provision of suitably trained first aiders at places of work.

Work near underground cables and overhead power lines

224 Serious injuries have occurred during excavation and other work near underground power cables and work under or near overhead power lines. This work comes within the scope of regulation 14 if there is a risk of injury from these cables or power lines.

225 Underground power cables present a risk of serious or fatal injury during excavation or similar work, particularly to people using hand tools (eg picks, concrete breakers, etc). Precautions should include:

(a) mapping, recording and marking on site of cable runs;
(b) use of cable locating devices; and
(c) safe digging practices.

226 Overhead power lines may be readily accessible to people working on elevated platforms, scaffolding or roofs. People working with tall vehicles such as cranes, tipper lorries, or farm machinery or handling metal ladders, pipes or other long articles may also be at risk from a flashover or contact with overhead power lines.

14

Guidance 14

227 Well established advice on matters in paragraphs 225 and 226 is given in HSE guidance notes which are listed in Appendix 1.

Regulation

15

Regulation 15 Working space, access and lighting

*For the purposes of enabling **injury** to be prevented, adequate working space, adequate means of access, and adequate lighting shall be provided at all **electrical equipment** on which or near which work is being done in circumstances which may give rise to **danger**.*

Guidance

15

228 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

229 The purpose of the regulation is to ensure that sufficient space, access and adequate illumination are provided while people are working on, at or near electrical equipment so that they may work safely. The requirement is not restricted to those circumstances where live conductors are exposed but applies where any work is being done in circumstances which may give rise to danger. The regulation makes no requirement for such space, access or illumination to be provided at times other than when work is being done. (But see guidance under regulation 12(1)(a), paragraph 187(b) in respect of safe access to means of cutting off the supply.)

Working space

230 Where there are dangerous exposed live conductors within reach the working space dimensions should be adequate:

(a) to allow people to pull back away from the conductors without hazard; and
(b) if people need to pass one another, to do so with ease and without hazard.

231 Among the legal provisions revoked upon the coming into force of these Regulations were the Electricity (Factories Act) Special Regulations 1908 and 1944. Regulation 17 of those Regulations specified minimum width and height dimensions of switchboard passageways where there were bare conductors exposed or arranged to be exposed when live so that they may be touched. That regulation and the relevant definitions used are reproduced at Appendix 3 to this Memorandum. The dimensions specified were arrived at after much consideration of the circumstances in a Public Inquiry at the time that those Regulations were being drafted. However, those dimensions can still be taken as providing guidance for an appropriate level of safety in many circumstances and where the voltages do not significantly exceed 3000 volts. This is not to condone the use of equipment having normally bare and exposed conductors if a safe alternative can reasonably be adopted.

Lighting

232 Natural light is preferable to artificial light but where artificial light is necessary it is preferable that this be from a permanent and properly designed installation, for example in indoor switchrooms etc. However, there will always be exceptions and special circumstances where these principles cannot be achieved where handlamps or torches etc will be the sole or most important means of lighting. Whatever level of lighting is used, it must be adequate to enable injury to be prevented. See Appendix 1 for further guidance on lighting.

Regulation

16

Regulation 16 Persons to be competent to prevent danger and injury

*No person shall be engaged in any work activity where technical knowledge or experience is necessary to prevent **danger** or, where appropriate, **injury**, unless he possesses such knowledge or experience, or is under such degree of supervision as may be appropriate having regard to the nature of the work.*

Guidance

233 The defence (regulation 29) is available in any proceedings for an offence under this regulation.

234 The object of the regulation is to ensure that people are not placed at risk due to a lack of skills on the part of themselves or others in dealing with electrical equipment.

"... prevent danger or, where appropriate, injury ..."

235 This regulation uses both of the terms, 'injury' and 'danger'. The regulation therefore applies to the whole range of work associated with electrical equipment where danger may arise and whether or not danger (or the risk of injury) is actually present during the work. It will include situations where the elimination of the risk of injury, ie the prevention of danger, for the duration of the work is under the control of someone who must therefore possess sufficient technical knowledge or experience, or be so supervised, etc to be capable of ensuring that danger is prevented. For example, where someone is to effect the isolation of some electrical equipment before they undertake some work on the equipment, they will require sufficient technical knowledge or experience to prevent danger during the isolation. There will be no danger from the equipment during the work, provided that the isolation has been carried out properly; danger will have been prevented but the person doing the work must have sufficient technical knowledge or experience so as to prevent danger during that work, for example by knowing not to work on adjacent 'live' circuits.

236 But the regulation also covers those circumstances where danger is present, ie where there is a risk of injury, as for example where work is being done on live or charged equipment using special techniques and under the terms of regulation 14. In these circumstances, people must possess sufficient technical knowledge or experience or be so supervised etc, to be capable of ensuring that injury is prevented.

Technical knowledge or experience

237 The scope of 'technical knowledge or experience' may include:

(a) adequate knowledge of electricity;
(b) adequate experience of electrical work;
(c) adequate understanding of the system to be worked on and practical experience of that class of system;
(d) understanding of the hazards which may arise during the work and the precautions which need to be taken;
(e) ability to recognise at all times whether it is safe for work to continue.

16

Guidance

16

Allocation of responsibilities

238 Employees should be trained and instructed to ensure that they understand the safety procedures which are relevant to their work and should work in accordance with any instructions or rules directed at ensuring safety which have been laid down by their employer.

Supervision

239 The regulation recognises that in many circumstances people will require to be supervised to some degree where their technical knowledge or experience is not of itself sufficient to ensure that they can otherwise undertake the work safely. The responsibilities of those undertaking the supervision should be clearly stated to them by those dutyholders who allocate the responsibilities for supervision and consideration should be given to stating these responsibilities in writing. Where the risks involved are low, verbal instructions are likely to be adequate but as the risk or complexity increase there comes a point where the need for written procedures becomes important in order that instructions may be understood and supervised more rigorously. In this context, supervision does not necessarily require continual attendance at the work site, but the degree of supervision and the manner in which it is exercised is for the dutyholders to arrange to ensure that danger, or as the case may be, injury, is prevented.

240 Further advice on working procedures is given in guidance publications listed in Appendix 1.

241 Note that regulations 17 to 28 inclusive apply only to mines (see SI 1989/635).

Regulation

29

Regulation 29 Defence

In any proceedings for an offence consisting of a contravention of regulations 4(4), 5, 8, 9, 10, 11, 12, 13, 14, 15, 16 or 25, it shall be a defence for any person to prove that he took all reasonable steps and exercised all due diligence to avoid the commission of that offence.

Guidance

29

242 Regulation 29 applies only in criminal proceedings. It provides a defence for a dutyholder who can establish that they took all reasonable steps and exercised all due diligence to avoid committing an offence under regulations 4(4), 5, 8, 9, 10, 11, 12, 13, 14, 15 or 16. (Regulation 25 applies only to mines.)

Regulation

30

Regulation 30 Exemption certificates

(1) Subject to paragraph (2), the Health and Safety Executive may, by a certificate in writing, exempt -

(a) any person;
(b) any premises;
(c) any electrical equipment;
(d) any electrical system;
(e) any electrical process;
(f) any activity,

or any class of the above, from any requirement or prohibition imposed by these Regulations and any such exemption may be granted subject to conditions and to a limit of time and may be revoked by a certificate in writing at any time.

Regulation 30

(2) The Executive shall not grant any such exemption unless, having regard to the circumstances of the case, and in particular to -

(a) the conditions, if any, which it proposes to attach to the exemption; and
(b) any other requirements imposed by or under any enactment which apply to the case,

it is satisfied that the health and safety of persons who are likely to be affected by the exemption will not be prejudiced in consequence of it.

Guidance 30

243 HSE is given power to issue general or special exemptions and to impose conditions and time limits on them. It is a standard power given to allow the variation of legal duties where, in circumstances unforeseen by those drafting the legislation, they are in practice unnecessary or inappropriate. Exemptions would be granted only in very exceptional circumstances.

Regulation 31

Regulation 31 Extension outside Great Britain

These Regulations shall apply -

(a) in Great Britain; and
(b) outside Great Britain as sections 1 to 59 and 80 to 82 of the Health and Safety at Work etc Act 1974 apply by virtue of the provisions of the Health and Safety at Work etc Act 1974 (Application outside Great Britain) Order 1995.

Guidance 31

244 Regulation 31 was modified by the Offshore Electricity and Noise Regulations 1997. Although the regulation refers to the Health and Safety at Work etc Act 1974 (Application outside Great Britain) Order 1995, this order has been revoked and replaced by the Health and Safety at Work etc Act 1974 (Application outside Great Britain) Order 2001 (as amended) and the regulation should be read as referring to the 2001 Order or any subsequent replacements.

245 The Electricity at Work Regulations apply to all work activities on offshore installations, wells, pipelines and pipelines works and to certain connected activities within the territorial waters of Great Britain or in the designated areas of the UK Continental Shelf. They also apply to certain other activities within territorial waters, including the construction and operation of wind farms.

Regulation 32

Regulation 32 Disapplication of duties

The duties imposed by these Regulations shall not extend to -

(a) the master or crew of a sea-going ship or to the employer of such persons, in relation to the normal ship-board activities of a ships crew under the direction of the master; or
(b) any person, in relation to any aircraft or hovercraft which is moving under its own power.

Guidance

32

Sea-going ships

246 Sea-going ships are subject to other electrical safety legislation which gives protection to people on board. Regulation 32 disapplies the Electricity at Work Regulations from these ships as far as the normal ship-board activities of a ship's crew under the direction of the master is concerned. It does not disapply them in respect of other work activities however, for example where a shore-based electrical contractor goes on board to carry out electrical work on the ship. That person's activities will be subject to the Regulations within the general applicability of the Regulations. The Regulations will apply outside Great Britain only as provided for under regulation 31.

Aircraft and hovercraft

247 The Regulations may apply only while an aircraft or hovercraft is not moving under its own power.

Vehicles

248 The Regulations may apply to electrical equipment on vehicles if this equipment may give rise to danger.

Regulation

33

Regulation 33 Revocations and modifications

(1) The instruments specified in column 1 of Part I of Schedule 2 are revoked to the extent specified in the corresponding entry in column 3 of that Part.

(2) The enactments and instruments specified in Part II of Schedule 2 shall be modified to the extent specified in that Part.

(3) In the Mines and Quarries Act 1954, the Mines and Quarries (Tips) Act 1969[(a)] and the Mines Management Act 1971[(b)], and in regulations made under any of those Acts, or in health and safety regulations, any reference to any of those Acts shall be treated as including a reference to these Regulations.

(a) 1969 c.10.
(b) 1971 c.20.

Guidance

33

249 The Regulations replace or modify a number of statutory provisions in accordance with the intention of the HSW Act section 1(2).

250 Systems and equipment which were subject to provisions which have been revoked are now subject to these Regulations.

Appendix 1

HSE publications on electrical safety

Title	***Regulations particularly relevant***
Electrical risks from steam/water pressure cleaners Plant and Machinery Guidance Note PM29 (Second edition) HSE Books 1995 ISBN 978 0 7176 0813 3	4, 6, 7, 8 and 10
Selection and use of electric handlamps Plant and Machinery Guidance Note PM38 (Second edition) HSE Books 1992 Web only: www.hse.gov.uk/pubns/guidance/pm38.pdf	4, 6, 7, 8, 10 and 12
Avoidance of danger from overhead electric powerlines General Guidance Note GS6 (Third edition) HSE Books 1997 ISBN 978 0 7176 1348 9	4, 14, 15 and 16
Electrical test equipment for use by electricians General Guidance Note GS38 (Third edition) HSE Books 1995 ISBN 978 0 7176 0845 4	10, 14 and 16
Electrical safety at places of entertainment General Guidance Note GS50 HSE Books 1997 ISBN 978 0 7176 1387 8	4, 5, 6, 7, 8, 10, 11 and 12
Lighting at work HSG38 (Second edition) HSE Books 1997 ISBN 978 0 7176 1232 1	4, 13, 14 and 15
Avoiding danger from underground services HSG47 (Second edition) HSE Books 2000 ISBN 978 0 7176 1744 9	4, 14 and 16
Electricity at work: Safe working practices HSG85 (Second edition) HSE Books 2003 ISBN 978 0 7176 2164 4	4, 7, 12, 13, 14, 15 and 16
Electrical safety on construction sites HSG141 HSE Books 1995 ISBN 978 0 7176 1000 6 (out of print)	4–16 inclusive
Keeping electrical switchgear safe HSG230 HSE Books 2002 ISBN 978 0 7176 2359 4	4, 5, 6, 11 and 12
Electrical safety and you Leaflet INDG231 HSE Books 1996 (single copy free or priced packs of 15 ISBN 978 0 7176 1207 9) Web version: www.hse.gov.uk/pubns/indg231.pdf	2–16 inclusive

Note: The publications listed in Appendix 1 are available from HSE Books (see ‘Further information’ for address etc).

Appendix 2

Other publications having an electrical safety content

Standards, Codes of Practice and other publications which contain guidance relevant to the Regulations and electrical safety, which have been published by bodies other than HSE, are given in this appendix. Most of these documents are the product of technical committees on which HSE has been represented. This does not mean, however, that the documents are concerned solely with safety and users should bear in mind the scope of the safety content of these documents and the fact that they have largely been arrived at through a process of consensus.

Note: British Standards Institution publications can be obtained in PDF or hard copy formats from the BSI online shop: www.bsigroup.com/Shop or by contacting BSI Customer Services for hard copies only Tel: 020 8996 9001 e-mail: cservices@bsigroup.com.

(BS = British Standard)

Title of publication	***Principal regulations relevant***	***Comments***
DD IEC/TS 60479-1:2005 *Effects of current on human beings and livestock. General aspects* PD 6519-2:1998, IEC 60479-2:1987 *Guide to effects of current on human beings and livestock. Special aspects relating to human beings*	2	Definition of 'danger' and 'injury' - electric shock
IEC Guide 105 *Principles concerning the safety of equipment electrically connected to a telecommunications network*	2	Ditto, on telecommunication systems
IEC 61201:1992 *Extra-low voltage (ELV) – Limit values*	2	Electric shock - sets out limit values
BS 7671:2008 *Requirements for Electrical Installations. IEE Wiring Regulations. Seventeenth edition* BS 7909:2008 *Code of practice for temporary electrical systems for entertainment and related purposes*	4(1), 5-12 inclusive	Selection of equipment and construction of installations up to 1000 volts ac
BS 4363:1998 *Specification for distribution assemblies for reduced low voltage electricity supplies for construction and building sites*	4, 6, 10	
BS 7375:1996 *Code of practice for distribution of electricity on construction and building sites*	4, 6, 10	
BS EN 60439-1:1999 *Low-voltage switchgear and controlgear assemblies. Type-tested and partially type-tested assemblies* BS EN 62271-100:2009 *High-voltage switchgear and controlgear. Alternating current circuit breakers*	4, 5, 12, 15	Particular attention for switchgear clearance distances. Safety clearances and work sections
BS 6423:1983 *Code of practice for maintenance of electrical switchgear and controlgear for voltages up to and including 1 kV*	4(2), 4(3), 12, 13	Precautions to secure safety of maintenance, personnel isolation procedures
BS 6626:1985 *Code of practice for maintenance of electrical switchgear and control gear for voltages above 1 kV and up to and including 36 kV*	4(2), 4(3), 12, 13	Precautions to secure safety of personnel

Title of publication	***Principal regulations relevant***	***Comments***
BS 6867:1987 *Code of practice for maintenance of electrical switchgear for voltages above 36 kV*	4(2), 4(3), 12, 13	Ditto
BS EN 60204-1:2006 *Safety of machinery. Electrical equipment of machines. General requirements*	4, 6	
BS EN 60903:2003 *Live working. Gloves of insulating material*	4(4), 14	
BS 921:1976 *Specification. Rubber mats for electrical purposes*	4(4), 14	Mats for covering floor near electrical equipment where direct contact may occur
BS EN 60529:1992 *Specification for degrees of protection provided by enclosures (IP Code)*	6, 7	Index of Protection (IP) system against contact with live and moving parts and ingress of solids and moisture and Finger Test
BS EN 60947-1:2007 *Low-voltage switchgear and controlgear. General rules*	6, 7	Ditto
BS EN 60034-5:2001 *Rotating electrical machines. Degrees of protection provided by the internal design of rotating electrical machines (IP Code). Classification*	6, 7	Index of Protection (IP) system against contact with live and moving parts and ingress of solids and moisture
BS EN 60079-14:2008 *Explosive atmospheres. Electrical installations design, selection and erection*	4(1), 4(2), 6	
BS EN 60079-0:2006 *Electrical apparatus for explosive gas atmospheres. General requirements*	4(1), 6	
BS EN 50050:2006 *Electrical apparatus for potentially explosive atmospheres. Electrostatic hand-held spraying equipment*	6	Protection against ignition
BS EN 61241-1:2004 *Electrical apparatus for use in the presence of combustible dust. Protection by enclosure 'tD'*	6	Ditto
BS EN 61241-14:2004 *Electrical apparatus for use in the presence of combustible dust. Selection and installation* BS EN 60079-17:2007 *Explosive atmospheres. Electrical installations inspection and maintenance*	4, 5, 6	Ditto
BS EN 62305-1:2006 *Protection against lightning. General principles*	6	As relevant to protection of electrical equipment from lightning
PD CLC/TR 50404:2003 *Electrostatics. Code of practice for the avoidance of hazards due to static electricity*	6	Precautions against ignition and electric shock
BS 4444:1989 *Guide to electrical earth monitoring and protective conductor proving*	8	
BS 7430:1998 *Code of practice for earthing*	8	

Title of publication	*Principal regulations relevant*	*Comments*
BS EN 60947-3:1999 *Specification for low voltage switchgear and controlgear. Switches, disconnectors, switch disconnectors and fuse-combination units*	12	
BS 2754:1976 *Memorandum. Construction of electrical equipment for protection against electric shock*	7, 8	
BS EN 81-1:1998 *Safety rules for the construction and installation of lifts. Electric lifts*	15	Clear areas in front of electric equipment specified (Clause 6.3.3.1)
BS EN 62271-102:2002 *High voltage switchgear and controlgear. High voltage alternating current disconnectors and earthing switches*	12	

Appendix 3

Working space and access; historical comment on revoked legislation (see regulation 15)

Among the legal provisions revoked upon the coming into force of the Electricity at Work Regulations 1989 were the Electricity (Factories Act) Special Regulations 1908 and 1944. Regulation 17 of those Regulations specified minimum width and height dimensions of ‘switchboard passage-ways’ if there were ‘bare conductors’ exposed or arranged to be exposed when ‘live’ so that they may be touched. These related to what are commonly known as ‘open type’ switchboards which had much exposed copper work, knife switches etc. That regulation (and the key definitions used at that time) are reproduced below for information. The dimensions which were specified by that regulation were arrived at after much consideration of the circumstances at the time. A compromise was struck between the objective of achieving the safety of those who had to work at and operate these ‘open type’ switchboards and the need to recognise the constraints imposed by the installations existing and the nature of the technology in 1908. Even though the dimensions were a compromise, it was widely recognised that they were a good minimum standard which had been found necessary following a number of severe and fatal accidents in factories and power stations due to inadequate space or cluttered access in the vicinity of bare live conductors at these ‘open type’ switchboards. The dimensions chosen allowed workmen to operate or otherwise work upon the switchboard in reasonable safety and allowed, for example, people to pass one another in the switchboard passageway without being placed at unacceptable risk of touching live conductors.

Where the need does arise to work on or near live conductors, the principles of providing adequate working space and uncluttered access/egress, which were expressed in regulation 17 of the Electricity (Factories Act) Special Regulations 1908 and 1944, should be given proper consideration.

Regulation 17 (of 1908 Regulations)

At the working platform of every switchboard and in every *switchboard passage-way*, if there be *bare conductors* exposed or arranged to be exposed when *live* so that they may be touched, there shall be a clear and unobstructed passage of ample width and height, with a firm and even floor. Adequate means of access, free from danger, shall be provided for every *switchboard passage-way*.

The following provisions shall apply to all such *switchboard* working platforms and *passage-ways* constructed after January 1, 1909 unless the bare conductors, whether overhead or at the sides of the *passage-ways*, are otherwise adequately protected against *danger* by divisions or screens or other suitable means:

(a) Those constructed for *low pressure* and *medium pressure switchboards* shall have a clear height of not less than 7 ft and a clear width measured from *bare conductor* of not less than 3 ft.
(b) Those constructed for *high pressure* and *extra high pressure switchboards*, other than operating desks or panels working solely at *low pressure*, shall have a clear height of not less than 8 ft and a clear width measured from *bare conductor* of not less than 3 ft 6 in.
(c) Bare conductors shall not be exposed on both sides of the *switchboard passageway* unless either (i) the clear width of the passage is in the case of *low pressure* and *medium pressure* not less than 4 ft 6 in and in the case of *high pressure* and *extra high pressure* not less than 8 ft in each case measured between bare conductors, or (ii) the *conductors* on one side are so guarded that they cannot be accidentally touched.

Key definitions used in the 1908 Regulations

Switchboard means the collection of switches or fuses, *conductors*, and other *apparatus* in connection therewith, used for the purpose of controlling the current or pressure in any *system* or part of a *system*.

Switchboard passage-way means any passage-way or compartment large enough for a person to enter, and used in connection with a *switchboard* when *live*.

Low pressure means a *pressure* in a *system* normally not exceeding 250 volts where the electrical energy is used.

Medium pressure means a *pressure* in a *system* normally above 250 volts, but not exceeding 650 volts, where the electrical energy is used.

High pressure means a *pressure* in a *system* normally above 650 volts, but not exceeding 3000 volts, where the electrical energy is used or supplied.

Extra-high pressure means a *pressure* in a *system* normally exceeding 3000 volts where the electrical energy is used or supplied.

Further information

HSE priced and free publications can be viewed online or ordered from www.hse.gov.uk or contact HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA Tel: 01787 881165 Fax: 01787 313995. HSE priced publications are also available from bookshops.

For information about health and safety ring HSE's Infoline Tel: 0845 345 0055 Fax: 0845 408 9566 Textphone: 0845 408 9577 e-mail: hse.infoline@natbrit.com or write to HSE Information Services, Caerphilly Business Park, Caerphilly CF83 3GG.

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Innovation and Market Design

Peter Cramton, *University of Maryland*

Executive Summary

Market design plays an essential role in promoting innovation. I examine emission allowance auctions, airport slot auctions, spectrum auctions, and electricity markets and demonstrate how the market design can encourage innovation. Improved pricing information is one source of innovation. Enhancing competition is another driver of innovation seen in all the applications. Market design fosters innovation in other ways as well by addressing other potential market failures.

I. Introduction

Market design determines the rules under which market participants interact. In this chapter, I argue that market design can play an essential role in promoting innovation. Fundamentally, this is done by establishing rules that strengthen the incentives for innovation. Enhancing competition is one common way the market design encourages innovation. This is seen in all the examples I present. Improved price information is another. Better price information reduces innovation risk and improves decisions to innovate. Innovation is also encouraged by identifying other sources of market failure and then mitigating these potential failures through the market rules.

I discuss four important applications of market design: (1) emission allowance auctions, (2) airport slot auctions, (3) spectrum auctions, and (4) electricity markets. For each I describe how the market design can foster innovation.

Emission allowance auctions illustrate the important role of using prices to motivate innovation. In contrast to command-and-control approaches to managing pollution, emission allowance auctions—part of cap and trade programs—price the scarce allowances for the various

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pollutants. Firms can then respond to the prices and make efficient decisions, both short-term and long-term, on how best to reduce emissions. In this way, the environmental goal can be achieved at least cost. The objective of the market is to provide reliable price information for each of the pollutants and enable market participants to purchase the desired portfolio of allowances. The market design allows for both forward and spot purchase.

Airport slot auctions are a preferred method of allocating scarce runway capacity at congested airports, such as those serving New York City. An open auction prices and assigns the scarce runway capacity, which has desirable benefits for investment and operation, as was the case with emission allowances. In addition, an airport slot auction can be designed to encourage competitive entry. The alternative of giving airport slots to incumbent carriers and then allowing trade has proved to be ineffective. Trades other than barter transactions among incumbents have not taken place. In contrast, a well-designed auction of airport slots provides a viable opportunity for entrants to secure the slots needed to provide an innovative service.

Spectrum auctions have promoted the efficient pricing and assignment of radio spectrum for wireless services. The market design has played a key role in enhancing competition and innovation in wireless services. State-of-the-art auction designs allow the band plan and technology choices to be made by the bidders rather than being set by the regulator before the auction. Innovative technologies and business models can then compete on par with the incumbent approaches. Technology-neutral auction designs are currently being implemented in the United Kingdom.

Electricity market design demonstrates how the product design can play an important role in enhancing competition, reducing risks, and promoting innovation on the demand side as well as on the supply side. Wholesale electricity markets are organized as a number of auctions: long-term investment markets for capacity (or firm energy in the case of hydro systems), medium-term auctions for forward energy, and spot auctions for day-ahead and real-time electricity. These markets price a variety of products at different times and locations. Good designs mitigate market power problems that frequently can arise, especially during times of scarcity. Forward capacity auctions coordinate the efficient investment in new capacity. In addition, by bundling a call option to provide energy at prices above a strike price, the auction greatly mitigates incentives to exercise market power during times of spot scarcity. The forward energy market provides an additional hedge to customers at lower energy prices. The two markets combined go a long way toward eliminating market power in the spot market, improving the dispatch of energy resources. The product definition in the forward energy market can also encourage innovation on the demand side. Customers with hourly meters can be hedged for their expected energy purchase, thereby reducing risk, yet exposed on the margin to the hourly price. This exposure motivates demand response and investment in innovative demand management systems.

Auction applications are rapidly expanding. Communication and computational advances have certainly played an important role, but the development of simple and powerful auction methods has been important too. Market designers now have a much richer set of tools to address more complex problems.

I now discuss each of the four applications—emission allowances, airport slots, spectrum, and electricity—in greater detail. Each application uses auctions to facilitate the efficient allocation of scare resources, promote competition, and foster innovation.

II. Emission Allowance Auctions

In many settings, there are essential gains from government policies to curb pollution. Humans have an ever expanding ability to destroy or preserve our environment. In the past, pollution has been addressed through command-and-control regulation. Governments establish specific rules that describe what pollution abatement measures must be taken. The problem of course is that the government setting the rules has limited knowledge about the costs and benefits of various approaches across emitters. Indeed, the government is not even aware of the full set of abatement methods. As a result, inflexible and inefficient rules are established.

The alternative, which is fast growing in popularity, is for the government to use a market-based approach to pollution control. The lead examples are cap and trade programs, which are now used for global pollutants such as carbon dioxide as well as regional and local pollutants such as sulfur dioxide and nitrogen oxides. The idea is simple. The government focuses on establishing the environmental goal: setting a cap on the maximum quantity of each pollutant. Then it relies on competitive auctions to price the scarce resource—emission allowances. There is no need to tell emitters whether and how each should reduce its emissions. Rather, the abatement decision making is done by each emitter on the basis of the price information determined in competitive auctions. In this way, the environmental goal is achieved at least cost. Each emitter reduces emissions to the point at which the auction price of allowances is equal to the emitter's marginal cost of abatement. Reductions are done by those who can reduce emissions at least cost.

A key advantage of the approach is the enormous flexibility each emitter has to manage its emissions strategy. In addition, the approach is simple. Prices are used to motivate the emitter to adopt efficient approaches on the basis of today's abatement measures. Prices also motivate the development of new abatement techniques—techniques that are both less expensive and more effective at reducing emissions. In contrast, with command and control there is no incentive for the development of new techniques; rather the incentive is to find ways to satisfy the command at least cost, which may actually undermine the environmental goal.

Experience with cap and trade programs, such as the U.S. acid rain program, has confirmed the economic insight that prices are effective at achieving environmental goals at least cost and foster innovative techniques for abatement going forward (Ellerman et al. 2000).

Market designs that provide better price information both in the short term and in the long term will be more effective. When there are several pollutants, a simultaneous ascending clock auction can allow emitters to bid for an efficient portfolio of emission allowances (Ausubel and Cramton 2004). Forward auctions can allow emitters to lock in prices early as part of a risk reduction strategy. These forward prices are especially useful in motivating efficient investment decisions for longer-run abatement approaches.

Emission markets are relatively simple, especially for a global pollutant such as carbon. Carbon allowances are a homogeneous good that can be defined broadly. Complicating factors such as time and place are less important. Competitive factors and network factors are also less important. As we will see, the other applications I look at must deal with each of these complicating factors, so more complex market designs are required. Nonetheless, the foundation for each is the same: auctions are used to price and assign scarce resources efficiently.

III. Airport Slot Auctions

Package auctions have been proposed for auctioning takeoff and landing rights at congested airports, such as the three New York City airports (Ball et al. 2007). The goal of the auction is to make the best use of the scarce runway capacity. Left to their own devices, airlines will overschedule flights during peak hours, creating congestion and costly delay. The package auction enables each airline to bid for its preferred package of slots. The resulting competitive prices motivate airlines to substitute away from expensive slots, either by shifting flights to less expensive times or by using larger aircraft to carry the same passengers with less runway use.

Some airports, such as New York LaGuardia or Washington National, manage congestion by limiting the number of scheduled operations in any 15-minute period to the airport's capacity. The airport slots are assigned on the basis of historical use and negotiation. Then the participants can trade slots as desired. What we have learned after many years with this approach is that there is almost no liquidity in the market for airport slots. Despite large changes in the industry, there are few trades, and the few trades that do occur tend to be barter transactions between two airlines. Prices for airport slots are not established, and an airline, such as a new entrant, is unable to buy any significant number of slots on the market. As a result, the airport slot cap serves as an entry barrier, limiting competition and discouraging the efficient use of the runway capacity. In addition, use-it-or-lose-it rules cause airlines with surplus slots to schedule more small-plane operations rather than sell or lose the excess slots.

An airport slot auction promises to improve the allocation of airport slots as a result of transparent pricing and improved liquidity for slots. Liquidity is important in this application since airlines require a critical mass of routes to and from the airport, and each route requires a minimum number of operations each day. Shifts in strategy are apt to involve many slots. An auction allows for entry and exit in a dynamic industry.

An alternative to an auction is congestion pricing. Both seek efficient pricing. Auctions can be designed with a multiyear lease and, thereby, more stability in airline planning. Congestion pricing gives airlines more flexibility to change schedules. The difficulty with congestion pricing is establishing a workable process for setting prices. This process is apt to become politicized, and in any event, determining the market-clearing prices without an auction is challenging.

A common critique of a slot auction is that it is just another tax that will raise prices to consumers and limit service. This is wrong in several ways. First, the auction is not a tax, but a method for efficiently pricing a scarce resource—runway capacity. Indeed, the revenues from an auction can displace the distortionary passenger fees and weight-based fees. Revenues can also be used to improve airport infrastructure, say to encourage more flexible use of airport facilities. Second, in airports that limit scheduling to capacity, the scarcity price is already reflected in the airline's fare. Finally, slot auctions do not limit service, but rather constrain scheduling to be consistent with runway capacity. When schedules are not constrained to physical limits, the result is congestion and delay, not increased through-put.

Consumers benefit most from a slot auction. The immediate benefits are reduced congestion and delay and improved predictability. Travel costs are reduced, especially for the time-sensitive business traveler. In the longer term, consumers benefit from enhanced competition and innovation. Even just the threat of entry can cause airlines to reduce costs and improve services.

A slot auction also has benefits for airlines. With fewer delays and more predictable schedules, airlines save fuel, labor, and capital. Since business travelers put a premium on predictability and short trips, demand for business travel—the most profitable segment of the market—expands. Larger and fuller planes translate into more profit per flight.

I now describe the mechanics of one proposed airport slot auction with illustrative parameters. The product is the right to schedule a landing within a particular 15-minute time interval and a takeoff within 90 minutes of landing. Bundling a landing and takeoff makes sense since every landing requires a takeoff. The number of slots is determined by the Federal Aviation Administration (FAA) on the basis of through-put.

Since schedules are done on roughly a yearly basis and commitments to airports and routes are longer term, a 5-year term for the slot is reasonable. The terms are staggered so that 20% of the slots expire each year. These slots are auctioned every year, providing annual liquidity and price information. Secondary market trades of both the primary product and derivatives are also allowed.

A single simultaneous auction is held for all congested airports. The annual auction is a package clock auction. All slots are up for auction at the same time. Bids are always for packages of slots: the bidder wins one of its desired packages or nothing. As a result, there is no risk that the bidder will win just part of what it needs.

The auction begins with an ascending clock stage. The auctioneer announces prices, and then the bidders respond with the quantity demanded at these prices. Prices then increase on slots with excess demand, and bidders again respond with demands at the new prices. The process continues until there is no excess demand for any slot. The clock stage provides essential price discovery during the auction. The prices help focus each bidder's valuation efforts on the most relevant packages of slots.

A supplementary round follows the clock stage. Bidders can improve their clock bids and submit additional package bids.

On the basis of the set of all package bids, the auctioneer then determines the value-maximizing assignment of slots and the prices for slots in each time interval. To encourage truthful bidding, a second price rule may be used as described in greater detail in the next section.

This design has been well tested in the two applications discussed next: spectrum auctions and electricity auctions. It has also been tested in the experimental lab and found to have excellent efficiency properties. In addition, in February 2005, a test auction with the FAA, airport, and airline participants was conducted to demonstrate the feasibility of the approach.

The package clock auction gives airlines a simple and effective way to express preferences for packages of slots. Given these preferences, the auction then determines the efficient assignment of slots and prices.

Efficient pricing of slots motivates airlines to adjust schedules. Flights are shifted to less congested hours. Larger planes and fewer flights are used to serve the same number of passengers. These adjustments are managed in a flexible way by each airline.

Importantly, the package clock auction facilitates efficient entry and exit. In part this comes from transparent pricing and liquidity in the market for slots but more directly from the package auction, which enables a new entrant to bid for and win the package of slots it desires.

Although slot auctions have been discussed for at least 20 years, the application is still in the proposal stage. It may be some time before the benefits of slot auctions are seen in practice. In contrast, our next application, spectrum auctions, has been an active area of both design and implementation for 14 years. The benefits of the approach are not speculative.

IV. Spectrum Auctions

Since 1994, spectrum auctions have been used to assign and price scarce radio spectrum for wireless communication services in the United States and elsewhere. Before auctions, beauty contests, in which companies lobby the regulator for spectrum, were the primary method of assigning spectrum. Beauty contests were both slow and costly, so slow in the United States that, despite developing the cellular technology in the 1960s, by the 1980s the United States had fallen behind both Europe and Japan in developing and deploying the technology. Innovation clearly was harmed by an ineffective method of assigning and pricing spectrum. Beginning in July 1994, the United States switched to auctions. Auctions allowed the spectrum to quickly get in the hands of those best able to use it. Competition increased. Consumers enjoyed lower prices and improved services. Throughout this period, the market for wireless communications has been characterized by rapid growth and innovation.

The spectrum auction application involves assigning many items that are heterogeneous but similar. Often there are competing technologies that make use of the spectrum in different ways and therefore require a different organization of the spectrum. There is a complex structure of substitutes and complements, and this structure varies across bidders.

The government's primary objective is efficiency: make the best use of the scarce spectrum resource. To a large extent this involves assigning the spectrum to the companies that value it the most, although there are also important competition issues in the downstream market for wireless services that further complicate the market design problem.

A. Simultaneous Ascending Auction

In July 1994, the Federal Communications Commission (FCC) began using the simultaneous ascending auction to award spectrum licenses. The approach has been replicated around the world with minor variations and has become the standard approach for assigning and pricing spectrum (Cramton 2002, 2006; Milgrom 2004). The FCC now has conducted over 67 auctions using the simultaneous ascending auction. Roughly 59,000 licenses have been auctioned, with winning bids exceeding $79 billion. Over the last dozen years, enhancements to the design have appeared, but the enhancements have been evolutionary, not revolutionary.

The popularity and durability of the design are a reflection of its many desirable properties. Simplicity is an important virtue. The simultaneous ascending auction is easily described and understood. It is a natural generalization of the English auction when selling many related lots. All the lots are auctioned at the same time. Each lot has a price and a high bidder associated with it. The bidders can bid on any of the lots by raising the high bid. The bidding continues until no bidder is willing to raise the bid on any of the lots. Then the auction ends with each bidder winning the lots on which it is the high bidder and paying its bid for any lots won.

A transparent process of price discovery is another key virtue. As the auction progresses, bidders see the tentative price information and condition subsequent bids on this information. Over the course of the auction, bidders are able to develop a sense of what the final prices are likely to be and can adjust their purchases in response to this price information. To the extent price information is good and the bidder retains sufficient flexibility to shift toward its best package, the bidder is able to piece together a desirable package of lots. Moreover, the price information helps each bidder focus its valuation effort on relevant packages.

To encourage price discovery, an activity rule requires each bidder to maintain a level of bidding activity throughout the auction or have its eligibility reduced in future rounds. Each lot has a number of eligibility points, based on the size of the lot, typically measured as the product of the bandwidth (megahertz [MHz]) and the population coverage of the lot. A bidder's initial eligibility is determined by its deposit at qualification. The bidder must be active on a specified percentage of its eligibility or its eligibility is reduced. A bidder is active on a lot either if it is the current high bidder or if it places a bid on the lot. The bidder's total activity in the round is the sum of the eligibility points on all lots the bidder is active in. Typically, the required activity percentage is less than 100% early in the auction to give the bidder greater flexibility but is 100% or close to 100% later in the auction. With a 100% activity requirement, the quantity of spectrum a bidder bids for can only stay the same or fall as prices rise. This prevents the bidder from bid sniping—waiting until the end of the auction to reveal its true demand.

A main simplification is accepting bids only for individual lots rather than for packages. As a result, a bidder may attempt to win a synergistic package of lots but may later find that the package is too expensive and yet remain a high bidder on some of the lots in the package. The auction allows bid withdrawals to enable the bidder to back out of a failed aggregation of lots. To maintain the credibility of bids, the withdrawing bidder remains on the hook for assuring that the seller receives at least the amount of the withdrawn bid in revenues: the withdrawing bidder must make up any shortfall between its bid and the eventual sale price. This ability to withdraw bids is intended to mitigate the exposure the bidder faces of the possibility of winning just some of what it needs.

For reasons of transparency and also price discovery, the auctioneer reports all the bids made by each bidder at the end of each round.

Despite the simplicity of the rules, the simultaneous ascending auction is complex for bidders. The reason is that bidders often have strong incentives to engage in various gaming strategies, which undermine efficiency.

In summary, the simultaneous ascending auction has many strengths. It is a simple price discovery process. Bidders can arbitrage across substitutes and piece together desirable packages of complementary licenses. The price discovery reduces common value uncertainty and the winner's curse.

At the same time, years of experience has demonstrated important weaknesses in the design, which can reduce efficiency. Large bidders engage in demand reduction strategies to reduce the prices paid for the spectrum (Ausubel and Cramton 2002). Tacit collusion has also been a problem, with bidders proposing splits of the spectrum through their bids (Cramton and Schwartz 2002). The activity rule has led to various parking strategies, where eligibility is maintained by bidding on spectrum that the bidder does not desire. Since bids are for individual lots, a bidder is exposed to the risk of winning some of what it needs. Speculators engage in various holdup strategies. Finally, depending on how the spectrum is divided into lots by the regulator, the substitution across blocks may be limited.

Limited substitution has been especially problematic in the two most recent spectrum auctions in the United States: the Advanced Wireless Services (AWS) auction and the 700 MHz auction. In both auctions, the FCC, in order to accommodate the needs of a diversity of bidders, split the bandwidth into blocks of various sizes and then used a number of different geographic partitions for licensing. Lot sizes varied from large regional licenses with six covering the continental United States to small submarkets, requiring 734 lots to cover the nation. This heterogeneity in lot sizes undermines substitution. Despite the simultaneous sale, bidding in the AWS auction was largely sequential. Blocks with large regional lots were bid on first, followed in turn by the blocks with smaller lots. A bidder seeking large regions would start out bidding for the large lots. If prices got too high, it could switch down to the small lots, but it would find it almost impossible to switch back up to the large lots since it would likely remain the high bidder on many of the small lots. This one-way substitution means that the bidder must guess the right time to drop down to the smaller licenses. If the bidder waits too long, it may overpay for the large lots; if the bidder drops down too early, it may overpay for the small lots. In the AWS auction, concluding in September 2006, the limited substitution led to large price differences across substitute blocks throughout the auction. At the end, the blocks with small lots sold for a 40% discount relative to the blocks with large lots. In the 700 MHz auction, concluding in March 2008, the difference in prices across blocks was even more extreme, but this time in the other direction: the block with the small lots sold at a price several times higher than the price of the block with the largest lots.

Given the packaging limitations of the simultaneous ascending auction, there is a strong tendency for the regulator to address these limitations with a band plan that offers something for everyone. The basic problem with this approach is that it tends to resolve matters that should be settled in the auction. The more the band plan is tailored to fit the needs of particular bidders, the less competition in the auction and the less efficient the outcome. The auction has little to do if the band plan makes clear who should win what.

B. Package Clock Auction

With a package auction, bidders can express preferences for complementary items without running the risk that they will win just some of what they need. This is important, for example, in spectrum auctions in which different technologies require that the spectrum be organized in different ways. In the past, the regulator has been forced to decide how the spectrum is organized with a specific band plan—effectively deciding how much spectrum is available for each technology. A package auction enables the regulator to conduct a technology-neutral auction, which lets the bidders determine the band plan through their competitive bids. A good example is the United Kingdom's 2.6-gigahertz (GHz) auction of 2008: the quantity of paired versus unpaired spectrum is determined in the auction, not by the regulator. Some technologies, such as Long Term Evolution, require paired spectrum; others, such as WiMax, require unpaired spectrum.

One of the challenges of package auctions is finding an effective way for bidders to convey preferences. There are simply too many packages to ask for preferences for all possible packages. A common approach is to begin with a clock auction (Porter et al. 2003; Ausubel and Cramton 2004; Ausubel, Cramton, and Milgrom 2006). The auctioneer names a price for each product, and each bidder responds with its most preferred package. The price is then raised on all products with excess demand, and the bidding continues. This price discovery process focuses the bidders' attention on packages that are most relevant. Once this price discovery is over, the bidders are in a much better position to submit any additional bids, as well as to improve the bids already submitted. An optimization is then done to determine the value-maximizing assignment as well as competitive prices that satisfy the stability constraints. Typically, there are many such prices, so a further optimization is done to find the prices that provide the best incentives for truthful bidding. This is the basis for the package clock auction, introduced in the last section. It addresses the deficiencies of the simultaneous ascending auction.

This basic design is being used for a series of spectrum auctions in the United Kingdom and has been proposed for an auction in the Netherlands. The design is readily tailored to alternative settings.

Here are some of the important design choices of the United Kingdom's 2.6 GHz auction to assign 190 MHz of spectrum.

• *Generic 5 MHz lots*. The use of generic, rather than specific, lots is a huge simplification. This improves substitution, enhances competition, and greatly simplifies bidding. Further, a winner's lots are guaranteed to be contiguous, which makes the spectrum more valuable. Generic lots are appropriate in this auction since the value differences of specific assignments are likely second order. The bidder's main determinant of value is the quantity of paired or unpaired spectrum won.

• *Package bids*. There is no exposure problem since the auction uses package bids. A bid specifies the number of paired and unpaired lots from 2,500 to 2,690 MHz. The number of packages is modest, thanks to the generic lots.

• *Clock stage*. The auction begins with a clock stage. Typically, only a single price is needed: the price of a generic 5 MHz lot from 2,500 to 2,690. The clock stage provides excellent and simple price discovery. The simplicity of the process is enhanced by generic lots.

• *Activity rule*. A simple yet powerful activity rule improves price discovery. As prices increase, a bidder cannot increase the size of the package.

• *Supplementary bids*. At the end of the clock stage, each bidder can improve its clock bids as well as bid on any other packages that appear desirable given the information revealed in the clock stage. For packages that are larger than the bidder's final clock bid, the supplementary bid has an upper bound. In particular, the supplementary bid can be no more than the package price at the clock prices from the round in which the bidder first shifted to a package that is smaller than the supplementary package.

• *Assignment stage*. The assignment stage translates the generic winnings of the clock stage into a specific assignment for each winning bidder. This is a sealed-bid combinatorial auction in which each bidder may submit top-up bids for each feasible package consistent with the bidder's winnings. The value-maximizing assignment is determined.

• *Pricing rule*. Incentives for truthful bidding are enhanced through the use of "second pricing" (bidder-optimal core pricing). This rule is used to determine base prices both for the generic assignments and for the additional payment for the specific assignment.

The design is both highly practical and theoretically sound. Although the design is complex, my view is that it is as simple as possible, given the complex problem that the auction is asked to solve. Any further simplifications would compromise one or more of the objectives of the auction. In addition, much of the complexity of the rules has the effect of simplifying bidder decision making. The design allows each bidder to focus on its demand for paired and unpaired spectrum rather than complex gaming strategies.

I have conducted a series of mock auctions for Ofcom, the U.K. regulator, to test the auction design. The mock auctions demonstrated the high efficiency of the package clock auction. Twelve auctions were conducted with realistic scenarios and well-motivated and experienced bidders. In 11 out of 12 mock auctions, full efficiency was achieved. In the single inefficient mock auction, the inefficiency was the result of bidder error—the failure of a single bidder to submit her supplementary bids. Both the assignment and prices were identical to the theoretical benchmark. Base prices were at or close to opportunity cost (Vickrey prices) in all cases, despite some complementarities.

The scenarios were constructed to span a wide range of outcomes. In some, the paired bidders were so strong that the unpaired bidders won the minimum quantity of nine. In others, the unpaired bidders were so strong that all the spectrum went to unpaired bidders. In still others, there was a good mix of paired and unpaired winners.

I evaluated the mock auctions with respect to six measures.

• *Efficiency*. The outcomes were highly efficient in a full-scale mock auction with realistic preferences and well-motivated subjects.

• *Robustness*. The desirable properties of the package clock auction were robust to different levels of competition and different demand structures.

• *Risk*. Variation in outcomes was the result of different valuation models. High efficiency and other desirable properties were observed in all mock auctions.

• *Simplicity for bidders*. Subjects were able to understand the auction format and participate in the full-scale mock auction after only a few hours of training. Strategic considerations were easy to manage.

• *Revenues*. The mock auctions achieved competitive revenues. There was little tendency to overbid or underbid.

• *Simplicity for the auctioneer*. The full-scale mock auctions were readily conducted. The mock auctions demonstrated the feasibility of implementation.

The success of these mock auctions leads me to conclude that the package clock auction should perform well in the 2.6 GHz environment as well as related environments. As a result, I expect it to be adopted more broadly.

C. Competition Issues

Assigning the spectrum to those companies with the highest value goes a long way to fostering innovation. This has been readily apparent over the last 14 years of spectrum auctions. Nonetheless, there is good reason to think that there may be a divergence between the bidder's private value and its social value of the spectrum, as a result of the bidder's current position in the market. Incumbents typically have an incentive to limit competition. To avoid foreclosure of new entry, the market design needs to address this important asymmetry between incumbents and new entrants (Jehiel and Moldovanu 2000; Cramton, Skrzypacz, and Wilson 2007).

Since oligopoly rents fall as competition increases, an incumbent has an incentive to foreclose new entry. The incumbent's value consists of its economic value of incremental spectrum plus the value of deterring entry. Since an entrant's value is just its economic value of the spectrum, it is certainly possible for the entrant to have a higher economic value for the spectrum; yet the incumbent is willing to pay more as a result of its foreclosure value. This potential inefficiency is strongest when there are only a few strong incumbents. Then the benefits of foreclosing entry are greater, and the ability of the incumbents to coordinate on an entry-blocking strategy are greater.

The first U.S. broadband auction provides an excellent illustration. At the time of that auction at the end of 1994, there were two cellular operators in each U.S. market. The auction sold two additional large licenses in each market. The FCC understood the importance of competition in the downstream market for wireless services and took essential steps to enhance competition. Specifically, the auction rules forbid either cellular incumbent from bidding on the licenses, and an entrant could win at most one in any geographic market. As a result, the auction resulted in two new entrants in each market.

If instead the FCC had ignored the competition issue, then I suspect that each incumbent would win one large license in each of the markets. Doing so would maintain the substantial duopoly profits, and "each incumbent wins one" is an obvious strategy for coordinating the foreclosure of entry by the duopolists. Indeed, it is unlikely that the incumbents would face much competition in the auction since potential entrants would see the futility of bidding against the incumbents.

This restriction on incumbents, implemented as a spectrum cap, was arguably the most important feature of the initial market design in fostering competition and innovation in the downstream market. Moving from a duopoly to four competitors had a dramatic impact in reducing prices and enhancing services.

Interestingly, in the 700 MHz auction, concluding March 2008, no restrictions were placed on how much any incumbent could win in any market. The result was largely predictable (Cramton et al. 2007). The two strongest incumbents, Verizon and AT&T, bid for and won the lion's share of the spectrum (85% by value). This spectrum was particularly valuable to Verizon and AT&T because of their incumbent position of holding nearly all the cellular spectrum located at 850 MHz. In contrast, the other operators, such as Sprint and T-Mobile, rely on Personal Communications Services and AWS spectrum, which is at higher frequencies. Thus, Verizon and AT&T, which held a duopoly position in low-frequency spectrum before the auction, retained their duopoly position after the auction. This position gives Verizon and AT&T a competitive advantage in providing nationwide coverage. Customers value coverage, and the low-frequency spectrum allows for much less expensive geographic coverage. Dramatically fewer cell sites are needed since the low-frequency signals travel farther. Importantly, Verizon and AT&T did not need the new spectrum to provide nationwide coverage with low-frequency spectrum: both already had that capability with their current cellular licenses. Rather, winning the 700 MHz spectrum *prevented* any other competitor from acquiring this same capability.

One countervailing force is the "open-access" provision included in the C Block won by Verizon. At least in theory, this provision opens the Verizon network to any device and any application. In the past, each operator tightly restricted the devices that could operate on its network and what applications would be allowed and how they could be used. This level of control enables the operator to extract additional economic rents from the network but limits innovation. Any party with a good idea for a device or an application has to negotiate with the network operator first. In contrast, the open-access provision pushes the industry closer to the Internet model, where the network operator is not able to control devices or applications. Any nondestructive device or application is allowed. Including the provision on just one block may suffice, provided that competitive pressures cause AT&T and others to adopt Verizon's open-access policy.

Regulators have used a variety of tools to address competition issues in spectrum auctions. The most direct are spectrum caps, set-asides, bidding credits, and installment payments. In many instances these instruments have been effective at promoting entry and enhancing competition. At other times, the instrument resulted in undesirable and unintended consequences. For example, in the second U.S. broadband auction, which was a set-aside auction for small businesses, the FCC used overly attractive installment payments. The result was speculation, default, and delayed use of the spectrum. Installment payments were subsequently eliminated. In other instances, bidding credits led to the formation of fronts closely aligned with incumbents.

Establishing desirable competitive interventions is challenging. Still it is a challenge that the regulator must face with careful analysis and judgment. The interventions are often of first-order importance to successful market outcomes.

V. Electricity Markets

My final example of market design is electricity markets. Modern electricity markets are organized as a number of auction markets. The markets taken together are designed to provide reliable electricity at the least cost to consumers. Spot markets determine how much each supplier is generating on a minute-by-minute basis; forward energy markets enable customers and suppliers to lock in medium-term (1–3 years) prices for electricity; and long-run investment markets coordinate new entry to cover any expansion in electricity demand. These auction markets must be carefully designed to work together in achieving the goal of least-cost reliable supply. Design failures can be quite costly as the California electricity crisis of 2000–2001 demonstrated. When the stakes are high, an important step in market design is building prototypes and then testing those prototypes in the experimental lab or in the field before full-scale implementation.

Electricity markets have a number of complicating features, which make their design especially challenging. It is not possible to address all these complications here. Rather, I will focus on some particular features of designs for the medium-term and long-term markets and argue how these markets can work together to better achieve the goal of least-cost reliable supply.

A. Long-Term: Forward Reliability Market

In current electricity markets, the demand side has no way to express its preferences for reliability. For this reason, in most markets the regulator has taken on the role of assuring that there are adequate generating resources. One recent approach with many desirable properties is the forward reliability market, adopted in New England and Colombia (Cramton 2006; Cramton and Stoft 2007, 2008). In this market generating resources are procured on an annual basis well in advance (3 years or more) of the eventual need. When capacity is lined up well in advance of the need, new entry can compete to provide capacity. This has two important benefits. First, the market coordinates new entry and avoids the boom/bust cycles that are common with uncoordinated entry. Second, it makes the market for capacity contestable and lets competitive new entry set the price for capacity.

A key element of the design is the definition of the capacity product, which I call a reliability option. It is physical capacity bundled with a financial call option to supply energy above a strike price. The physical capacity assures that there are adequate generating resources, whereas the financial call option provides efficient performance incentives. Capacity resources face a financial obligation to supply energy whenever the spot price is above the strike price. This obligation follows load in that it is stated as a share of the actual demand in the hour. In this way, the capacity payment fully hedges load from high spot prices and reduces supplier risk as well. Market power is reduced in the spot market since suppliers enter the spot market with a nearly balanced position in times of scarcity. Market power in the reliability market is addressed by not allowing existing supply to affect the capacity price. The approach is readily adapted to either a thermal system or a hydro system.

Importantly, the hedge in the form of a reliability option does not distort a supplier's marginal incentives in the spot market. Since any deviation from the obligation is priced at the spot price, the supplier receives the spot price on the margin and is motivated by the spot price. An important variation for load with hourly meters is to hedge load for its expected demand rather than its actual demand, thus exposing load to the spot price on the margin to preserve incentives for demand response during scarcity. The impact of the option is to hedge both load and suppliers from price volatility above the strike price. This approach greatly reduces the risk from weather-related price fluctuations. It does not, however, reduce performance risk. Although all risk is costly and hence undesirable, performance risk cannot be eliminated without eliminating the performance incentive.

The second advantage of the option is that it greatly reduces market power in the spot market during times of scarcity. Whenever the price exceeds the strike price of, say, $300 per megawatt-hour, the supplier obligation puts the suppliers in roughly a balanced position. A supplier in a balanced position has no incentive to distort its offer away from marginal cost. This reduction in market power improves the efficiency of the real-time dispatch as well as the spot price signal.

A third advantage of the hedge is that it makes high scarcity prices politically acceptable. High prices during scarcity are essential to motivate performance. A pervasive problem in nearly all electricity markets has been prices that are too low in times of true scarcity. A hedge enables the spot price to go much higher during scarcity without political backlash.

The capacity auction sets the payments to generators for providing reliability options just high enough to induce optimal investment and adequate capacity. An annual auction is used to purchase new capacity up to the level required for reliability. These auctions determine the price of reliability options that is just sufficient to induce the required entry. If the cost of constructing new capacity increases or decreases as a result of environmental restrictions or new technology, new entrants will bid just enough higher or lower to maintain a normal rate of return, assuming that there are no barriers to entry.

The result is that the regulator controls the level of capacity, but the market controls the price of capacity and the type and quality of capacity built. Hence the regulatory intervention is limited to determining the one factor about which the market has little information—the adequate level of capacity.

Although the auction design requires care to address the potential exercise of market power, the following simple procedure would work well. Each September an auction is held for reliability options (ROs), which take effect on January 1, just over 3 years in the future. Existing generators may choose either to enter the auction as a price taker (i.e., with a zero bid) or not to sell ROs. New projects are allowed to bid without restriction. The regulator bids a demand curve that intersects the target adequacy level at the most recent RO price. The auction is held using a descending clock procedure. All accepted bids are paid the clearing price, but existing generation receives 1-year contracts whereas new generation may choose any contract length up to 10 years. Once a new generator's initial contract expires, it becomes an "existing" generator. If no new generation is purchased in a given year, all existing generators that bid have their contracts extended for 1 year.

All generation, new and existing, will want to sell ROs for their full capacity because these options fetch a high price relative to the financial cost of the option.

The benefits of this design are significant. The design minimizes risk and market power while coordinating efficient entry.

B. Medium-Term: Forward Energy Market

Forward contracts for energy play an important role in reducing risk and market power in electricity markets. The reliability options, discussed above, provide price coverage above the strike price, but forward energy contracts are still needed to provide price coverage below the strike price. In most markets these forward contracts are negotiated bilateral contracts. These informal markets often are fragmented with little liquidity, nonstandard contracts, and high transaction costs. An organized market with standard contracts can increase competition and liquidity and reduce transaction costs. Such an approach has recently been proposed for Colombia (Cramton 2007). The design, summarized here, illustrates again the importance of the product design to achieve the objectives of the market.

The forward energy market is an organized market to procure energy for electricity customers on a forward basis. It includes both the regulated market (residential and other small customers) and the nonregulated market (large customers). Currently, regulated customers represent 68% of the total electricity demand and nonregulated customers represent the remaining 32%. The proposed design is novel in that it integrates both the regulated and nonregulated customers into a single organized market. Although the regulated and nonregulated energy products remain distinct, their integration into a single market facilitates arbitrage between the products, improves liquidity, and reduces transaction costs. Both regulated and nonregulated customers benefit from this unified approach.

The two customer groups, regulated and nonregulated, are integrated into a single market. Regulated customers are small customers without hourly meters; nonregulated customers are large customers with hourly meters. The nonregulated product will make use of the hourly meters to encourage demand response. In addition, because of their large size, nonregulated customers will be active buyers in the forward energy market, submitting demand bids. In contrast, the regulated customers will have a more limited demand response capability and will not be active buyers in the forward energy auction; their demands will be set administratively. The two products in one market can be summarized as follows:

Regulated customers (68% of the load):

- Small customers without hourly meters.
- Passive buyers in the auction.

Nonregulated customers (32% of the load):

- Large customers with hourly meters.
- Active buyers in the auction.

The proposed market is based on two load-following products: a regulated product and a nonregulated product. For the regulated product, each supplier bids to serve its desired share of Colombia's regulated load. A supplier that wins a 10% share at auction has an obligation to serve 10% of the actual regulated load in every hour of the commitment period. The supplier is paid the clearing price for every megawatt hour of energy supplied. Deviations between the supplier's hourly supply and obligation are settled at the spot energy price or the scarcity price, whichever is lower. The spot settlement price is capped at the reliability options strike price since the firm energy market provides price coverage for prices above the strike price (about $260 per kilowatt-hour in January 2007 Colombian pesos, or US$120 per megawatt-hour; see Cramton and Stoft 2007). The nonregulated product is essentially the same, except each supplier bids to serve its desired share of the nonregulated load.

One hundred percent of regulated load is purchased on behalf of the regulated customers in a sequence of auctions. Thus, the forward energy market together with the firm energy market provide 100% price coverage for all regulated customers, as shown in figure 1. The forward energy market provides price coverage from zero to the scarcity price, and the firm energy market provides price coverage above the scarcity price. This accomplishes two things: (1) it provides rate stability for regulated customers, and (2) it provides revenue stability for suppliers. The result is reduced risk for both sides of the market.

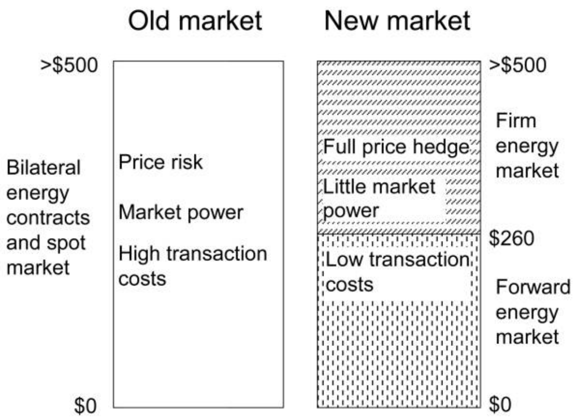

Fig. 1. Price coverage of a regulated customer

The prior approach of bilateral contracts and the spot market suffers from three problems. Price risk is greater since the contract cover is incomplete. Market power in both the spot market and the bilateral market is more of a concern since supplier positions are more apt to be out of balance entering the spot market and competition for bilaterals is weaker with specialized local products. The absence of a standard contract also results in high transaction costs in addition to weaker competition. In contrast, the new market provides full price coverage, suppliers enter the spot market with nearly balanced positions, and the single product minimizes transaction costs. In addition, the problem of self-dealing between the utility and its supplier affiliate is eliminated.

The market is mandatory for regulated customers but voluntary for suppliers. Mandatory participation on the demand side motivates robust participation on the supply side.

The nonregulated customers enjoy benefits from the forward energy market similar to those of the regulated customers. The main difference is that the nonregulated customers actively bid in the forward energy market and thus decide how much contract cover to purchase and in which auction. Although nonregulated customers participate voluntarily, I believe that most will decide to participate fully and will adopt procurement strategies that do not differ too much from those of the regulated customers. Since the regulated and nonregulated products are close substitutes, the active participation of the nonregulated customers should yield improved pricing for both products.

An enormous simplification is having only a single product for each customer group, regulated and nonregulated. Although differences in load shapes across customers mean that the cost of serving each customer is different, these differences are relatively minor and can be accounted for with a customer-specific load shape adjustment to avoid any cross subsidies that otherwise would result. Notice that the adjustment affects only the load side and not the suppliers, since each supplier is serving a share of the aggregate load for the particular customer group.

The energy share product enables load to be fully covered with a single product. For a supplier, the load-following product is natural since in aggregate suppliers must follow load. A supplier is able to manage its exposure to the spot energy price through its portfolio of resources and its portfolio of nonregulated energy contracts. Even for a small supplier without a portfolio of resources or energy contracts, the risk from spot price exposure is modest.

The proposed product does an excellent job of rate stability. Regulated load is fully hedged from the spot price. This makes sense for customers without hourly meters and demand management systems. However, for large, nonregulated customers, hourly meters are required and demand response is encouraged. This is done by basing the nonregulated product on *expected* load rather than on *actual* load. The actual-load contract (pay as demand) is based on the customer's actual load in each and every hour of the commitment period. In contrast, the expected-load contract is based on the customer's expected (forecasted) load in each and every hour of the commitment period as specified by the nonregulated customer or, if not specified, as estimated from its historical load shape and estimated growth over the period.

The expected-load contract hedges price risk yet still exposes the customer to the spot price on the margin, motivating demand response, and innovation in demand management systems.

There are a number of possible choices for the timing and frequency of auctions and the duration of contracts. These three elements can be adjusted to manage price and credit risk while minimizing transaction costs. One sensible approach is quarterly auctions of 2-year contracts, which are rolling on an annual basis. The use of 2-year contracts is consistent with the most common contract in Colombia's bilateral market. The approach is simple and yet provides broad time diversification, shielding customers from transient events. One-eighth of regulated load is purchased in each auction. At any one time, two products are active, and the customer rate reflects the average of eight auctions equally spaced over a 2-year period. Even the auction with the shortest planning period occurs 5 months before the start of the contract. This means that the auction price will be set before there is much resolution of how severe conditions will be in the following dry season. This structure strikes a balance between risk reduction and the cost of guarantees to assure performance.

Efficient price formation is one of the most important objectives of the forward energy market. The simultaneous descending clock auction is used to promote efficient price formation. The descending clock auction provides excellent price discovery and enables suppliers to freely arbitrage across the regulated and nonregulated products. This assures that any price difference between the two products is a reflection of cost differences.

The integration of the regulated and nonregulated markets will lead to greater liquidity, improved price formation, and lower transaction costs. My view is that the forward energy market as proposed here will dramatically improve the energy contract market for both regulated and nonregulated customers, and improve the spot market as well, since suppliers typically will enter the spot market with a nearly balanced position, eliminating incentives to exercise market power.

At first glance, it might appear that Colombia's earlier design of informal bilateral contracts would enhance innovation. It did lead to hundreds of different contract types. But this heterogeneity fragmented markets and reduced competition to the detriment of the consumer. Rather, by standardizing products and relying on one central market, we enhance competition and liquidity and improve price signals. This fosters the right kind of innovation—innovation for cost reduction on the supply side and demand response on the load side.

VI. Conclusion

I presented four examples of how market design fosters innovation. In all cases, a basic ingredient is harnessing the power of markets and prices to motivate decentralized decision making. Effective pricing of scarce resources drives market participants to make good decisions in both the short and long term. Innovation flows naturally from the incentives of prices, allowing flexible and creative responses to managing resource use.

In the case of airport slots, spectrum, and electricity, a second ingredient in fostering innovation is a market design that enhances competition. Competition can be especially difficult to maintain in network industries since network constraints tend to limit substitution and introduce scale economies and other nonconvexities in production. A good market design promotes competition in a number of ways, such as transparency of prices, improved liquidity, enhanced substitution, and reduced transaction costs. A fragmented market can be unified with standard products and a centralized auction. Sometimes competition is directly managed in the design with quantity caps that limit the size of any party, set-asides, or bidding credits that favor new entrants. Competition inspires innovation, and good market design enhances competition.

A final ingredient in fostering innovation with market design is addressing other potential market failures. The free-rider problem must be addressed in markets for pollution and runway use. Coordination failures of new entry are seen in electricity markets. Another potential failure is overcoming economies of scale in providing demand management systems for electricity.

One exciting aspect of market design is working on the forefront of theory and yet bringing that theory to practice. In the auction applications discussed here, solving real problems has proved to be an excellent way to develop new theory. Nonetheless, the goal of market design is not theory but practice: making markets work better through designs that promote the efficient use of scarce resources, enhance competition, and encourage innovation.

Endnote

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Lessons on the Rise and Fall of Great Powers: Conquest, Commerce, and Decline in Enlightenment Italy

Author(s): Sophus A. Reinert

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AHR Forum

Lessons on the Rise and Fall of Great Powers: Conquest, Commerce, and Decline in Enlightenment Italy

SOPHUS A. REINERT

Though the theme of his Sidgwick Memorial Lecture at Cambridge was "Decadence," and though he knew that "somewhere in the dim future" decline lay inevitably ahead, former British prime minister Arthur Balfour saw in 1908 "no symptoms either of pause or of regression in the onward movement which for more than a thousand years has been characteristic of Western civilisation."[1] Just over a century later, his "dim future" has become our grim present. With the relative decline of the West upon us, historians have an important role to play in supplying the perspectives necessary to make sense of changing circumstances. It might aid us in this process to revisit the debate embedded in the political economy of Enlightenment Italy, which was almost certainly the most advanced debate on decline in the history of the West. Why? Because, uniquely, Italy had twice declined from a hegemonic position: once through conquest, with the barbarian invasions that toppled Rome's Western Empire; and once through commerce, with the economic competition from territorial monarchies that signaled the end of the Italian Renaissance. These two catastrophes provided theorists there with unique insights into the nature of decline and inspired ceaseless (though now little-known) debate about the means of overcoming it. As a guide through these uncharted and often melancholy lands, we can look to the nearly forgotten poet Agostino Paradisi (1736–1783) of Modena, the peninsula's third professor of political economy and one of his century's most acute theorists of decline. Our poet presents us with an ideal case study for rethinking not only the political economy of decline, but the very nature of Enlightenment itself.

The time when one could speak boldly of "the Enlightenment" is long gone. The old Enlightenment was Parisian, ruthlessly reforming the Old Regime in reason's name.[2] Commended and condemned by historians, it ostensibly gave birth to democracy and to the rights of man, as well as to Nazism and the gulags.[3] Today the

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[1] Arthur James Balfour, *Decadence* (Cambridge, 1908), 39, 59.

[2] The classic synthesis of this historiographical paradigm remains Peter Gay, *The Enlightenment*, 2 vols. (New York, 1966–1969).

[3] For this striking historiographical history, see David A. Hollinger, "The Enlightenment and the Genealogy of Cultural Conflict in the United States," in Keith Michael Baker and Peter Hanns Reill,

FIGURE 1: Agostino Paradisi. Eighteenth-century print by an unknown artist. Private Collection.

phenomenon of Enlightenment has become fragmented, "exploded" in Krzysztof Pomian's words, with scholars differentiating between the high and the low; the radical, the moderate, and the conservative; the Socinian and the Utrechtian; all endlessly inflected across the different nations and regions of a long eighteenth century.[4] Given how much has changed, it is striking that many of the assumptions behind "the Enlightenment"—such as unwavering commitments to reason and peaceful free

eds., *What's Left of Enlightenment? A Postmodern Question* (Stanford, Calif., 2001), 7–18; and John Robertson, *The Case for the Enlightenment: Scotland and Naples, 1680–1760* (Cambridge, 2005), 1–51.

[4] Krzysztof Pomian, "Illuminismo e illuminismi," *Rivista di filosofia* 94, no. 1 (2005): 13–31, 13. See, on this debate, from different perspectives J. G. A. Pocock, *Barbarism and Religion*, 4 vols. to date (Cambridge, 1999–2005), vol. 1: *The Enlightenments of Edward Gibbon, 1737–1764*; vol. 2: *Narratives of Civil Government*; vol. 3: *The First Decline and Fall*; vol. 4: *Barbarians, Savages and Empires*; Dorinda Outram, *The Enlightenment* (Cambridge, 2005); Robertson, *The Case for the Enlightenment*; and Jonathan Israel, *Enlightenment Contested: Philosophy, Modernity, and the Emancipation of Man* (Oxford, 2006), 866.

trade—remain so deeply entrenched even in revisionist historiography. Cultures of Enlightenment, we are told, were infinitely varied, yet most of them supposedly embraced libertarian economic principles in pursuit of their goals.[5] As Nietzsche so deftly put it, "new opinions live for a long time in the desolate and strangely unfamiliar house of their predecessors and even preserve it themselves, since they need some sort of shelter."[6]

This tendency is particularly apparent in the regular recurrence of the historiographical judgment that sets in opposition conquest and commerce, holding that modern commerce superseded ancient conquest and that the Enlightenment mainstream believed that "free trade" would secure peace and progress. Already delineated by John Locke and lionized by French political economists such as Montesquieu, this scheme was elevated by nineteenth-century economic liberals in the tradition of Benjamin Constant to a veritable article of faith: "Our world is, in this respect, precisely the opposite of the ancient world."[7] In one form or another, Constant's message is reiterated by historians, pundits, Nobel Laureates, and world leaders to this day, and is acted upon to the frighteningly ironic point where wars are fought to secure peaceful trade.[8] With this in mind, seeing the world through Paradisi's eyes challenges many of our preconceptions about Enlightenment political economy by highlighting its historical awareness and supreme preoccupation with decline and subjugation in relation to international competition.[9] Italy is a privileged

[5] The examples of this equation are too numerous to count, but see Roy Porter, *Enlightenment: Britain and the Creation of the Modern World* (London, 2000), particularly 385–388; Roger E. Backhouse, *The Penguin History of Economics* (London, 2002); Martin Fitzpatrick, "Introduction," in Martin Fitzpatrick, Peter Jones, Christa Knellwolf, and Iain McCalman, eds., *The Enlightenment World* (London, 2004), 421–425, 423; Till Wahnbaeck, *Luxury and Public Happiness: Political Economy in the Italian Enlightenment* (Oxford, 2004); Darren Staloff, *Hamilton, Adams, Jefferson: The Politics of Enlightenment and the American Founding* (New York, 2007), 3; Joel Mokyr, *The Enlightened Economy: An Economic History of Britain, 1700–1850* (New Haven, Conn., 2009), 158. Even contemporary critics of *laissez-faire* make the connection between Enlightenment and economic liberalism; see Stephen Eric Bronner, *Reclaiming the Enlightenment: Toward a Politics of Radical Engagement* (New York, 2004), 155; and John Gray, *Black Mass: Apocalyptic Religion and the Death of Utopia* (London, 2007), 135.

[6] Friedrich Nietzsche, *Human, All Too Human: A Book for Free Spirits*, trans. Gary Handwerk (Stanford, Calif., 1995), 249–250.

[7] Benjamin Constant, "The Spirit of Conquest and Usurpation and Their Relation to European Civilization," in Constant, *Political Writings*, ed. Biancamaria Fontana (Cambridge, 1988), 52; John Locke, *Some Considerations of the Consequences of the Lowering of Interest, and Raising the Value of Money* (London, 1692), 15; Jean François Melon, *Essai politique sur le commerce*, 2nd rev. ed. (n.p., 1736). On Melon, see his *Opere*, ed. Onofrio Nicastro and Severina Perona, 2 vols. (Pisa, 1983); and Istvan Hont, *Jealousy of Trade: International Competition and the Nation-State in Historical Perspective* (Cambridge, Mass., 2005), 30–34. The classic discussion of "sweet commerce" is in Albert O. Hirschman, *The Passions and the Interests: Political Arguments for Capitalism before Its Triumph* (Princeton, N.J., 1977); but see also Pocock, *Barbarism and Religion*, 1: 109; 2: 79, 221; 3: 309, 377–378.

[8] For statements of this doctrine, see Paul Krugman, *Pop Internationalism* (Cambridge, Mass., 1998), 69–84; Condoleezza Rice, "The President's National Security Strategy," in Irwin Stelzer, ed., *The Neocon Reader* (New York, 2004), 81–87; Tony Blair, "Doctrine of International Community," ibid., 107–116; Daniel Griswold, "Peace on Earth? Try Free Trade among Men," Cato Institute, December 28, 2005, http://www.cato.org/pub_display.php?pub_id=5344; see also http://www.peacethroughcommerce.com. The literature on this is immense, but see Stephen C. Neff, *Friends but No Allies: Economic Liberalism and the Law of Nations* (New York, 1990), 30; Katherine Barbieri, *The Liberal Illusion: Does Trade Promote Peace?* (Ann Arbor, Mich., 2002); and Michael P. Gerace, *Military Power, Conflict and Trade* (London, 2004).

[9] In effect, Italy's three first professors of political economy all conceptualized Enlightenment reform in relation to the painful history of decline, and the first-ever university textbook on the subject on the peninsula, Antonio Genovesi's extraordinarily influential 1757–1758 translation of Georges-Marie Butel-Dumont's 1755 translation of John Cary's 1695 *Essay on the State of England*, was renamed

site for examining these ways because, as Paradisi lyricized, it was humbled both in the Roman time of "iron and anger" and in the Renaissance era of "gold," the war-monger "Mars" ever "thundering from above."[10]

These points may seem unnecessarily punctilious, important only to specialists, but they deeply problematize some of our most cherished historiographical assumptions, not least of which is the grand narrative of modernity as man's emancipation from coercion through commerce. The shorthand of "Enlightenment" lends both moral and scientific authority to contemporary political projects, but its usage is often misleading. Simply put, eighteenth-century axioms cannot be straightforwardly equated with peaceful *laissez-faire*, and whatever economic progress the world has seen since then has had far less complacent causes. Even if individual works paint a more complicated picture than this, they have been unable to overturn the mainstream consensus.[11] Historically, the great goals of liberty, welfare, and public happiness have been reached by a variety of means, yet we now seem less aware of the potentials of political economy than were our Enlightenment predecessors. Uncovering their rich world requires venturing outside the canon, beyond the easy labels and hypotheses, which, though widely shared, are simply unsustainable in light of the historical evidence.

Paradisi, for example, has habitually been considered a "physiocrat," making him manageable by affiliating him with the canonical sect of *économistes* who orbited around François Quesnay in 1760s Paris.[12] Famous for their advocacy of *laissez-faire*, their trust in applied natural law, and the theory that all activities but agriculture

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A History of Great Britain's Commerce for an Italian audience. From its incipience, academic political economy was a historical science, and a principal point it came to emphasize was how England's greatness was the result of Italy's second decline: as England once had emulated Italy, so Italy now had to emulate England. See Sophus A. Reinert, "Traduzione ed emulazione: La genealogia occulta della *Storia del Commercio*," in Bruno Jossa, Rosario Patalano, and Eugenio Zagari, eds., *Genovesi economista* (Naples, 2007), 155–192.

[10] Agostino Paradisi, "Ode per la solenne dedicazione della statua equestre innalzata dal Pubblico di Modena a Francesco III d'Este," in *Prose e poesie scelte di Giuseppe Parini—Agostino Paradisi—Luigi Cerretti—Teodoro Villa—Giovanni Fantoni—Luigi Lamberti—Ugo Foscolo* (Milan, 1833), 153–154.

[11] My caveat is old. See Edwin R. A. Seligman, *Curiosities of Early Economic Literature: An Address to His Fellow Members of the Hobby Club of New York* (San Francisco, 1920), ix. See, for some recent examples of far more nuanced analysis of eighteenth-century political economy, Emma Rothschild, *Economic Sentiments: Adam Smith, Condorcet, and the Enlightenment* (Cambridge, Mass., 2001); Hont, *Jealousy of Trade*; William J. Ashworth, "The Intersection of Industry and the State in Eighteenth-Century Britain," in Lissa Roberts, Simon Schaffer, and Peter Dear, eds., *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam, 2007), 349–377; and Paul Cheney, *Revolutionary Commerce: Globalization and the French Monarchy* (Cambridge, Mass., 2010).

[12] Virtually all the literature defines Paradisi as a physiocrat; see Augusto Graziani, *Le idee economiche degli scrittori emiliani e romagnoli sino al 1848* (Modena, 1893), 60–63; Giuseppe Ricca Salerno, "Agostino Paradisi e Gherardo Rangone," *Nuova Antologia*, 3rd ser., 53 (1894): 605–632, 607; Alberto Vecchi, "Un giudizio di Agostino Paradisi sul Machiavelli," *Atti e memorie della Accademia di scienze lettere e arti di Modena*, 5th ser., 14 (1956): 118–135, 124; Franco Venturi, "Ritratto di Agostino Paradisi," *Rivista storica italiana* 74, no. 4 (1962): 717–738, 733 (later expanded in the introduction to Paradisi in Giuseppe Giarrizzo, Gianfranco Torcellan, and Franco Venturi, eds., *Riformatori delle antiche repubbliche, dei ducati, dello stato pontificio e delle isole* [Milan, 1965], 435–452); Laura Margherita Alfieri, "Aspetti della cultura economica modenese nella seconda metà del XVIII secolo: Agostino Paradisi e Ludovico Ricci," in Maria Livia Fornaciari Davoli and Margherita Laura Alfieri, eds., *Economisti emiliani fra il XVI e il XVIII secolo* (Modena, 1988), 117–170, 122; Giuseppe Armani, "Le lezioni di 'Economia Civile' di Agostino Paradisi," in Armani, *Un'idea di progresso: Da Beccaria a Galante Garrone* (Reggio Emilia, 2005), 63–79; Laura N. Alfieri, "Gli scritti di Agostino Paradisi (1736–1783) e la pubblica felicità," *Bollettino storico reggiano* 39, no. 132 (2006): 53–87, 62.

were "sterile," the physiocrats were responsible for a well-intentioned but disastrous liberalization of the grain trade that resulted in widespread chaos, sporadic death, and general subsistence trauma at the time.[13] They were, in short, close to the commonly accepted stereotype of Enlightenment political economy, and most histories of the subject trace the genealogy of modern economics back to them. Nonetheless, Paradisi's extant manuscripts show that the convenient label of "physiocrat" does violence both to him and to any sense of what physiocracy meant. In truth, Paradisi accepted the ruthless nature of international trade and combined his interests in antiquarianism and political economy to suggest an active politics of melioration. Through economic policies, one could, he mused, capitalize even on decline itself, but not only in terms of lower wages rendering industry more competitive internationally. As a result of expanding tourism in Enlightenment Europe, ruins were no longer merely repositories of culture and learning, they could be important sources of lucre as well. A close reading of his lectures reveals a refreshingly alternative vision of the possibilities and constraints of competing commercial societies, shedding light on a powerful contemporary debate over antiquarianism and political economy that too often is reduced to slogans and untenable oppositions. But if the example of Paradisi proceeds as a careful case of historical archaeology with specific historiographical repercussions, it will also serve as a sounding board for some of the more melancholy preoccupations of our own age, our own political economies, our own declines.

THERE IS A LONG HISTORY to fearing the future. At least since Hesiod placed man in a rusting age of iron or since clay feet entered the dreams of Nebuchadnezzar, "Western" culture has been infatuated with the possibility of decline.[14] Yet where scholarship and the mainstream media today can be uncompromisingly apocalyptic, Hesiod's *Works and Days* and the biblical Book of Daniel both hinted that dark clouds have silver linings.[15] Herodotus and Aristotle formalized a similar idea, presenting

[13] On the physiocrats, their context, and subsistence trauma, see particularly Steven L. Kaplan, *Bread, Politics, and Political Economy in the Reign of Louis XV* (The Hague, 1976); and now Michael Sonenscher, *Before the Deluge: Public Debt, Inequality, and the Intellectual Origins of the French Revolution* (Princeton, N.J., 2007).

[14] Hesiod, *Works and Days*, ll. 110–180; Daniel 2:31–45. For the conceptual problems of cyclical time, see still Stephen Jay Gould, *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time* (Cambridge, Mass., 1987). On cyclical history, see Ernst Breisach, *Historiography Ancient, Medieval, and Modern*, 2nd ed. (Chicago, 1994), 210–214; and Arnaldo Momigliano, *La storiografia greca* (Turin, 1982), 64–94. On decline, see Randolph Starn, "Meaning-Levels in the Theme of Historical Decline," *History and Theory* 14, no. 1 (1975): 1–31. On empire and decline, see Anthony Pagden, *Lords of All the World: Ideologies of Empire in Spain, Britain and France, c. 1500–c. 1800* (New Haven, Conn., 1995), 103–125. Finally, see J. G. A. Pocock, *The Machiavellian Moment: Florentine Political Thought and the Atlantic Republican Tradition*, 2nd ed. (Princeton, N.J., 2003); and Pocock, *Barbarism and Religion*, particularly vol. 3.

[15] For impressionistic examples, see Immanuel Wallerstein, *The Decline of American Power: The U.S. in a Chaotic World* (New York, 2003); Jason Colavito, *The Cult of Alien Gods: H. P. Lovecraft and Extraterrestrial Pop Culture* (Amherst, N.Y., 2005); David Leonhardt, "A Power That May Not Stay So Super," *New York Times*, October 11, 2008, WK1; George Monbiot, *Bring On the Apocalypse: Six Arguments for Global Justice* (London, 2008); and even the recent anacyclotic disaster movie *The Day after Tomorrow* (Twentieth Century Fox, 2004). For a general argument that "humanity is more at risk than at any earlier phase in its history," see Martin Rees, *Our Final Century: Will Civilisation Survive the Twenty-First Century?* (London, 2003), 188.

"human affairs" as a "wheel" and "a circle," respectively, before the concept received its most famous rendition in Polybius.[16] In the sixth book of his *Histories*, Polybius, the second-century B.C.E. scholar of Rome, proposed the cyclical theory of anacyclosis, whereby "careful observation" could establish the "growth, zenith, and decadence" of a polity. Rather than simply infusing politics with a cyclical chronology, anacyclosis established that what J. G. A. Pocock has called a "politics of time" was necessary to mediate the vicissitudes of fortune.[17] While Polybius diachronized politics, he crucially also politicized time. Although erudite anacyclosis was contested by numerous other frames of reference, cyclicality would nonetheless form one of the most prevalent temporal philosophies from the medieval rediscovery of ancient learning through the eighteenth century.[18]

Yet there was an important moment, first experienced in Italy, when the evolution of commercial society meant that the canons of classical philosophy could no longer explain the full array of human interactions, when the wheels of commerce intersected those of time, and economics became a principal engine of rise and fall. Although Paradisi's analysis of this phenomenon drew on a venerable tradition of political economy, his antiquarian predilections and Italian context enabled him to inflect common tropes in striking ways. The economic history he composed was not an "Enlightenment Narrative" of the supplanting of virtue and empire by the Church and Europe's subsequent release from both through commercial society; nor was it Edward Gibbon's Anglican history of the Eastern Empire.[19] While many elements of Gibbon's work would align with Paradisi's lectures, largely because the Modenese antiquarian Ludovico Antonio Muratori loomed so large over both their enterprises, their remembrance and appropriation of Rome in the end differed greatly, with radical consequences for the continuing anacyclotic interdependence of conquest, commerce, and liberty in the modern world.[20]

The cardinal point of divergence between these historiographies was Italy's

[16] Herodotus, *Histories*, 1: 207; Aristotle, *Physics*, IV: 223b–224; Polybius, *Histories*, 6.4–10. On ancient Greek temporal culture, see Katherine Clarke, *Making Time for the Past: Local History and the Polis* (Oxford, 2008). On Polybius, see F. W. Walbank, *Polybius* (Berkeley, Calif., 1972); on anacyclosis, see Stephan Podes, "Polybius and His Theory of *Anacyclosis*: Problems of Not Just Ancient Political Theory," *History of Political Thought* 12, no. 4 (1991): 577–587.

[17] Pocock, *The Machiavellian Moment*, 183, 262, 274. See also J. G. A. Pocock, "Time, Institutions and Action: An Essay on Traditions and Their Understanding," in Pocock, *Politics, Language and Time: Essays on Political Thought and History* (New York, 1973), 233–272.

[18] See for examples Bernard of Cluny, *Scorn for the World: Bernard of Cluny's "De contemptu mundi,"* ed. and trans. Ronald E. Pepin (East Lansing, Mich., 1991); Theodor E. Mommsen, "Petrarch's Conception of the 'Dark Ages,'" *Speculum* 17, no. 2 (1942): 226–242; Gennaro Sasso, "Machiavelli e la teoria dell'anacyclosis," *Rivista storica italiana* 70, no. 3 (1958): 333–375; Giambattista Vico, *The New Science*, trans. David Marsh (London, 2001), 171–178, 461; David Hume, *Political Essays*, ed. Knud Haakonssen (Cambridge, 1994), 75, 233. Not all anacyclotic theory was Polybian, as his works were lost for a long time; see Arnaldo Momigliano, "Polybius' Reappearance in Western Europe," in Momigliano, *Sesto contributo alla storia degli studi classici e del mondo antico*, 2 vols. (Rome, 1980), 1: 104–124. For the medieval context, Jacques Le Goff, *Time, Work, and Culture in the Middle Ages* (Chicago, 1980), is still essential; and now see also John M. Fyler, *Language and the Declining World in Chaucer, Dante, and Jean de Meun* (Cambridge, 2007).

[19] On which see Pocock, *Barbarism and Religion*, vol. 2. Neither, however, was Paradisi really an exponent of the cosmopolitan historiography discussed in Karen O'Brien, *Narratives of Enlightenment: Cosmopolitan History from Voltaire to Gibbon* (Cambridge, 1997).

[20] Gibbon referred often to "Muratori, my guide and master in the history of Italy"; Edward Gibbon, *The History of the Decline and Fall of the Roman Empire*, ed. David Womersley, 3 vols. (London, 1994), 3: 1060–1061n.

unique sequence of greatnesses and declines, noted by local thinkers and international luminaries alike.[21] In spite of the quintessential reformism of Enlightenment Italy, ruminating over the thanatology of civil society became nothing less than a cultural obsession for the generation of thinkers coming into maturity in the second half of the eighteenth century.[22] The economic "falling behind" of the Italian city-states, the second decline, had robbed Rome of its historical monopoly on the theme.[23] Although Roman history would remain a canon with which other declines could be compared, contrasted, and conflated, by Paradisi's time it had been joined by a legion of other unsuccessful states and empires, the despondent roster of which included the Spanish, the Portuguese, and the Dutch, not to mention a veritable hecatomb of ancient civilizations observable, in the transient spirit of Shelley's *Ozymandias*, only through the scattered fragments uncovered by antiquarians.[24] Only Italy, though, was understood to have declined twice, through both ancient conquest and modern commerce. Perhaps this was why most thinkers there would not join their Scottish colleagues in considering ancient Rome an antithesis of the modern world.[25] The causes of their recent loss of economic preeminence were just not different enough from those that had brought down the Eternal City; just as Rome had been ravaged by barbarians, so the Dutch and English had conquered the world's markets by force. Conquest was not always a corruption of trade's intrinsic *telos*, and it could be its most natural consequence.[26]

[21] Sebastiano Franci, "Alcuni pensieri politici," in Gianni Francioni and Sergio Romagnoli, eds., *"Il Caffè," 1764–1766* (Turin, 1993), 143–150; Agostino Paradisi, "Miscellanea di scritti," Biblioteca Panizzi, Reggio Emilia [hereafter BPRE], MSS. TURRI C 56, 2: [1]. For examples of foreign luminaries, see George Berkeley, *Viaggio in Italia*, ed. Thomas E. Jessop and Mariapaola Fimiani (Naples, 1979), 135; Montesquieu, *Voyages* (Paris, 2003); Adam Smith, *Essays on Philosophical Subjects*, ed. W. P. D. Wightman and J. C. Bryce (Oxford, 1980), 243. For economic approaches to Italy's second decline, see Carlo M. Cipolla, "The Economic Decline of Italy," in Cipolla, ed., *The Economic Decline of Empires* (London, 1970), 196–214; Guido Quazza, *La decadenza italiana nella storia europea: Saggi sul Sei-Settecento* (Turin, 1971); Mancur Olson, *The Rise and Decline of Nations: Economic Growth, Stagflation, and Social Rigidities* (New Haven, Conn., 1982), 122–123; and J. K. J. Thomson, *Decline in History: The European Experience* (Cambridge, 1998), 97–134. On the poetics of self-victimization, which affected the economic discourse, see Natalia Costa-Zalessow, "Italy as a Victim: A Historical Appraisal of a Literary Theme," *Italica* 45, no. 2 (1968): 216–240.

[22] Franco Venturi, *Settecento riformatore*, 5 vols. in 7 (Turin, 1969–1990), inaugurated the modern study of the relationship of "Enlightenment" and reformism. This tradition is still vibrant, as in Robert Darnton, *George Washington's False Teeth: An Unconventional Guide to the Eighteenth Century* (New York, 2003), 4. On the multiplicity of Enlightenments, see particularly Pocock, *Barbarism and Religion*, vols. 1 and 4: 206. On political economy as the kernel of the Enlightenment, see Franco Venturi, *Utopia and Reform in the Enlightenment* (Cambridge, 1971), 123–126; and now Robertson, *The Case for the Enlightenment*.

[23] I am indebted here to the analytical vocabulary of Moses Abramovitz, "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History* 46, no. 2 (1986): 385–406. There is an important literature on the anacyclotic aspects of economics; see Olson, *The Rise and Decline of Nations*; Charles P. Kindleberger, *World Economic Primacy, 1500–1990* (Oxford, 1996); Chris Freeman and Francisco Louçã, *As Time Goes By: From the Industrial Revolutions to the Information Revolution*, 2nd ed. (Oxford, 2002); Carlota Perez, *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages* (Cheltenham, 2003); and Giovanni Arrighi, *Adam Smith in Beijing: Lineages of the Twenty-First Century* (London, 2007).

[24] Pagden, *Lords of All the World*, 11–28; and for an excellent example of conflation, see Sabine MacCormack, *On the Wings of Time: Rome, the Incas, Spain, and Peru* (Princeton, N.J., 2007).

[25] Hont, *Jealousy of Trade*, 9.

[26] On the Scottish take on the problem, see ibid., 6. On the historical processes at play supporting the "Italian" interpretation of events, see Charles Tilly, *Coercion, Capital, and European States, AD 990–1990* (Cambridge, Mass., 1990); and Ronald Findlay and Kevin H. O'Rourke, *Power and Plenty: Trade, War, and the World Economy in the Second Millennium* (Princeton, N.J., 2007).

This unique intersection of chronography and historiography that characterizes many Italian political economists differentiates them markedly from the gallery of thinkers whom Pocock has so magisterially been unveiling in his ongoing sequence of books *Barbarism and Religion*.[27] Although men such as Antonio Genovesi and Cesare Beccaria, respectively the first and second Italian professors of political economy, were deeply preoccupied with the politics of time and Italy's conceptually unique dual decline, they were quintessentially men of action. Theirs was an erudite discourse with previous historians, yes, but the immediacy of their reformist needs made their historical awareness itself more contingent than Pocock in effect allows for. The existence of a widespread tradition emphasizing the complementarity of trade and war has profound consequences for the popular paradigm of *doux commerce*—the notion, associated with Adam Smith and others, that trade makes men more civil—and the contested yet still commonly accepted "Enlightenment Narrative" of progress, reason, and peaceful cosmopolitanism founded upon commerce. The looming threat of decline inflecting eighteenth-century Italian political economy, paradigmatically so in the figure of Paradisi, cannot be dismissed as an anomaly, as somehow outside of Enlightenments proper, for similar preoccupations were widespread even among the canonical figures of the time.[28]

A CITIZEN OF REGGIO EMILIA—a city, then under control of the Este family of Modena, that was precariously embroiled in the power politics of the peninsula and of Europe—Paradisi in many ways incarnated the concerns of his generation.[29] His father, Taddeo Agostino, who had been a successful tribunal lawyer and governor of Vignola, was called to administer the taxes of Reggio in 1712. He remains best-known for his six-volume Baroque masterpiece *The School of the Nobleman*, and there can be no doubt that his early death in 1737 spared his son from the sort of oedipal conflict—galvanized by the rapidly changing political culture of northern and central Italy—that would tear apart such contemporaries as Pietro Verri and Beccaria.[30] Like them, although primarily a *belletrist*, Agostino Paradisi sought to escape his inherited Arcadian paradigm by imbuing poetry with political pertinence, and it was from literature, primarily Petrarch, that he drew his preoccupation with the decline of Italy and how to overturn it. In 1757, he became secretary of Reggio's "Academy of Hypochondriacs," one of the numerous comically named learned circles in Enlightenment Italy, and a comparison of the problems that its members sought to resolve—say, whether or not Adam had a navel—with those pursued by the likes of Genovesi in Naples demonstrates the extent to which Paradisi would keep a foot in two traditions often thought to be in conflict: Baroque erudition and En-

[27] For a discussion of such intersections, see Clarke, *Making Time for the Past*.

[28] On the Spanish case, which both differed from that of Italy and had trenchant similarities to it, see Jorge Cañizares-Esguerra, *Nature, Empire, and Nation: Explorations of the History of Science in the Iberian World* (Stanford, Calif., 2006), 96–111.

[29] On Paradisi's Modenese context, see Dino Carpanetto and Giuseppe Ricuperati, *Italy in the Age of Reason, 1685–1789* (London, 1987), 174–178.

[30] Venturi, "Ritratto di Agostino Paradisi"; Agostino Paradisi, *Elogio del Principe Raimondo Montecuccoli* (Modena, 2004), unpaginated introduction; Carlo Capra, *I progressi della ragione: Vita di Pietro Verri* (Bologna, 2002).

lightenment reformism.[31] Engaging with both sorts of questions at an early age, he translated several works of Voltaire (who thought the young Paradisi had "balls and good taste"), lamented the decline of Italy while eulogizing what greatness was left, and filled his poems with anacyclotic themes.[32] What worth was "erudition," he asked late in life, if it was not employed to further "public happiness"?[33] Although his preoccupations would speak to far larger concerns regarding the future and interaction of commercial societies, they were thus inspired by a particularly Italian poetic nostalgia and a particularly Italian notion of reform.

These were the issues at stake when Paradisi set out to write the most extensive refutation of Alexandre Deleyre's famously derogatory 1765 article on Italy in the *Gazette littéraire de l'Europe*. The Renaissance, Diderot's friend Deleyre noted with venom, was a distant memory, Italy having been left behind by the other "nations" of Europe. It was too disjointed; there were—as an honored Italian tradition had argued—too many "capitals" breaking its spirit; and it lacked manufactures, culture, and the practical implementation of philosophy.[34] Paradisi's reply, "A Letter on the Present State of the Sciences and Arts in Italy," appeared in 1767, the same year he became official orator for the Este dukes. It was not true that the peninsula now was last in Europe, the young poet contended in the spirit of Petrarch's *Invective against a Detractor of Italy*, a work similarly aimed at challenging French cultural hegemony. The achievements of thinkers from Galileo to Genovesi proved Italy's continuing greatness, and if its commerce now had become "secondary" in the great scheme of things, he doubted whether "those two thousand people" who "die of hunger in London" every year were "comforted in their misery" by "some more American provinces conquered by English arms," a conflation of military and economic forces that he would develop more fully later in life.[35]

That said, the state of Italian letters clearly reflected a waning *grandezza* and the ever-increasing dominance of French and English models of thought and practice.[36]

[31] Vecchi, "Un giudizio di Agostino Paradisi sul Machiavelli," 123. On the Hypochondriacs, see *Le costituzioni degli Accademici Ipocondriaci di Reggio* (Reggio Emilia, 1750). The questions posed by the Academy did, thanks to Paradisi's influence, become more immediately pertinent; see Luigi Cagnoli, *Memorie per l'Accademia degli Ipocondriaci di Reggio* (Milan, 1839), 28, and for a list of Paradisi's talks there, greatly prefiguring his later interests, see 30. On the importance of such academies and of this union of interests, see Eric W. Cochrane, *Tradition and Enlightenment in the Tuscan Academies, 1690–1800* (Chicago, 1961).

[32] Venturi, "Ritratto di Agostino Paradisi," 720; Paradisi, "Ode per la solenne dedicazione della statua equestre innalzata," "Per Nozze Varano," "Al Conte Achille Crispi," and "Ode al Genio Estense," in *Prose e poesie scelte*, 153–154, 168–171. Voltaire's letter to Paradisi and comment on his character is in Francesco Algarotti to Voltaire, November 14, 1759, in Voltaire, *Correspondence and Related Documents, XX*, ed. Theodore Besterman (Geneva, 1971), 452–453.

[33] BPRE, MSS. TURRI G 4, *Lezioni di storia*, 4v–5r.

[34] See, for example, Paolo Sarpi to Dudley Carleton, Summer 1614, in Sarpi, *Dai "consulti": Il carteggio con l'ambasciatore inglese Sir Dudley Carleton*, ed. Gaetano Cozzi and Luisa Cozzi (Turin, 1979), 210. The same argument was made by Scipione Maffei, as discussed in Giuseppe Silvestri, *Scipione Maffei: Europeo del settecento* (Verona, 1968), 144; and by Antonio Genovesi, *Storia del commercio della Gran Brettagna scritta da John Cary mercatante di Bristol*, 3 vols. (Naples, 1757–1758), 2: 36n. Alexandre Deleyre, "Lettre écrite de Parme aux auteurs de la Gazette littéraire," *Supplément a la Gazette littéraire de l'Europe*, no. 64 (March 3, 1765): 337–353; on which see Pietro Schedoni, *Elogio del conte Agostino Paradisi*, 3rd ed. (Modena, 1819), 16; and Venturi, "Ritratto di Agostino Paradisi," 721.

[35] Agostino Paradisi, "Sopra lo stato presente delle scienze e delle arti in Italia: Lettera contra una lettera Francese del Sig. D . . . ," in *Prose e poesie scelte*, 203–207, 204. Cf. Petrarch, *Invectives*, ed. David Marsh (Cambridge, Mass., 2008), 364–475.

[36] On this problem, see Arturo Graf, *L'anglomania e l'influsso inglese in Italia nel secolo XVIII* (Turin,

In this context, Paradisi, like much of the Modenese establishment, naturally sought inspiration in more vibrant centers of reformist thought such as Habsburg Milan, of which Francesco III d'Este had been made governor by Maria Theresa of Austria in 1755.[37] Like the coterie of Lombard reformers (among them Beccaria) united in the pugnacious "Academy of Fists," Paradisi, too, would engage with sensualist moral philosophies as a way of penetrating the mysteries of sociability, even publishing a "Metaphysical Essay on Enthusiasm for the Fine Arts" inspired by these very theories.[38] An undated manuscript in which he criticized Rousseau similarly bears witness to his affinity for the preoccupations of the Milanese Enlightenment.[39] Since everyone was driven by "the *desire for happiness*" and "the *pain of not possessing it*," he mused, laws had developed to give people "civil liberties" that were far more protective than the "infinite license" to base society on violence and power allowed by "natural liberty." Far from Rousseau's peaceful frolickers, Paradisi's primitives led lives of toil and trauma.[40] His conclusion is indicative of what was to come:

> Happiness, which thus is an enemy of the forests, is no good friend of cultured cities and exquisite education, either . . . Perhaps she loves a middle state between barbarism and culture; perhaps that is the only one she finds worthy of delighting in, if she ever delights in any man, and does not only appear momentarily and in short instances in which pain is absent, for a flash of evanescent happiness.[41]

Happiness could be achieved in light of the Aristotelian mean and the avoidance of excess, but never with more than varying degrees of ephemerality.[42] Politics, economic and temporal, was the technology of achieving and maintaining that precious balance, of prolonging the moment of "evanescent happiness."

WHILE APPROPRIATING THESE THEORIES, Paradisi also began searching for more practical ways of channeling his learning. This resulted in a veritable campaign to be elected fellow of the Royal Academy of Science and Literature, established in Man-

1911); and D. Maxwell White, *Zaccaria Seriman (1709–1784) and the "Viaggi di Enrico Wanton": A Contribution to the Study of the Enlightenment in Italy* (Manchester, 1961).

37 Vecchi, "Un giudizio di Agostino Paradisi sul Machiavelli," 125. On the larger context, see Carpanetto and Ricuperati, *Italy in the Age of Reason*, 175–176.

38 Agostino Paradisi, "Saggio metafisico sopra l'entusiasmo delle belle arti," in *Prose e poesie scelte*, 200–203. See also Paradisi, "Nel solenne aprimento dell'Università di Modena: Orazione recitata nella chiesa di S. Carlo il giorno 25 novembre dell'anno 1772," ibid., 210–215, especially 214. For context, see Venturi, *Settecento riformatore*, 1: 645–747; Sophus A. Reinert, " 'One will make of Political Economy . . . what the Scholastics did with Philosophy': Henry Lloyd and the Mathematization of Economics," *History of Political Economy* 34, no. 4 (2007): 643–677.

39 BPRE, MSS. TURRI C 56, 6: "Ragionamento sopra i costumi de'selvaggi americani sul rapporto della felicità," published in Agostino Paradisi, *Poesie e prose scelte del conte Agostino Paradisi*, 2 vols. (Reggio, 1827), 1: 117–142.

40 Ibid., 117, 119, 125–126, 130; emphasis in the original.

41 Ibid., 141.

42 This stance had been theorized by the school of Antonio Genovesi in Naples, a tradition on which Paradisi often drew. For examples, see Genovesi, *Storia del commercio*; Carlo Salerni, *Riflessioni sull'economia della provincia d'Otranto*, ed. Vittorio Zacchino (Lecce, 1996). The argument was also made by Cesare Beccaria in his poem "Sopra la felicità," in Beccaria, *Edizione nazionale delle opere di Cesare Beccaria*, 15 vols. to date, ed. Luigi Firpo et al. (Milan, 1984–), 2: 245.

tua by edict of Maria Theresa in 1767.[43] The academy, Paradisi wrote to its secretary, Pellegrino Salandri, upon hearing the news that he might be found worthy of membership, was "among the first in Italy to be forcibly shaken by the electricity that animates all of Europe" to "conduct science for the use of civil life, and for the happiness of the human species."[44] Upon Paradisi's subsequent acceptance into its ranks, Salandri asked him to suggest a reading list and to compose an oration fitting the goals of their intellectual community, including in his letter a list of recent prize essay contests that the Mantuan academy had offered. Compared to what he had discussed in Reggio, the academic program in Mantua emerges as a textbook example of its age and the problems it faced, focusing on the issues of the grain trade, whether poetry was useful to the state, and a paper by the Count D'Arco on natural law and social order. Paradisi thought the problems then being engaged with in Mantua were "excellent," particularly, given his own penchant for "moral and political subjects," the work of D'Arco.[45]

Paradisi took to being a member of the academy with brio, suggesting to Salandri that he should devote his time to studying the "metaphysics" of Locke and Condillac. In the realm of "Politics," he had no doubt that "the great Montesquieu, Hume, the incomparable discourses of our Machiavelli, and the *Lessons* of the *abbé* Genovesi will show you what is necessary."[46] This resulted in his being invited, alongside Beccaria, to Mantua to lecture on some "political" topic.[47] Only in a later, undated letter did Paradisi's thoughts mature into their final form, as he sorted through his many ideas to settle on "the most interesting of them all," namely a "Political Essay on the Last Decline of Italy," that is, "the last time the largest part of Italy became the dominion of foreigners" by "losing liberty," which occurred at the beginning of the sixteenth century and brought about a still-surviving order. To understand the "causes of its decline," he would focus on not only political but also military, commercial, and cultural factors. The "moral object" of the treatise, he noted, echoing the teachings of both the antiquarian and fellow Hypochondriac Muratori and the reformer Genovesi, would be to explain past mistakes for the sake of "present times."[48] What, in other words, were the causes of decline, what were its consequences, and what could they say about the future?

As is evident from Paradisi's manuscripts, the "Political Essay" became the blueprint for a series of writings and lectures on decline.[49] His analysis was so well re-

[43] Today the Accademia Nazionale Virgiliana (http://www.accademiavirgiliana.it).

[44] Agostino Paradisi to Pellegrino Salandri, November 4, 1769, in G. B. Intra, "Agostino Paradisi e l'Accademia Mantovana (Da carteggio inedito)," *Archivio storico lombardo*, 2nd ser., 12, no. 2 (1885): 110–137, 112–113.

[45] Paradisi to Salandri, n.d., ibid., 116–118, and see also 136–137. On D'Arco's political economy, see his manuscripts on luxury and the *annona* in Romano Molesti, *Economisti e accademici nel settecento veneto: Una visione organica dell'economia* (Milan, 2006), 21–57.

[46] Paradisi to Salandri, n.d., in Intra, "Agostino Paradisi e l'Accademia Mantovana," 116–118.

[47] Paradisi to Salandri, September 28, 1770, ibid., 118–119; Paradisi to Salandri, October 15, 1770, ibid., 120–121.

[48] Paradisi to Salandri, n.d., ibid., 122–124; as well as a subsequent letter, again undated, 126. On Muratori as a Hypochondriac, see Cagnoli, *Memorie per l'Accademia*, 41.

[49] In addition to the manuscript at the Reale Accademia Virgiliana of Mantua, see BPRE, MSS. REGG. E 139, "Economia civile del conte Agostino Paradisi reggiano"; MSS. TURRI C 56, 1, "Saggio sopra le città libere d'Italia," 2, "Saggio politico su la origine e decadenza delle libertà d'Italia"; MSS. TURRI G 4, *Lezioni di storia*; MSS. TURRI G 14, "Compendio della storia romana di Agostino Paradisi."

ceived that, following Salandri's sudden death (in an accident involving a bridge, a marauding horse, and a broken head), he was offered the latter's job as "perpetual secretary" of the Mantuan academy by Count Carlo Firmian, Habsburg plenipotentiary for Lombardy.[50] Francesco III, however, would not lose out in the emulative race between Italian city-states, and countered with an offer that Paradisi could not refuse, an offer that would enable him to pursue his predilection for reformist erudition. When the duke ratified a new chair of political economy at the University of Modena in January 1772, it was only the third in Italy, following those awarded to Genovesi in Naples (1754) and to Beccaria in Milan (1769).[51] And at a time when a mason made one lira a day, Paradisi was offered six thousand lire per annum, a counthood, and the title of chamberlain to teach civil economics and head the faculty of philosophy at the refurbished university, which, having been founded in 1175, ranked among the world's oldest. His gratitude and his place in the larger Este program of cultural and territorial development were manifest in the inaugural lecture he was invited to give, a lecture that strikingly united his dual interests in reformism and antiquarian erudition in the context of Italy's historical declines.

Comparing the "useless pride" that went into building "pyramids" to the Roman "prudence" of building "marble aqueducts," Paradisi drew on the theories of the Milanese Enlightenment to place Francesco III in an august tradition of sovereigns nurturing "that noble *utilità* which aligns with *virtù*." For "the founding of an accomplished University of sciences" was both the most "useful" and the "most glorious" project one could undertake, because academics had a unique role to play in the historical development of a nation by grounding debates and policies with their learning. How "adventurous" would "that nation be in which the philosopher is listened to, where philosophy moderates public affairs no less than the laws!" Nowhere was Paradisi's faith in the possibility of reform and the role of learning in ensuing progress more clearly stated: "Everything is to be hoped for, everything is to be promised, everything is to be attempted."[52] It seemed almost as if reform and progress had eclipsed anacyclosis in its entirety.

Yet when classes started three days later, the eschatology of Paradisi's poetic economy reemerged.[53] Beginning with the study of "civic society," the course continued with modules on "civil freedom" and "the different forms of civil society" before going on to the historical analysis of the same subjects, explored through sessions on "feudal government" and finally his "Political Treatise on the Origin and Decline of Italy's Liberty," the very theme for which he had been praised in Mantua. But what was this thesis, which became such a recurring concern for Paradisi's po-

[50] *Gazzetta di Mantova*, April 26, 1771, 17; Schedoni, *Elogio*, 17.

[51] Wolfgang Rother, "The Beginning of Higher Education in Political Economy in Milan and Modena: Cesare Beccaria, Alfonso Longo, Agostino Paradisi," *History of Universities* 19, no. 1 (2004): 119–158; Marco Bianchini, "Una difficile gestazione: Il contrastato inserimento dell'economia politica nelle università dell'Italia nord-orientale (1769–1866)—Note per un'analisi comparativa," in Massimo M. Augello et al., eds., *Le cattedre di economia politica in Italia: La diffusione di una disciplina "sospetta" (1750–1900)*, 3rd ed. (Milan, 1992), 47–92.

[52] Paradisi, "Nel solenne aprimento dell'Università di Modena," 210–215.

[53] Archivio di Stato di Modena, Antica Università, "Massime dei riformatori 1772–77," December 8, 1772, b. 119, quoted and discussed in Venturi, "Agostino Paradisi e l'Accademia Mantovana," 445–446; Bianchini, "Una difficile gestazione," 65.

litical economy, and how did it relate to the polyvalent themes of decline and fall, conquest and commerce?

"Politics," Paradisi began, was a "science," which depended on the analysis of "copious examples." "Experimental" rather than "speculative," it was better approached through "history" than through "theoretical intuitions."[54] Only then could the life cycles of nations be uncovered, according to which they "are born, prosper, decline, die."[55] "The history of Italy," he argued, "was full of excellent teachings for politics"; for example, it could unveil the arcane mechanisms by which *libertà*, that most powerful of concepts in the historiography of decline and fall, could become a "destroyer of itself." The first blow to Italy's liberty, the first decline, resulted from the "usurpation of Caesar," after which "one no longer said *Republic*, but *Empire*." In this condition, Italy lingered in the "image of its ancient *grandezza*" until Constantine "transferred the seat [of empire] to *Byzantium*," an act that paved the way for the barbarian invasions and Italy's first decline. It was true, Paradisi wrote, that Charlemagne ultimately resurrected the Western Empire, but this merely made the peninsula a German dominion—an uninteresting development from the perspective of Italian liberty.[56]

FROM THE FIRST FEW PAGES of his manuscript, it is obvious just how different Paradisi's narrative is from the one that Gibbon would soon publish, and how different the former's Este context, ever in tenuous jeopardy between the competing Milanese, Florentine, and Roman spheres of influence, was from the latter's cosmopolitan milieu.[57] For Gibbon, "the decline and fall of the Roman empire" was "the greatest, perhaps, and most awful scene, in the history of mankind."[58] For Paradisi, ancient Rome was a city in a particular historical and geographical context, and its history was primarily part of the history of Italy and of its liberty; Rome was not first and foremost a dream of universal order, nor was its history a vehicle for freeing religious orthodoxy from the institutional legacy of Peter and Paul.[59] Gibbon, on the other hand, would craft his masterpiece of Enlightenment historiography around the process of *translatio imperii*, the historical "transfer of rule" that kept the dream of Rome

[54] The same idea appeared both in Ludovico Muratori, *Della pubblica felicità, oggetto de' buoni principi* (Lucca, 1749), 84; and in the works of his disciple Genovesi, for example, letter to Camillo Tori, March 20, 1759, in Antonio Genovesi, *Autobiografia e lettere*, ed. Gennaro Savarese (Milan, 1962), 123–124; and Genovesi, *Storia del commercio*, 1: ix–x. On history as a propaedeutic of other sciences for Genovesi, see Maria Teresa Marcialis, "Antonio Genovesi e la costruzione scientifica dell'economia civile," in Marcialis, ed., *Ragione, natura, storia: Quattro studi sul Settecento* (Milan, 1999), 103–134.

[55] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 1: 118. For this idea as channeled from Giambattista Vico to Antonio Genovesi and beyond, see Robertson, *The Case for the Enlightenment*, 402–403.

[56] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 1: 119–121; emphasis added.

[57] On which see Pocock, *Barbarism and Religion*, vol. 1.

[58] Gibbon, *The History of the Decline and Fall of the Roman Empire*, 3: 1084.

[59] On the importance of this for the Church of England, see Pocock, *Barbarism and Religion*, 1: 41. On Modena's and Francesco III's strained relationships with the Catholic Church at the time of Paradisi's writing and lecturing, see Carpanetto and Ricuperati, *Italy in the Age of Reason*, 175–178; and Venturi, *Settecento riformatore*, 2: 86–100.

alive throughout its spatial transfers and ensured the survival of a European antiquity unsoiled by Catholicism.[60]

This process of *translatio*, although central to European cultural history, was blithely uninteresting to Paradisi, be it eastward to Constantinople or northward, in James Bryce's later phrase, toward "the banks of the Danube."[61] Italy emerged as a political landscape besieged by turmoil, which over time adopted several instruments for achieving and securing—however fleetingly—its terrestrial fulfillment of liberty and public happiness, only one of which was the relentless march of legionnaires under the Roman Eagle. As a gnoseological category, Paradisi's decline and fall was thus severed from its exclusive focus on Rome, instead drawing an exquisitely Italian cultural, historical, and poetic resonance from Petrarch, while remaining Polybian in emphasizing the universality of such processes and in identifying the armory of causes and effects by which all states would have to mediate the cyclicality of time.[62] There had once been a dream of Rome, but it was a dream by and for Italy, not the world. Gibbon had seen in the barbarian invasions a prelude to Byzantine rebirth; but for our poet, the "hostile banners in the wind" ushered in only a "time of iron."[63]

Yet anacyclosis taught Paradisi that Italy inevitably would rise again. The "great events of states," however sudden, were always "previously preordained," and what the "masses" called *fortuna* was nothing, to a philosophical materialist such as Paradisi, but "an effect preceded by unknown causes."[64] And as a historian it was difficult for him not to sense the coming of a revolution in the political situation of medieval Italy. Indeed, while there were no free states there in the tenth century, many emerged in the eleventh, and by the twelfth nearly all "the communes lifted themselves from the tenuous principle of dependent and circumscribed authority to the dignity and rank of republics." But what, then, were "the causes of Italy's liberty"? It was a problem that had long vexed the "erudite," but Paradisi suggested, building critically on the arguments of his fellow Modenese antiquarians Carlo Sigonio and Muratori, that the answer had more to do with politics than with *fortuna*. Particularly, he suggested closer scrutiny of the political constitutions of Rome's subject cities. During both the republic and the empire, he lectured, the cities of the peninsula had been given extreme leeway in organizing their "internal economy." Although tributaries of Rome, they retained a significant degree of self-rule, could "elect their own magistrates," and "possessed public revenues to supply what the comfort, security, and prosperity of the citizens required." This, Paradisi exclaimed, was "precisely what today we intend by the word 'community.'" Italy's liberty did not survive the

[60] See Werner Goez, *Translatio imperii: Ein Beitrag zur Geschichte des Geschichtsdenkens und der politischen Theorien im Mittelalter und in der frühen Neuzeit* (Frankfurt am Main, 1954); Pocock, *Barbarism and Religion*, 3: 98–100.

[61] James Bryce, *The Holy Roman Empire* (New York, 1961), 1; on Bryce, decline, and *translatio imperii*, see Francesca Lidia Viano, *Una democrazia imperiale: L'America di James Bryce* (Florence, 2003), 25–78.

[62] On the history of a cultural "Italy," see Gene A. Brucker, "From *Campanilismo* to Nationhood: Forging an Italian Identity," in Brucker, *Living on the Edge in Leonardo's Florence: Selected Essays* (Berkeley, Calif., 2005), 42–61; and Angelo Mazzocco, "Un'idea politica italiana in Petrarca?" in Comitato Nazionale per le Celebrazioni del VII Centenario della Nascita di Francesco Petrarca, *Petrarca politico: Atti del convegno (Roma—Arezzo, 19–20 marzo 2004)* (Rome, 2006), 9–26.

[63] Paradisi, "Ode per la solenne dedicazione della statua equestre innalzata," 153.

[64] Paradisi, "Saggio politico su la origine e decadenza della libertà d'Italia," 456.

barbarian invasions through the *translatio* of empire to Byzantium; it survived in the institutions of enduring polities already used to de facto autonomy.[65]

As the last vestiges of barbarian influence were repulsed, these diehard communities "expanded the sphere of their dignity and their rights" to emerge as "*sovereign republics* and, in the substance of government, *independent*."[66] Republican liberty—self-rule independent of arbitrary interference—spread first through those cities that had resisted vassalage to "the empires," and so it was "the form of the communes" that "produced the liberty of Italy."[67] Such liberty and *grandezza* could not help but cause envy in those to whom the city-states had once been vassals, and Emperor Frederick Barbarossa soon descended from the Alps to subdue them. In a war against all odds, however, the republics "forced Frederick to perpetually assure their liberty."[68] Yet, again, Paradisi lamented anacyclotically, "Italy's liberty" was so glorious at this point that "it could not be destroyed but by itself." For the time came when their internal politics were torn asunder by factionalism, as the Guelphs and the Ghibellines, supporters of the Vatican and the Holy Roman Empire, respectively, began to wage war. As a result, free republics fell "prey to usurpers," who backed one party or the other or, "spontaneously,"

> gave themselves up to a prince, choosing rather to obey a peaceful monarchy than be in a turbulent republic. Thus ended the liberty of Italy. The public interest of the commune had founded it; contrasts educated and established it; contentions destroyed it. All states desire liberty, but few know how to use it reasonably.[69]

At the height of their powers, it was the republics themselves that brought their liberty and greatness to an end.

What is perhaps most striking about Paradisi's lessons, apart from the frankness of his republican message in a context of enlightened absolutism, is their conspicuous lack of economic elements. It is as if he only had time to read up on what ostensibly was his subject over the holidays. For he weaves an entirely different though related

[65] Ibid. For an example of his praise of them, see BPRE, MSS. TURRI G 4, *Lezioni di storia*, 2v. This was a significant choice of interlocutors for Paradisi, which corroborates Franco Venturi's argument regarding the simultaneously local and cosmopolitan nature of the Italian Enlightenment. See John Robertson, "Franco Venturi's Enlightenment," *Past and Present* 137 (1992): 183–206; and Vittorio Foa, "Franco Venturi storico e politico," in Venturi, *La lotta per la libertà: Scritti politici*, ed. Leonardo Casalino (Turin, 1996), ix–xxxiii, particularly xix. Compare with the approaches to decline in Orosius, Leonardo Bruni, and Flavio Biondo, who emphasized the way Rome had cannibalized Italy; Pocock, *Barbarism and Religion*, vol. 3. Gibbon's argument would be similar to Paradisi's in this case; *The History of the Decline and Fall of the Roman Empire*, 3: 143.

[66] Paradisi, "Saggio politico su la origine e decadenza della libertà d'Italia," 458–459; emphasis in the original.

[67] Ibid., 459–460. On liberty as non-dependence in this tradition, see Pocock, *The Machiavellian Moment*, 125–126; and Pocock, "Foundations and Moments," in Annabel Brett and James Tully with Holly Hamilton-Bleakley, eds., *Rethinking the Foundations of Modern Political Thought* (Cambridge, 2006), 37–49; but principally Quentin Skinner, *The Foundations of Modern Political Thought*, 2 vols. (Cambridge, 1978), 1: 6–7; Skinner, *Liberty before Liberalism* (Cambridge, 1997); and now Skinner, *Hobbes and Republican Liberty* (Cambridge, 2008).

[68] Paradisi, "Saggio politico su la origine e decadenza della libertà d'Italia," 461. Cf. Gibbon, *The History of the Decline and Fall of the Roman Empire*, 3: 144.

[69] Paradisi, "Saggio politico su la origine e decadenza della libertà d'Italia," 465. Cf. Montesquieu, *Reflections on the Causes of the Rise and Fall of the Roman Empire*, 2 vols. (London, 1752), 1: 147.

image of decline when he returns to the topic in his lectures on "The History of Commerce." This was tellingly the first module of the strictly economic part of his teaching, which in the third year would conclude with a fascinatingly iconoclastic take on "The Balance of Trade," the culmination not only of his lectures but also of their progressive interest in the theme of decline and fall in light of Polybius and Petrarch. Taking his cue from earlier authors on the subject, Paradisi began his first lecture on economic history by defining "commerce" as "communication."[70] In more strictly economic terms, "commerce" had become "the foundation of the power of states," so important that "one cannot have a right idea of governments when one does not know the influence that commerce has on them."[71] The rise of commerce in the modern world entailed that politics no longer could be studied as a "science" divorced from economics. Paradisi did not despair at this, for the true cipher of political economy would forever remain "history." As he lectured to his students: "there is no better way of understanding the uses of a machine than to observe the process of its construction."[72] And this is precisely what his later lectures sought to do.

Since antediluvian times, he began, empires had come and gone, alternately by force of conquest, commerce, or both.[73] Rome was unique only by virtue of its grandeur and characteristic disregard for commerce; it was at this point that Paradisi's earlier narrative of Italian liberty reappeared with certain amendments. Once it had gained "sovereignty over the universe then known," the Rome of economic history fused with that of political history, since it "scorned exercising commerce," relying instead on "tributes" for its economic needs, "not wanting to become the World's provider, since governing it sufficed." The cities it governed, in other words, provided for themselves like true "communities," economically as well as politically. Once "the seat of the Roman Empire was transferred to Constantinople" and the "ancient maxims" of the "Republic" were "changed," however, New Rome emerged as an "extremely flourishing emporium," while Italy, in which the "Empire" became "extinguished," was overcome by barbarians and lay "in squalor, in misery, and in desperate poverty." When Italy's republics regained their wealth and liberty in the Middle Ages, however, "nothing then equaled the[ir] *grandezza*."[74] The liberty of the medieval communes here found their economic equivalent, but as in the traditional explanations for the decline and fall of Rome, whereby its very success became its undoing, Italy's recovered greatness itself contained the "secret poison," to borrow Gibbon's phrase, ensuring its second decline.[75] For as Italian merchants crisscrossed the known world, their voyages became longer and more arduous, and since

[70] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 99. For a discussion of these manuscripts, see Armani, "Le lezioni di 'Economia Civile,' " 63–79. See similarly Pierre-Daniel Huet, *Histoire du commerce et de la navigation des anciens*, 2nd rev. ed. (Paris, 1716); Montesquieu, *Reflections on the Causes of the Rise and Fall of the Roman Empire*, 1: 55.

[71] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 101.

[72] Ibid., 102–103.

[73] Ibid., 107–111.

[74] Ibid., 112–116; cf. Franci, "Alcuni pensieri politici," 144. See similarly Montesquieu, *Reflections on the Causes of the Rise and Fall of the Roman Empire*, 1: 83–84; Montesquieu, *The Spirit of the Laws*, ed. Anne M. Cohler, Basia C. Miller, and Harold S. Stone (Cambridge, 1989), 386.

[75] Gibbon, *The History of the Decline and Fall of the Roman Empire*, 1: 83; discussed in Pocock, *Barbarism and Religion*, 3: 10–11.

it was established that the voyages between going and returning could not last more than a year, the Italians chose Flanders, a nation equidistant from North and South, as their resting place, and there had their businesses [*fondachi*], and established the greatest fairs that ever had been in Europe.[76]

And, harnessing a mechanism of "falling behind" already employed by the two previous Italian professors of political economy, Paradisi explained how Italy made itself the victim of emulation:

The Flemish were at first simple agents of the Italians, but having learned commerce through good exercise, they began to do it themselves, becoming ingenious merchants: they happily attempted long voyages, reduced many useful manufactures to perfection, and for the proximity of the site attracted all the commerce of Europe.[77]

The Italians themselves, in other words, in their incessant search for profits and their eagerness to outsource, gave their competitors the skills and technologies necessary to supplant them in international trade, to inaugurate their second decline.[78]

In discussing these problems of "competition," Paradisi gave a uniquely Italian twist to one of the greatest economic debates of eighteenth-century Europe, the so-called "rich country–poor country" debate—a debate over how success in international competition increased domestic wages, thus undermining the very competitiveness by which a country could grow wealthy.[79] It was what led Gabriel Bonnot de Mably to pronounce, in a Polybian manner, that "trade" was a "monster that destroys itself with its own hands."[80] This was why Paradisi's historical lectures underscored France's attempts to "emulate" more efficient manufacturing techniques in order to "win over those of other nations," and how England sought to "increase profits, and split hairs about savings" in order to remain competitive in spite of its success.[81] Genovesi, on whom Paradisi often drew, had made a similar argument in the light of Italy's repeated declines. Once a country became comparatively richer than its competitors, there were market mechanisms—the economic manifestations of anacyclosis, so to speak—that began countervailing its advantages. Its costs of production would inevitably increase to the point where it would no longer "have preference in foreign markets." Exports would decline, and with them wages, to the point where they would be thrown back into "poverty." Decay and greatness followed each other like clockwork, however, for in a declined state, the "sweet price" of Italian manufactures could again cause the downfall of wealthier nations. Where "everything" was "lacking," the silver lining lay in conquering foreign markets with cheap manufactures, just as Paradisi would argue.[82]

[76] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 116. A similar, Genovesi-inspired sentiment is again in Franci, "Alcuni pensieri politici," 144.

[77] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 116–117.

[78] Adam Smith would soon theorize the birth of many manufactures in a very similar fashion; Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, ed. Edwin Cannan (Chicago, 1976), 429.

[79] On this problem, see Hont, *Jealousy of Trade*, 267–322; and Istvan Hont, "The 'Rich Country–Poor Country' Debate Revisited: The Irish Origins and French Reception of the Hume Paradox," in Carl Wennerlind and Margaret Schabas, eds., *David Hume's Political Economy* (London, 2008), 243–323.

[80] Gabriel Bonnot de Mably, *Le droit public de l'Europe fondé sur les traités*, in Mably, *Œuvres complètes*, 13 vols. (London, 1789–1790), 6: 311, cited in Michael Sonenscher, *Sans-Culottes: An Eighteenth-Century Emblem in the French Revolution* (Princeton, N.J., 2008), 389.

[81] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 127–128.

[82] Genovesi, *Storia del commercio*, 2: 189–190n, 248–249n; see also 22–23n.

But even more succinctly than Genovesi, Paradisi expounded the often violent nature of such economic competition. The Portuguese and subsequently Dutch commercial expansions into the East Indies, and their lucrative enslavement of peoples to supply the burgeoning bourgeoisie of Europe with luxuries, demonstrated how these great powers had acted "despotically," as "Conquerors." However virtuous the republican Dutch thought themselves to be, "the Indians had no reason to rejoice, because they found themselves subject to a Dutch yoke worse than the first [Portuguese] one: that is how easy it is for oppressed men to become oppressors," for former thralls of Spain to enslave the world. Since the Dutch had nothing "that one could call their own," their "trade" aimed at supplanting and "destroying" that of others; Holland owed "the prosperity of its Commerce" only to "the malignity with which it exercised it." Similarly, Columbus's discovery of the New World and the subsequent Spanish conquest unleashed horrors upon the earth, but made Spain "Sovereign over Endless Kingdoms," seemingly "the lone receiver of the riches of the universe." The same was true of France's achievement of the "*grandezza* of commerce" after Colbert, and particularly of England, which "with Arms, with knowledge, and with diligence has promoted Commerce to its full power" and become "dominator of the Ocean." Conquest and commerce, then, in striking opposition to the ostensibly canonical Enlightenment narrative and the still-popular theory of *doux commerce*, went hand in hand in Paradisi's lectures.[83] Gibbon, to draw a natural parallel again, had argued that Venice did not "often forget that if armed galleys were the effect and safeguard, merchant vessels were the cause and supply, of her greatness."[84] For Paradisi, the relationship between conquest and commerce was not only symbiotic, but nearly interchangeable.

Of course, history, too, spoke clearly to Paradisi of trade's benefits. "Commerce" could produce "power," "conquests," "magnificent enterprises," and even "the ennoblement of the entire human species." Through it "the human species had itself, in a way, returned to the primitive system of a single society."[85] But his antiquarian prejudices, his deep-seated cultural and historical erudition, in this case inoculated him against excessive conjectural abstractions. History taught him that a single society was not necessarily a peaceful one, for single societies could be unjust, too—as the conspiracies and contentions of the Italian communes bore witness. The importance of active politics informed by history therefore remained paramount throughout his course, reaching its most refined meditation in his culminating third-year lectures.

This is where the categorical labeling of Paradisi as a "physiocrat" demonstrates the dangers of historiographical fashions, for his concluding section, "On External Commerce," in effect traces a series of proposals for counteracting decline diametrically opposed to those of physiocracy. Where Quesnay repeatedly encouraged free international trade and the export of agricultural products in exchange for manufactured goods, Paradisi proposed the opposite: "the state that exchanges its manufactured goods for the produce of the lands of other states," he observed, "will have the advantage," a maxim evident to him from the historical and present experiences

[83] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 120–129.
[84] Gibbon, *The History of the Decline and Fall of the Roman Empire*, 3: 669.
[85] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 2: 134–135.

of all great powers. Continuously improving manufactures was the only means of staying ahead in an international system of competing commercial societies. Given this take on political economy, it should not be surprising that Paradisi concluded his lectures with a section on the much-maligned "balance of trade," which he considered "the recapitulation of all that has been taught."[86] Here, however, his erudition inflected the canons of political economy with extraordinary results.

The "balance of trade" consisted in the difference between imports and exports, but what interested Paradisi were flows of wealth rather than material goods per se. Since the cat was out of the bag and the principles of political economy were no longer state secrets, the problem remained of how Italy, having twice declined, could regain its liberty and greatness in an internationally competitive context. Theorists across Europe had recently ventured beyond their earlier obsession with goods to consider the balance of trade in light of all the ways in which foreigners could supply nations with revenue, suggesting that this could happen even when they were "buying something" there or by "visiting, and staying there at their own expense." Tourism, in other words, was explicitly analyzed in economic terms.[87] Genovesi had incorporated this idea into his lectures almost twenty years earlier, but Paradisi took the issue much further than his predecessors had.[88] No region was more apt to draw advantage from this new way of conceiving the balance of trade than Italy, for no place had better reasons for foreigners to visit. "This advantage" of being attractive to foreigners "is enjoyed by Italy above all the countries of the World," for with every step one took across the peninsula, there was something "worthy of observation."[89]

Since Italy historically had been "divided into many states," it had developed "many Capitals," loci of lost *grandezza* containing "rarities" from "the ancient Romans, our ancestors," in the form of "monuments." These were boundless sources of wealth because they inspired remembrance and arguments "over the magnificence of that only Empire." This "erudition," Paradisi was quick to note, "is not useless because it continuously draws to us new guests, who run to admire the thermal baths, the amphitheaters, the temples, the cities buried for many centuries that have come to light again in our days," of which Herculaneum and Pompeii were the century's greatest examples. Myriad works of ancient art still attracted "erudite foreigners," and so did those of Italy's "renewal," the great artworks of the Renaissance.[90] Here Paradisi's love of antiquity, of erudition, and of his *patria* encountered the Milanese

[86] Ibid., 3: 95; see also 3: 99–100, 102–105, 166.

[87] In alignment with his theoretical predisposition, Paradisi drew on the suggestions of Véron de Forbonnais and "M. Cavalier Childh," whom one can presume he had read in the 1753 French translation by Vincent de Gournay and Georges-Marie Butel-Dumont. Ibid., 3: 170. Genovesi also quoted this passage both in his "Elementi del commercio," in *Delle lezioni di commercio o sia di economia civile con Elementi di commercio*, ed. Maria Luisa Perna (Naples, 2005), 1–256 and 257–890; and in his "Lezioni di commercio," ibid., 187 and 803–807. The source for both was probably Forbonnais's development of the issue in his *Elémens du commerce*, 2 vols. (Leyden, 1754), 2: 248–249, in the chapter "De la balance du commerce."

[88] Genovesi, *Elementi*, 188–189, where he concluded that the arts should be encouraged and that the "rarities discovered in arcades" could attract foreigners; a variation of this passage had made its way into the section on the "balance of trade" that Genovesi included in his supplementary "translation" of Thomas Mun in his *Storia del commercio*, 2: 441–444, presumably Paradisi's source.

[89] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 3: 175–177.

[90] Ibid., 177–179. On how the Renaissance itself drew on the material rediscovery of Italy's first *grandezza*, see Leonard Barkan, *Unearthing the Past: Archaeology and Aesthetics in the Making of Renaissance Culture* (New Haven, Conn., 1999).

school of utilitarian political economy that he emulated at his chair. In turning Italy's ostensibly greatest weakness—its division into numerous "capitals"—into its greatest strength, he showed how its frequent, conspicuous rises and falls could provide a unique comparative advantage in selling past glories to foreigners. The hunger for Italy's artistic heritage, he knew, stretched from "the furthest north of Russia to the southern extreme of Portugal."[91]

Ironically, the luxury to which Italy supposedly had twice fallen victim became the principal vehicle for elevating it again, and decline itself became the paradoxical precondition for future greatness. Although drawing on the aims and analytical vocabulary of his professed discipline, Paradisi formulated his theories in an explicit dialogue with antiquarianism. Having differentiated between the utilities of different colossal architectures in his inaugural dissertation, he now proposed that their ruins had differential values as well. Just as the Phoenix of legend had built its own regenerative pyre, so Italy had to adopt a politics of ashes to inaugurate a new cycle, cultivating not only agriculture and industry but culture as well. The last line of Paradisi's final lecture acutely expressed the essence of his work and the unlikely encounter of Petrarchan anacyclosis and Milanese utilitarianism: "From my point of view, I have to recommend to Italy the Arts, the fine Arts, which are its true [treasure], its own treasure; and as they were born in her, one may almost fear that they will perish in her."[92] History was not merely a repository of symbolic and cultural capital, it was itself a valuable economic resource. Although many *philosophes* of the Enlightenment besides Paradisi utilized the analytical instruments of antiquarianism, few quite so literally capitalized them.[93]

BUT HOW DOES THIS MINUTE STUDY of Paradisi's lectures on conquest, commerce, and decline fit into the larger theater of Enlightenment political economy? Surprisingly, better than one might think. As Franco Venturi established, the period was characterized by both pressing local concerns and a growing cosmopolitanism fueled by the increasing circulation of texts and the intensifying emulation of practices.[94] In a similar vein, John Robertson has demonstrated the commonality of "Enlighten-

[91] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 3: 176–181. See, among others, Johann Wolfgang von Goethe, *Italian Journey, 1786–1788*, trans. W. H. Auden and Elizabeth Mayer (London, 1962), 45. See for an overview Jeremy Black, *Italy and the Grand Tour* (New Haven, Conn., 2003).

[92] BPRE, MSS. REGG. E 139, *Lezioni di economia civile*, 3: 181–183. Paradisi died young, but not before giving another full course of similar lectures titled *Lezioni di storia*. The informal title he gave his course cemented his distance from Gibbon's sprawling history of the Roman Empire in the East: "Storia dell'Impero Occidentale, particolarmente riguardo alle cose dell'Italia," BPRE, MSS. TURRI G 4, *Lezioni di storia*, 2v.

[93] For a modern take on the economics of tourism based on antiquities, see James Cuno, *Who Owns Antiquity? Museums and the Battle over Our Ancient Heritage* (Princeton, N.J., 2008), 97–99. For an analysis of the dangers of turning Italy into the "theme park of the planet," see, with particular relevance for Paradisi's arguments, Roberto Fini, *"Sara' come Venezia, meravigliosi palazzo invece che flotte e regni": Osservazioni sul decline socio-economico dell'Italia* (Venice, 2006). On Enlightenment and antiquarianism, see Arnaldo Momigliano, "Ancient History and the Antiquarian," *Journal of the Warburg and Courtauld Institutes* 12, no. 3/4 (1950): 285–315. On this article and for a similar argument, see Peter N. Miller, "Introduction: Momigliano, Antiquarianism, and the Cultural Sciences," in Miller, ed., *Momigliano and Antiquarianism: Foundations of the Modern Cultural Sciences* (Toronto, 2007), 3–65.

[94] On this see Sophus A. Reinert, "In margine a un bilancio sui lumi europei," *Rivista storica italiana* 118, no. 3 (2006): 975–986; and Reinert, "Traduzione ed emulazione."

ment" ideas in Scotland and Naples by juxtaposing the moral and economic philosophies of Hume and Genovesi, two authors whom Paradisi knew well.[95] Although the contexts in which they wrote were different, their religious ideas strongly opposed, and their preoccupations remarkably diverse, the two thinkers did agree on the fundamentals of economic policy *and* the means of handling temporal cyclicalities. For Enlightenment reformism required no dreams of perpetual progress, and Hume hit a raw nerve in the eighteenth century:

> It is needless to enquire whether such a government would be immortal . . . It is sufficient incitement to human endeavours, that such a government would flourish for many ages; without pretending to bestow, on any work of man, that immortality, which the Almighty seems to have refused to his own productions.[96]

Political economy could go on with its business purposefully heedless of its ultimate eschatology. Its successes might never amount to "progress" in any perennial sense, and no teleology could be found in the process, but short-term worldly melioration was well within the possibilities of policy. Paradisi's lectures do not falter in pursuing a Polybian political economy, either, although the causes of decline could not fail to interest him deeply. Clio, after all, had bestowed upon Italy a longer, more complex legacy than she had upon Scotland.

Nowhere was what Michael Sonenscher has called "future-oriented speculation" more intrinsically intertwined with the institutionalization of political economy than in Italy.[97] But decline and fall were, for Paradisi and the economic historiography to which he contributed, primarily of Italian interest, and the mechanisms by which they assailed civilization had not, as was the case for better-known Scottish and French writers of the period, changed noticeably from the ancient order based on conquest to the modern one based on commerce. The difference between a horde of raging Ostrogoths and Langobards, on the one hand, and the Royal Navy with which England enforced its Navigation Acts or the Dutchmen who enslaved the East Indies, on the other, was academic from Paradisi's perspective. History showed that even though the influence of commerce as a force in the world was growing, the means of its extension remained soundly anchored in violence and coercion. Modern scholars risk being blinded to this fact by the dichotomy between ancient "conquest" and modern "commerce," and by the pervasive equation of Enlightenment with *laissez-faire*.[98] These views certainly had their grand theorists at the time, and studying them has borne extraordinary fruit in recent years, but they were far from the only way of conceptualizing international competition in the Enlightenment.

The sheer length of Paradisi's reformist lectures and his erudite formation in the shadow of Italy's cyclical history render the conflux of war and wealth that he identified particularly obvious, but similar statements were legion across the peninsula

[95] Robertson, *The Case for the Enlightenment*.

[96] Hume, *Political Essays*, 233. On Hume in Italy, see Marialuisa Baldi, *David Hume nel Settecento italiano: Filosofia ed economia* (Florence, 1983); and Robertson, *The Case for the Enlightenment*.

[97] Sonenscher, *Before the Deluge*, 27, 93.

[98] This dichotomy is discussed in Hirschman, *The Passions and the Interests*; Pagden, *Lords of All the World*, 115–125, 178–200; Pocock, *Barbarism and Religion*, 1: 109; 2: 79, 221; 3: 309, 377–378; Hont, *Jealousy of Trade*; Robertson, *The Case for the Enlightenment*, 343; Sonenscher, *Before the Deluge*; and Pagden, *Worlds at War: The 2,500-Year Struggle between East and West* (Oxford, 2008), 270, among many other places.

and elsewhere. Paradisi never published his ideas, and their direct influence in any larger sense was therefore negligible, but the grand tapestry of his teaching provides a larger narrative in which other, seemingly isolated observations of the time may regain their rightful presence at the forefront of political and cultural debates.[99] Giovanni Battista Zanobetti, for example, annotating a Leghorn edition of Girolamo Belloni's bestselling *Of Commerce* in 1751, noted:

> It seems indeed that the genius of commerce and that of conquest are contradictory within the same nation . . . Today, though, one sees these two geniuses united in some Kingdoms, and the happy peoples who have this fate are superior to the Romans because uniting commerce and conquest allows them to keep what they have acquired, binding the conquerors and the conquered and all the parts of the empire with mutual benefits.[100]

The focus of Zanobetti's discussion was England, and "England," as Giuseppe Pecchio would note in 1829, "is for the moderns what Crete was to the ancient philosophers."[101] As a polity, it was the linchpin of modernity par excellence; it had been the "object," the Neapolitan Gaetano Sotira noted in his Parisian manuscripts at the height of the French Revolution, "of universal envy" throughout "this century," the target of emulation by statesmen and private citizens alike.[102] Yet England crossed the line between conquest and commerce with abandon, with powerful repercussions for the parallel dichotomy between wealth and virtue and for the chain of causation between *grandezza* and decline, that is, the doctrine that heroic virtue allows for the establishment of empires, the corrupting consequences of which ultimately undermine their own foundations.[103] As the Venetian Francesco Algarotti put it in his 1764 *Treatise on Commerce*, "The English, who by land and by sea make use of their own arms, demonstrate well that one can graft military valor onto the mercantile profession; and if they pursue commerce with Carthaginian subtlety, they do not lack Roman *virtù* in war."[104] In Naples, Ferdinando Galiani would reiterate the message

[99] For contemporary praise of Paradisi's lectures, however, see Franco Venturi, *Saggi preparatori per Settecento riformatore* (Rome, 2002), 172.

[100] Girolamo Belloni with annotations by Giovanni Battista Zanobetti, *Del commercio* . . . (Leghorn, 1751), 70n. On this book, see Antonella Alimento, "Tra Bristol ed Amsterdam: Discussioni livornesi su commercio, marina ed impero negli anni Cinquanta del Settecento," in Donatella Balani, Dino Carpanetto, and Marina Roggero, eds., *Dall'origine dei lumi alla rivoluzione: Scritti in onore di Luciano Guerci e Giuseppe Ricuperati* (Rome, 2008), 25–45.

[101] Giuseppe Pecchio, *Storia della economia pubblica in Italia* (Lugano, 1829), 135.

[102] Archives nationales de France, T 1545, Papiers Sotira, "Discorsi politici sopra la forma del governo d'Inghilterra e sopra le cagioni della Grandezza, e decadenza di Quel Regno dell' Abate Gaetano Sotira Socio delle Regali Accademie delle scienze e belle lettere di Napoli e di Messina," 2r. On England as a ruthless "model" for generations of political economists in Europe, see Sophus A. Reinert, "Blaming the Medici: Footnotes, Falsification, and the Fate of the English Model in Eighteenth-Century Italy," *Journal of the History of European Ideas* 32, no. 4 (2006): 430–455.

[103] This dichotomy, promulgated above all by Pocock's *Machiavellian Moment*, is nearly ubiquitous in the secondary literature. For discussions, see Steve Pincus, "Neither Machiavellian Moment nor Possessive Individualism: Commercial Society and the Defenders of the English Commonwealth," *American Historical Review* 103, no. 3 (June 1998): 705–736; Mark Jurdjevic, "Virtue, Commerce, and the Enduring Florentine Republican Moment: Reintegrating Italy into the Atlantic Republican Debate," *Journal of the History of Ideas* 62, no. 4 (2001): 721–743.

[104] Francesco Algarotti, *Opere scelte*, 3 vols. (Milan, 1823), 1: 452. Machiavelli had paradigmatically argued that the Swiss harbored Roman *virtù* because they relied on their own arms rather than on mercenaries, and while this preoccupation remained in Algarotti, he was among the many who, by the time Britannia was ruling the waves, had abandoned the Florentine secretary's mistrust of commerce. See particularly Machiavelli's letters to Francesco Vettori of August 10 and 26, 1513, in Machiavelli,

in his 1770 *Dialogues on the Grain Trade*, noting that "England" was "simultaneously agricultural, industrial, warlike, commercial," and elsewhere stating unequivocally that "advantageous commercial treatises are solely the effect of victories and of conquests."[105] Paradisi's Milanese colleague Sebastiano Franci similarly conceived of modern commercial relations as a "bloodless war," and Genovesi's student Michele de Jorio precociously warned that commerce had bestowed upon England "dominion" even where it sent no troops, "a different kind of Empire."[106] Moreover, as an anonymous late-eighteenth-century Piedmontese manuscript on economic reform reveals, the ideal that modern commerce should free itself from the logic of conquest could go hand in hand with the painful realization that it had failed to do so:

> The importance of commerce has, with prosperous success, already occupied all the governments of Europe for two centuries. [But] extremely advantageous cures degenerated to maintain animosities between peoples, and produced disagreements, and wars. *The heavens would have wanted that they, driven by laudable emulation, had competed only through the superiority of their industry, and had not taken to violence, and to slaughter, which have transformed the sacred knot with which providence has wanted to tie men together into the most painful scourge of humanity!*[107]

And one could go on. The point is that Italian Enlightenment historiography—with Paradisi here as an emblematic representative—had developed a unique conception of the history of political economy and how it related both to the competitive rise and decline of nations and to the parallel debates over wealth and virtue in the modern world. Far from wealth and virtue always being polar opposites, history taught that there could be synergies between them much as there were between conquest and commerce.[108]

Whether we believe in "the Enlightenment" or we prefer to imagine that there were numerous strands of Enlightenment manifesting and interacting across Europe's different cultural and political contexts, we must accept that unyielding faith in peaceful *laissez-faire* was not a core Enlightenment value away from which theorists could deviate only into ignorance. Paradisi's rejection of it was the eminent product of an Enlightenment reformism mediated by historical awareness. Trade was not always, as Montesquieu sometimes argued, a "sweet" influence antithetical to violence, a cure for "Machiavellianism" and "destructive prejudices," but it could

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Tutte le opere, ed. Mario Martelli (Florence, 1971), letters 211 and 214. John M. Najemy has convincingly shown that it was in these two letters that "Machiavelli invented the Prince"; Najemy, *Between Friends: Discourses of Power and Desire in the Machiavelli-Vettori Letters of 1513–1515* (Princeton, N.J., 1993), 159.

[105] Ferdinando Galiani, *Dialogues sur le commerce des bleds* (Paris, 1770), 65; Galiani, *Nuovi saggi inediti di economia*, ed. Achille Agnati (Padova, 1974), 78.

[106] Sebastiano Franci, "La guerra senza sangue," ed. Pietro Verri, Fondazione Mattioli, Milan, Archivio Verri, 380.4; Michele de Jorio, *Storia del commercio e della navigazione: Dal principio del Mondo sino a' giorni nostri*, 4 vols. (Naples, 1778–1783), 1: 21.

[107] Archivio di Stato, Turin, Materie di commercio, 3° Categoria, Mazzo d'addizione 1 [Mazzo 1 da ordinare], n° 20, n.d., *Pensieri d'un' anonimo sul Commercio in generale, "Del Commercio del Piemonte*," 3v; emphasis added.

[108] See, for the classic argument about wealth and virtue always being mutually exclusive, Pocock, *Machiavellian Moment.* For discussions see fn. 103 above.

actually be terribly bitter.[109] Italy tasted the full spectrum of it, which is why Paradisi's thoughts so clearly suggest that a widening of our historiographical horizons might be warranted.[110] Even adopting a global perspective on the phenomenon, one can argue that the mainstream of Enlightenment political economy—as manifest in the works that actually were published, translated, taught, and acted upon in the eighteenth-century European world—in the end was less about removing all obstacles to some supposedly optimal course of development than it was about identifying the right obstacles for channeling human passions to fruitful ends, in domestic matters as well as in international trade.[111]

For even though Italian thinkers were more vocal in expressing their concerns, their trepidation was hardly limited to any "national context."[112] Throughout Europe, both conquest and commerce were in effect understood to be means of "giving laws" to others, of establishing empire over them, subjecting them, and causing their decline—a challenge from which politics could hardly back down.[113] It is difficult to find a better student of these lessons than Alexander Hamilton, whose contributions to the Federalist Papers—so explicit in their regard for Italy's history and their resistance to the dichotomizing of wealth and virtue and conquest and commerce—reveal that he was participating in a wider tradition, one that seems unorthodox only from the perspective of twentieth-century canon-making.[114] "If Sparta and Rome perished," Rousseau asked rhetorically, "what State can hope to last forever?" Similarly, the Baron von Bielfeld did not conclude his Enlightenment bestseller *Political Institutions* with an ode to peaceful progress through political economy, but rather by dejectedly enumerating the scores of ways in which all states eventually declined.[115] And even Diderot, the avatar of "the Enlightenment," reacted to a painting

[109] Montesquieu, *The Spirit of the Laws*, 338, 389. Montesquieu, of course, did not always believe so, either; ibid., 328–329, and see also his *Reflections on the Causes of the Rise and Fall of the Roman Empire*, 1: 76. On this issue and its historiography see Anoush F. Terjanian, *Commerce in Eighteenth-Century French Political Thought* (Cambridge, forthcoming 2011).

[110] See similarly Sophus A. Reinert, "The Sultan's Republic: Jealousy of Trade and Oriental Despotism in Paolo Mattia Doria," in Gabriel Paquette, ed., *Enlightened Reform in Southern Europe and Its Atlantic Colonies, c. 1750–1830* (Farnham, 2009), 253–269.

[111] On the mainstream of political economy at the time as measured in terms of editions of works published in European languages, see Kenneth E. Carpenter, *The Economic Bestsellers before 1850: A Catalogue of an Exhibition Prepared for the History of Economics Society Meeting, May 21–24, 1975, at Baker Library* (Boston, 1975). For this argument, see at length Sophus A. Reinert, *Translating Empire: Emulation and the Origins of Political Economy* (Cambridge, Mass., forthcoming 2011).

[112] For important contributions to the debate over the singularity or plurality of Enlightenment, see Roy Porter and Mikuláš Teich, eds., *The Enlightenment in National Context* (Cambridge, 1981); Pocock, *Barbarism and Religion*; Robertson, *The Case for the Enlightenment*; Israel, *Enlightenment Contested*.

[113] See, for example, Jean-François Melon, *Essai politique sur le commerce* (Paris, 1736), 9; Jean-Bernard Le Blanc, *Letters on the English and French Nations*, 2 vols. (London, 1747), 2: 91–93, 347–348, 353; Montesquieu, *The Spirit of the Laws*, 328–329; John Cary, *Essai sur l'etat du commerce d'Angleterre*, translation and enlargement by Georges-Marie Butel-Dumont, 2 vols. (Paris, 1755), 1: 75; Genovesi, *Storia del commercio*, 1: lxxxv–lxxxvi, 35n–36n, 220n–221n, 367, and 2: 31n–32n; Ange Goudar [and Giacomo Casanova], *The Chinese Spy*, 6 vols. (London, 1765), 4: 1; Gaetano Filangieri, *La scienza della legislazione*, ed. Vincenzo Ferrone et al., 7 vols. (Venice, 2004), 2: 138–139. Autonomy was to have one's own laws in the original Greek, and to receive laws was thus to be conquered, whatever the means. See Richard Tuck, *The Rights of War and Peace: Political Thought and the International Order from Grotius to Kant* (Oxford, 1999), 226.

[114] Alexander Hamilton, *Federalist* no. VI: "Concerning Dangers from Dissensions between the States," in James Madison, Alexander Hamilton, and John Jay, *The Federalist Papers*, ed. Isaac Kramnick (London, 1987), 104–108.

[115] Jakob Friedrich von Bielfeld, *Institutions politiques*, 2 vols. (The Hague, 1760), 2: 309–338.

of ruins at the Salon of 1767 with forlorn resignation, saying, "everything is annihilated, everything perishes, everything passes."[116] Evidently, decline was an overriding preoccupation of this ostensibly progressive era.[117]

In terms of the temporal politics of Enlightenment, Paradisi also speaks directly to one of the great questions of modern historiography, and that is the relationship between antiquarian and conjectural history, between *érudits* and *philosophes*. In his justly famous 1950 article "Ancient History and the Antiquarian," Arnaldo Momigliano noted how "philosophic historians" in the eighteenth century had denigrated the antiquarians whose instruments they nonetheless employed when asking "questions about the general development of mankind of such a sweeping nature that exactness in detail might easily seem to be irrelevant."[118] As an intermediary figure informed by the unique historical vicissitudes of his Italian context, Paradisi was less exploitative: great narratives of modernity should be woven from conscientious learning; successful reforms required meticulous research. With a foot in each tradition, his economic reformism was not an antithesis of erudition, it was a culmination.[119] Taking a cue from important recent works that emphasize the historical influence of antiquarianism in other fields of early modern knowledge and even in practical politics, it is tempting to see Paradisi as symbolizing a striking moment in the transition from humanist erudition to institutionalized political economy.[120] To borrow a dichotomy from Anthony Grafton, Paradisi spoke both "for morality and eloquence" and "for rigor and power."[121] For him, conscientious "history" was "a tribunal of truth" able to "dissipate false systems of politics."[122] A comparison with the physiocrat François Quesnay, habitually considered Paradisi's main source of inspiration, is striking in this regard: "let us not seek into the history of nations or the mistakes of men," Quesnay proclaimed, "for that only presents an abyss of confusion . . . [These] do not serve to throw a light which can illuminate the darkness."[123]

The claim that Paradisi was a physiocrat thus subverts not only his conclusions but also his means of reaching them, the very culture of his learning. And to overturn this interpretation is not merely to change some footnotes but to expand our understanding of Enlightenment reformism and the academic origins of political economy. By highlighting the ways in which commerce, too, could be a form of conquest

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Bielfeld's work was widely translated and republished throughout the century; see Carpenter, *The Economic Bestsellers before 1850*, 17–18.

116 Jean-Jacques Rousseau, "Of the Social Contract or Principles of Political Right," in Rousseau, *"The Social Contract" and Other Later Political Writings*, ed. Victor Gourevitch (Cambridge, 1997), 109; Denis Diderot, *Salons*, ed. Michel Delon (Paris, 2008), 364. On Diderot, ruins, and the eighteenth-century imagination, see Daniel Brewer, *The Enlightenment Past: Reconstructing Eighteenth-Century French Thought* (Cambridge, 2008), 179–198. See similarly Constantin-François Volney, *The Ruins; or, A Survey of the Revolutions of Empires* (London, 1795), 7–8, discussed in Sonenscher, *Sans-Culottes*, 369–370.

117 See Henry Vyverberg, *Historical Pessimism in the French Enlightenment* (Cambridge, Mass., 1958).

118 Momigliano, "Ancient History and the Antiquarian," 307.

119 See similarly Peter N. Miller, *Peiresc's Europe: Learning and Virtue in the Seventeenth Century* (New Haven, Conn., 2000), 156–157.

120 Miller, "Introduction," 4; Jacob Soll, *The Information-Master: Jean-Baptiste Colbert's Secret State Intelligence System* (Ann Arbor, Mich., 2009).

121 Anthony Grafton, *Defenders of the Text: The Traditions of Scholarship in an Age of Science, 1450–1800* (Cambridge, Mass., 1994), 1.

122 BPRE, MSS. TURRI G 4, *Lezioni di storia*, 5r.

123 In Richard Olson, *The Emergence of the Social Sciences, 1642–1792* (New York, 1993), 132.

in the modern world, subject to rises and declines that had to be mediated by an active politics inspired by history, the vein of Enlightenment historiography that Paradisi represents supplies us with new and extraordinarily fruitful perspectives on the eighteenth century and on the history of economics. In the pursuit of worldly melioration, different situations demand different policies. Again, monolithically to equate Enlightenment reformism and political economy with the ideology of economic liberalism and the myth of peaceful progress through *laissez-faire* is misleading.[124] History taught Paradisi that liberty was something more complex than that, and we might do well to hear it for ourselves. There can be no doubt about it: Britain's rise to greatness depended on ceaseless economic interventionism in the eighteenth century; the physiocrats' overnight liberalization of the French grain trade, the shock doctrine of the eighteenth century, was an unmitigated disaster.[125] It is time we reconsidered our assumptions, for much is at stake, and the consequences of Quesnay's example for economics have historically—and presently—been harrowing.[126]

There are many reasons for the discipline's choices, but one problem is certainly historiographical, in terms of the influences that have been thought important for economics and the ways in which they are charted. Few contemplating the plates that codify the process of pin-making in Diderot and d'Alembert's *Encyclopédie* would doubt that these images are imperative for understanding the origins of Adam Smith's pin-based discussion of the division of labor in his *Wealth of Nations*.[127] That is the technical aspect of political economy that justifies its claims to universal operability. But do not the cyclopean etchings of Giovanni Battista Piranesi also provide an illuminating context for studying the discipline's institutionalization in Italy, the possibilities it imagined, and the constraints it faced?[128] The prospects and mem-

[124] Although Jonathan Israel, *A Revolution of the Mind: Radical Enlightenment and the Intellectual Origins of Modern Democracy* (Princeton, N.J., 2009), 117, 120–121, has demonstrated that *laissez-faire* was antithetical to the "Radical Enlightenment," that argument can be extended to show that it was not representative of the "moderate mainstream Enlightenment," either, for most of the eighteenth century.

[125] On England's interventionism well into the nineteenth century, see Patrick K. O'Brien, "The Security of the Realm and the Growth of the Economy, 1688–1914," in Peter Clark and Clive Trebilcock, eds., *Understanding Decline: Perceptions and Realities of British Economic Performance* (Cambridge, 1997), 49–72; William J. Ashworth, *Customs and Excise: Trade, Production, and Consumption in England, 1640–1845* (Oxford, 2003); John V. C. Nye, *War, Wine, and Taxes: The Political Economy of Anglo-French Trade, 1689–1900* (Princeton, N.J., 2007). This has even been accepted by general economic histories such as Findlay and O'Rourke, *Power and Plenty*. On the practical failure of physiocracy, see Kaplan, *Bread, Politics, and Political Economy*. For an example of the old mainstream on this, see Paul Kennedy, *The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000* (New York, 1987), 30.

[126] For perspectives on the death of history in economics, see Geoffrey M. Hodgson, *How Economics Forgot History: The Problem of Historical Specificity in Social Science* (London, 2001); E. Roy Weintraub, *How Economics Became a Mathematical Science* (Durham, N.C., 2002); on its consequences, see Erik S. Reinert, *How Rich Countries Got Rich . . . and Why Poor Countries Stay Poor* (London, 2007).

[127] Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, 8–9. Cf. the article "Épinglier" and corresponding plates in *Recueil de planches sur les sciences, les arts liberaux, et les arts méchaniques avec leur explication*, 11 vols. (Neuchâtel, 1762–1772), vol. 3, book 4, supplementing the *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers*, ed. M. Diderot and M. D'Alembert, 17 vols. (Neuchâtel, 1751–72). The similarity has been long debated in Smithiana. See, among others, Salim Rashid, "Adam Smith's Acknowledgments: Neo-Plagiarism and the Wealth of Nations," *Journal of Libertarian Studies* 9, no. 2 (1990): 1–24.

[128] On Piranesi and his art, see Kenneth Clark, *The Romantic Rebellion: Romantic versus Classic Art* (London, 1973), 45–67. On dilapidation and culture, see Christopher Woodward, *In Ruins: A Journey through History, Art, and Literature* (New York, 2003), and Michel Makarius, *Ruines* (Paris, 2004).

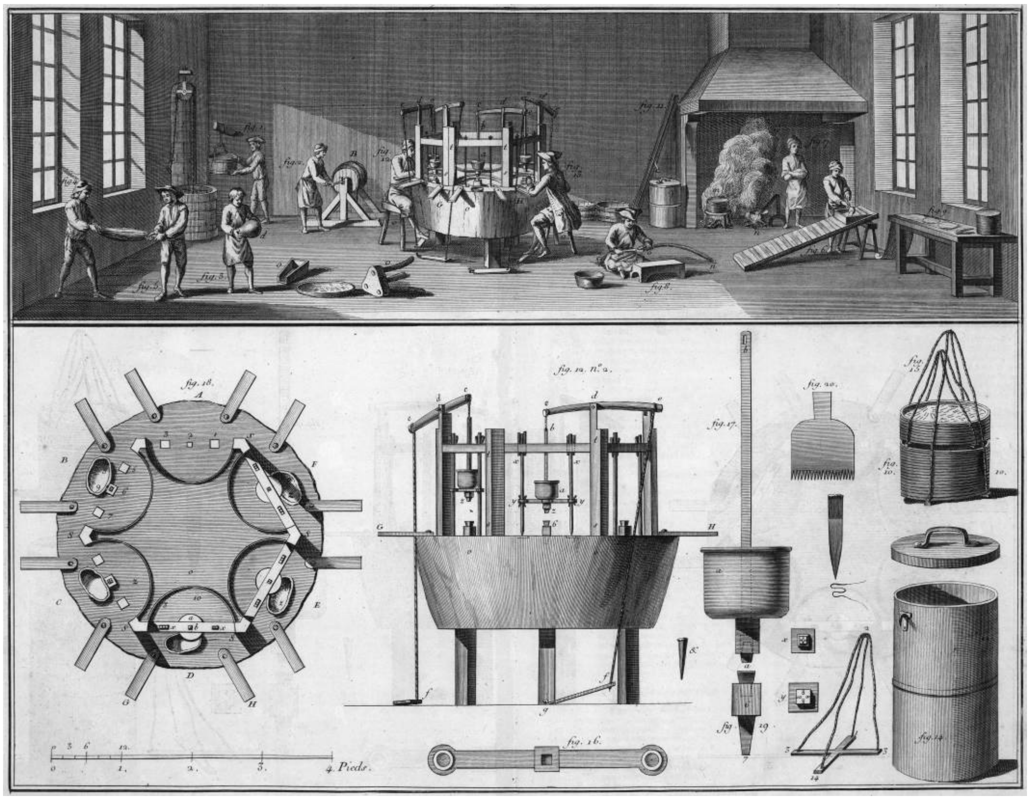

FIGURE 2: Plate 3 from the independently paginated article "Épinglier," in vol. 3, book 4, of the *Recueil de planches* to Diderot and M. D'Alembert's *Encyclopédie* (1765). Reproduced by kind permission of the Syndics of Cambridge University Library.

ories of decline constitute untapped hermeneutical categories for eighteenth-century studies, and demonstrate that something like a cultural history of political economy might be not only possible but necessary in order to understand the multifaceted problems posed by commerce and conquest, by the contingent nature of economic policy, and by how these relate to "Enlightenment" and the wider world of lived historical experience. And as yet another *translatio* overcomes us, the more complex, more historical, and more humble approach to political economy adumbrated in Paradisi's Italy remains worthy of critical attention.

FOR ONE, THE "RICH COUNTRY–POOR COUNTRY" dynamic continues to illuminate the workings of our world; international competition means that only never-ending technical refinement can keep a culture ahead. Americans view outsourcing to China with much the same trepidation that the Venetians once felt when they looked upon England's low wages and interventionist policies. That is simply the relentless logic of economic anacyclosis.[129] *Grandezza* itself contains the "secret poison"—in this case, higher costs of production—that brings about decline. The volume of trade and

129 For a modern Polybian political economy, see Arrighi, *Adam Smith in Beijing*, 234–249.

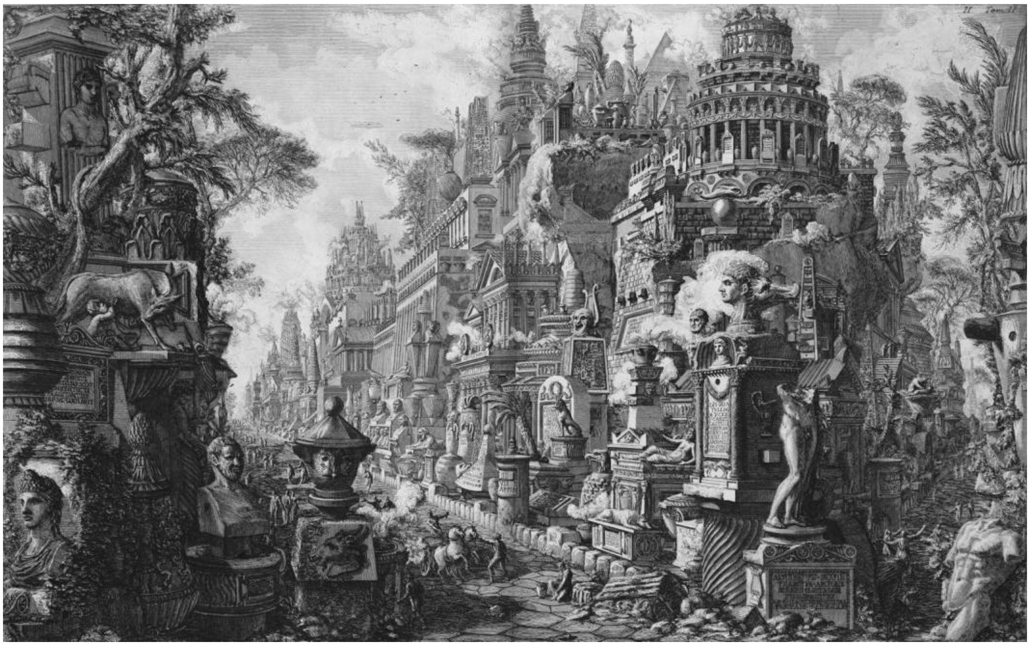

FIGURE 3: From Giovanni Battista Piranesi, *Antichità romane*, 4 vols. (Rome, 1756), vol. 2, plate 2. Reproduced by kind permission of the Syndics of Cambridge University Library.

the celerity of transactions have increased beyond measure, but the economic architecture drawn up in eighteenth-century Italy still has us tumbling down the rabbit hole, where, Lewis Carroll's Red Queen explained, "it takes all the running *you* can do, to keep in the same place."[130] To slow down is to fall behind, to decline. Development demands constant renewal. As Joseph Schumpeter gleefully vivisected the modern condition, a "perennial gale of creative destruction" is "the essential fact about capitalism."[131] Paradisi would have agreed.

Yet there are important ways in which this discourse of rise and decline has changed irrevocably since the Enlightenment. What is at stake today, we are told, is no longer the ups and downs of a cyclical history but human history itself.[132] Might the relentless industrialization embarked upon to stave off Paradisi's vision of decline be leading us to embrace something far worse than anacyclosis, an apocalypse bereft even of transcendence? George Monbiot is among those who have argued precisely this:

> if the engines of progress—technology and its amplification of human endeavour—have merely accelerated our rush to the brink, then everything we thought was true is false. Brought up to believe that it is better to light a candle than to curse the darkness, we are now discovering that it is better to curse that darkness than to burn your house down.

[130] Lewis Carroll, *"Alice's Adventures in Wonderland" and "Through the Looking Glass"* (London, 2003), 143.

[131] Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy* (London, 1943), 83–84.

[132] On different forms of cyclicality today and their politics, see Wallerstein, *The Decline of American Power*, 224–225.

Although humans' proclivity is to "reverse entropy for as long as possible," this has brought us to a point where "our works won't even be forgotten. There will be nothing capable of remembering."[133] And this, the argument goes, because of arrogant vices inherited from the Enlightenment.[134] Paradisi's lectures, and the historiography they help adumbrate, can serve as a foil against such scapegoating. Particularly, they show the decisive limits of interpretations based on the period's supposedly dogmatic faith in progress, night watchman states, and the peaceful spontaneity of commercial civilization. As a historiographical category, "Enlightenment" may be a necessary heuristic device. Yet "from time to time," as D. C. Coleman warned, one must be willing to revisit "invented signposts" and assess their continuing relevance.[135] Immanuel Kant famously defined the "age of enlightenment" as "the genuine age of criticism," when received dogma was subject to revaluation by reason.[136] In no field does our stereotype about the legacies of Enlightenment diverge further from this promise than in economics, and no field now requires a historical perspective more urgently.

Meanwhile, our media landscapes remain riddled with references to progress, decline, and decadence; to Asian tigers and failing states; to great depressions and gilded ages. Were we not rightly wary of deracinating historical phenomena from their specific contexts, we might call anacyclosis a perennial problem. To see FIAT's epic Mirafiori plant, once the pinnacle of Italian Fordism, corroding among tall weeds, or to walk the melancholy and empty halls of the former Buenos Aires branch of Harrods', is an experience not unlike Petrarch's visit to the ruins of Diocletian's baths in the midst of medieval Rome. In both of these places, as in countless others around the world, the public's mnemonic imagination is haunted by achievements that have not been surpassed but were in fact lost in the struggles of international competition.[137] There are many ways of reacting to this sentiment. Johann Heinrich Füssli rendered one natural response, hopelessness, in *The Artist in Despair over the Magnitude of Antique Fragments*. Paradisi was in the end closer to Johann Wolfgang von Goethe's sanguine musings upon surveying the remnants of Rome:

> The observation that all greatness is transitory should not make us despair; on the contrary, the realization that the past was great should stimulate us to create something of consequence ourselves, which, even when, in its turn, it has fallen into ruins, may continue to inspire our descendants to a noble activity such as our ancestors never lacked.[138]

[133] Monbiot, *Bring On the Apocalypse*, 35, 55–56. On what a world without mankind would be like, see Alan Weisman, *The World without Us* (London, 2007).

[134] See John Gray, *False Dawn: The Delusions of Global Capitalism* (London, 2002); the literature discussed in Robertson, *The Case for the Enlightenment*, 1–51; Gray, *Black Mass*; and similarly Thomas Homer-Dixon, *The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilisation* (London, 2007), 305–306, among many others.

[135] D. C. Coleman, "Editor's Introduction," in Coleman, ed., *Revisions in Mercantilism* (London, 1969), 1.

[136] Immanuel Kant, *Critique of Pure Reason*, ed. Paul Guyer and Allen W. Wood (Cambridge, 1999), 100–101.

[137] Mommsen, "Petrarch's Conception of the 'Dark Ages' "; on Italy's third decline in particular, see Gian Antonio Stella and Sergio Rizzo, *La Deriva: Perché l'Italia rischia il naufragio* (Milan, 2008). On the politics of such remembrance, see Brewer, *The Enlightenment Past*, 199–205.

[138] Goethe, *Italian Journey*, 434–435. See, for a conceptual framework for such thinking, Wolfgang Schivelbusch, *The Culture of Defeat: On National Trauma, Mourning, and Recovery*, trans. Jefferson Chase

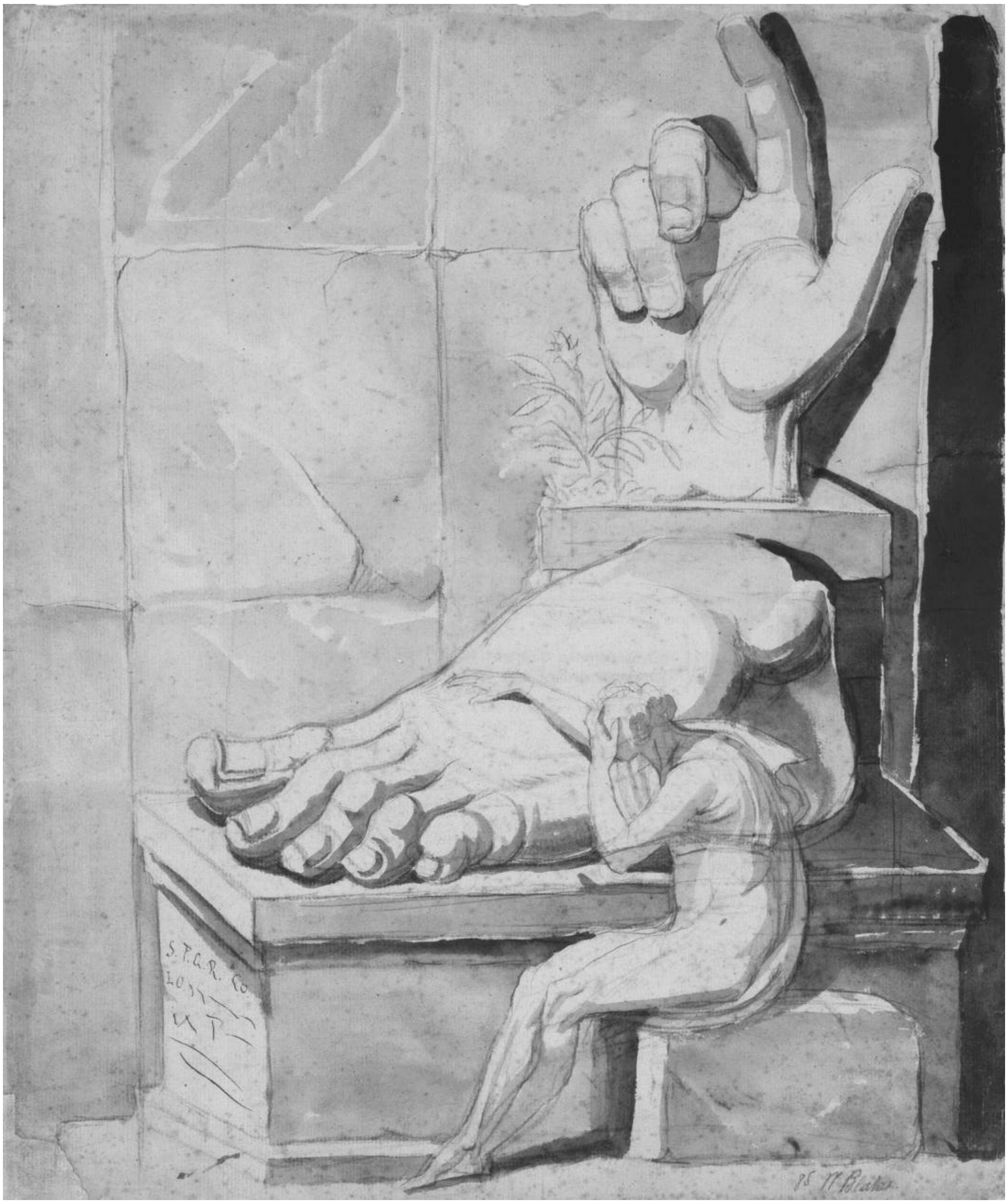

FIGURE 4: Johann Heinrich Füssli, *Der Künstler verzweifelnd vor der Grösse der antiken Trümmer, 1778/1780*. Red chalk and brown wash on paper. 42 x 35.2 cm.

Questions of why decline occurs, how we should react to it, and whether successful nations can fix the wheel of fortune in place—why, in the words of Æsop's fable, civilization is a delicate rose and not an everlasting amaranth—are now no less pertinent. We cannot, though, find any easy answers in the past. Earlier approaches

(London, 2003), 1–35. On the variety of reactions to decline in the eighteenth century, see Vyverberg, *Historical Pessimism in the French Enlightenment*, 231.

to decline will always be mirrors, at once reflecting and distorting, through which we may gain critical distance from contemporary debates and a deeper appreciation of the inherent fragility of our political economies. Since the story of how different cultures have responded and will respond to anacyclosis—with Achillean resolve, Socratic resignation, or outright desperation—remains to be told, historians can and must contribute to these debates.[139] However that story be told, though, we must remember that our greatness can disappear in a moment, that our history will always be the history of the lost, the ephemeral, and the fleeting.

Sic transit gloria mundi.

[139] See, for example, Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (New York, 2005); Jonathan Friedman and Christopher Chase-Dunn, eds., *Hegemonic Declines: Present and Past* (Boulder, Colo., 2005).

Sophus A. Reinert received his Ph.D. from the University of Cambridge in 2009, and is currently a Research Fellow in History at Gonville and Caius College, University of Cambridge. His research and publications focus on intellectual and economic history since the Renaissance. His first book, tentatively titled "Translating Empire: Emulation and the Origins of Political Economy," is forthcoming with Harvard University Press and explores the codification of political economy in the Enlightenment world through the translation of economic works and the exigencies of international competition at the time.

European Agency for Safety and Health at Work

EUROPEAN RISK OBSERVATORY

EN

LITERATURE REVIEW

Maintenance and Occupational Safety and Health: A statistical picture

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European Agency for Safety and Health at Work

Authors:

Project Managers: Malgorzata Milczarek, Joanna Kosk-Bienko, European Agency for Safety and Health at Work (EU-OSHA).

Topic Centre Risk Observatory:

Karen Muylaert (Task Leader) and Rik Op de Beeck, Institut pour la Prévention et le bien-être au travail/Instituut voor Preventie en Welzijn op het Werk (PREVENT), Belgium.

Silvia Royo, Instituto Nacional de Seguridad e Higiene en el trabajo (INSHT), Spain.

Corinne Grusenmeyer, l'Institut National de Recherche et de Sécurité pour la prévention des accidents du travail et des maladies professionnelles (INRS), France.

Grzegorz Owczarek, Centralny Instytut Ochrony Pracy - Państwowy Instytut Badawczy (CIOP-PIB), Poland.

Eva Flaspöler, Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA), Germany.

Simon Kaluza, Bettina Lafrenz and Ralph Hebisch, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Germany.

In cooperation with:

Bart De Norre**,** Statistical Office of the European Communities (EUROSTAT), Luxembourg.

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MAINTENANCE AND OCCUPATIONAL SAFETY AND HEALTH – A STATISTICAL PICTURE

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Executive summary

Maintenance is a generic term for a variety of tasks in different sectors and all kinds of working environments. This report aims to provide an overview of maintenance workers in Europe with regard to their exposure to hazards and the main risks, health problems and accidents. It also gives some indication as to appropriate prevention measures.

Maintenance influences the safety and health of workers in two ways. Regular maintenance that is correctly planned and carried out is essential to keep both machines and the work environment safe and reliable. Maintenance itself has to be performed in a safe way, with appropriate protection of maintenance workers and others present in the workplace.

Two different types of maintenance can be distinguished:

- **Corrective maintenance** – when actions are intended to restore a system from a failed state to a working state (e.g. repair or replacement of broken components). This type of maintenance is also known as ‘reactive maintenance’ because the action is initiated when the unscheduled event of an equipment failure occurs;
- **Preventive maintenance** – when actions are carried out at predetermined intervals or according to prescribed criteria intended to reduce the probability of failure or the degradation of the functioning of an item. In this case, actions are scheduled, proactive and intended to control the deterioration process leading to failure of a system (e.g. replacement, lubrication, cleaning or inspection).

There is also a third type of maintenance which concerns large-scale maintenance. This is carried out to allow an item to accomplish new or additional functions, or the same function in better conditions. It is frequently carried out during shutdown (an outage scheduled in advance) of the item.

The data included in this report are merely indications of the European situation as only a few countries are discussed. The first chapters are based on data from Spain and France only. Alongside a literature review, the exposure of maintenance workers to different risks is shown using information from the National Spanish Survey of Working Conditions. Although based only on data from Spain, the analysis is unique and carried out especially for this report; we can assume that the situation in other European countries may be similar.

A subsequent chapter contains unique data on occupational accidents from EUROSTAT, which are not published elsewhere and are based on the European Statistics on Accidents at Work (ESAW) methodology. Although these data also cover only a few European countries, they demonstrate the high level of accident statistics for maintenance workers.

Maintenance workers

Maintenance covers a number of occupations and concerns all types of activity. It is therefore difficult to identify the exact number of workers involved in maintenance activities. Data from France and Spain indicate that about 6% of the working population is involved in maintenance tasks. The majority of maintenance workers are men (around 90% in France and 65% in Spain) and, within this category of workers, the largest age group is 30–49 years old.

In France, 62% of maintenance workers in 2003 were in the tertiary (service) sector and about 33% in industry. Spain had a similar distribution (2003–2006) with about 70% of maintenance workers working in the service sector and about 19% in industry, though also about 10% in the construction. The large number of maintenance workers working in the service sector can be explained by the considerable outsourcing of maintenance work to service companies; according to a survey conducted in 2005 in France, maintenance is the most subcontracted function in industry.

In France in 2003, about half of all maintenance staff worked in companies with less than 50 employees. Nearly a third belonged to companies with 50–499 employees and 18.5% to companies with 500 employees and more. Nevertheless, there are considerable variations in relation to professional family (grouping used in the French survey).

Occupational safety and health risks related to maintenance

Because they carry out a wide range of activities, maintenance workers are exposed to many and varied hazards at work. There are physical hazards such as noise, vibrations (especially during maintenance of roads, tunnels or bridges), excessive heat and cold (outdoor maintenance workers), radiation, high physical workload and strenuous movements (carrying heavy materials, bending, kneeling, reaching, pushing and pulling, working in small places). Maintenance workers are also at risk of all types of accidents.

Maintenance workers often have contact with vapour or gases, particles (dust, smoke), fibres (asbestos, glass fibre) and mists. Typical maintenance tasks during which workers come in contact with chemical substances include:

- work with asbestos;
- working in confined spaces with dangerous atmospheres;
- electrical arc welding;
- maintenance of public swimming pools;
- working in car repair shops;
- work in solid waste treatment plants;
- maintenance of industrial installations;
- road maintenance;
- maintenance in paper mills.

Biological hazards (Legionella, Leptospira) are related to:

- maintenance of public swimming pools;
- maintaining laboratory instruments;
- maintenance in water supply installations or wastewater treatment plants;
- maintenance in solid waste treatment plants;
- maintenance of public buildings (pigeon droppings).

The characteristics of maintenance work also imply the presence of **psychosocial hazards**. During maintenance work, the productivity of an organisation is cut back and there is an urgency to restart activities as soon as possible. This can put considerable pressure on maintenance workers to complete their tasks. Time pressure and poor work organisation may lead to excessive stress. Moreover, working with contractors can sometimes lead to communication problems.

An analysis of the results of the Spanish National Survey of Working Conditions (2007) revealed interesting data on the exposure to hazards among Spanish maintenance workers. For this project two groups were created in order to exploit the data: maintenance workers (n = 1280) and other workers (n = 9793). The following occupations were considered as related to maintenance:

- bricklayer or bricklayer's mate;
- painter, varnisher/lacquerer, paperhanger;
- plumber, heating operator;
- electrician;

- parquetry worker, tile or floor layer, glazier, roofer, installer of insulating material, installer of air conditioning;
- cleaners of building façades;
- machinist, machine adjuster;
- electrical or electronic equipment repairer.

The results indicate greater exposure of maintenance workers to:

- loud noise (16% compared to 8%);
- very loud noise (3% compared to 2%);
- hand–arm vibrations (24% vs. 9%);
- whole–body vibrations (12% vs. 5%);
- ultraviolet light (8% vs. 4%);
- radiofrequencies (4% vs. 2%).

Maintenance workers are also more exposed to:

- heat in summer (44% compared to 19% among other occupations);
- cold in winter (44% compared to 17%);
- humid atmosphere (25% compared to 13%);
- dangerous substances, vapours and fumes.

Outcomes related to occupational safety and health

Scientific studies indicate that occupational diseases and work-related health problems (e.g. asbestosis, cancer, hearing problems and musculoskeletal disorders) are prevalent among workers involved in maintenance activities. Industrial maintenance employees have an 8–10 times greater chance of developing an occupational disease than the average population.

Analysis of EUROSTAT data based on the ESAW methodology helped to identify accidents related to maintenance operations in a number of European countries. Within the variable ‘working process’ used by ESAW for the classification of causes and circumstances of accidents, four subcategories relate to **maintenance operations**:

- setting up, preparation, installation, mounting, disassembling, dismantling;
- maintenance, repair, tuning, adjustment;
- mechanised or manual cleaning of working areas and machines;
- monitoring, inspection of manufacturing procedures, working areas, means of transport, equipment – with or without monitoring equipment.

The number of accidents for these subcategories was compared to the total number of accidents related to any other subcategory within the variable ‘working process’. The data show that around 20% of all accidents in Belgium (in 2005–2006) were related to maintenance operations, as well as around 18–19% in Finland, 14–17% in Spain, and 10–14% in Italy (in 2003–2006). In addition, figures from a number of European countries indicate that around 10–20% of all fatal accidents in 2006 were related to maintenance operations.

EUROSTAT data from five EU countries indicate that the majority of maintenance-related accidents occur in manufacturing, construction and ‘real estate, renting and business activities’,* and in Austria also in hotels and restaurants. In addition, in the electricity, gas and water supply sector in 2006, 50% of accidents in Finland and Belgium, 34% in Spain, and 23% in Italy were related to maintenance operations. In the real estate, renting and business activities sector, 40% of accidents related to maintenance in Finland, 34% in Spain, and 26% in Belgium. In Belgium, 41% of accidents in the education sector were maintenance-related. In other sectors, depending on the country, 10–20% of accidents related to maintenance operations.

The scientific literature indicates that most of the accidents occur during **corrective maintenance** activities. Moreover, an analysis of a French work accidents database shows that, in 2002, maintenance employees were the second most frequent victims of accidents related to subcontracting, followed closely by construction workers.

Lack of maintenance or inadequate maintenance can also lead to dangerous situations, accidents and health problems. This may be related to lack of, or poor maintenance of, vehicles, industrial or agricultural machines, electrical facilities, fire extinguishers, buildings or water facilities. Maintenance failures may contribute to large-scale disasters with extremely damaging consequences for humans and the environment.

Prevention measures

The process of maintenance should start at the design and planning stage, i.e. before maintenance workers even enter the workplace. It is essential to implement appropriate risk assessment procedures for maintenance operations, as well as employing adequate preventive measures to ensure the safety and health of workers involved in maintenance activities. After maintenance operations are complete, special checks (inspections and tests) should be carried out to ensure that maintenance has been properly carried out and that new risks have not been created. During the whole process, good maintenance management should ensure that maintenance is co-ordinated, scheduled and performed correctly as planned, and that the equipment or workplace is left in a safe condition for continued operation.

* ‘Real estate, renting and business’ activity consists of subcategories such as ‘maintenance and repair of office, accounting and computing machinery’ as well as ‘industrial cleaning’.

1. Introduction

- Maintenance is a generic term for a variety of tasks in different sectors and all kinds of working environments. This report aims to provide an overview of maintenance workers in Europe with regard to their exposure to hazards and the main risks, health problems and accidents. It also gives some indication as to appropriate prevention measures.
- Chapter 2 presents a definition of maintenance work and general employment figures in this field. Chapter 3 is dedicated to the risks to which maintenance workers are exposed and occupational diseases, while chapter 4 examines maintenance-related accidents. The data given are based on the findings of a literature review, as well as information from EUROSTAT and the Spanish National Survey on Working Conditions. Chapter 5 offers guidance on prevention measures.
- When reading this report it is important to bear in mind that the figures given are merely indications of the European situation, as only a few countries are discussed. The first chapters are based on data from Spain and France only. Alongside the literature review, the exposure of maintenance workers to different risks is shown using information from the National Spanish Survey of Working Conditions. Although based only on data from Spain, the analysis is unique and carried out especially for this report; we can assume that the situation in other European countries may be similar.
- Chapter 4 on occupational accidents contains unique data from EUROSTAT that are not published elsewhere and which are based on the European Statistics on Accidents at Work (ESAW) methodology [1]. Again these data cover only a few European countries, but they demonstrate the high level of accident statistics for maintenance workers.

2. Maintenance – contextual features

2.1. Definitions

According to European Standard EN 13306 [2], maintenance concerns 'the combination of all technical, administrative and managerial actions during the life cycle of an item[1] intended to retain it in, or restore it to, a state in which it can perform the required function'. A maintenance function is critical to:

- ensure continuous productivity;
- produce products of high quality;
- maintain a company's competitiveness.

It also contributes significantly to occupational safety and health [3,4]. Maintenance influences the safety and health of workers in two ways. First, regular maintenance that is correctly planned and carried out is essential to keep both machines and the work environment safe and reliable. Second, maintenance itself has to be performed in a safe way, with appropriate protection of maintenance workers and others present in the workplace.

Two different types of maintenance can be distinguished:

- **Corrective maintenance**, i.e. maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function [2]. In this case, maintenance actions are intended to restore a system from a failed state to a working state, i.e. to restore the functional capabilities of failed or malfunctioned systems. This involves, for example, repair or replacement of failed components [5]. This type of maintenance is also known as 'reactive maintenance' because the action is initiated when there is an unscheduled event of equipment failure [6];

[1] EN 13306 defines an item as 'any part, component, device, subsystem, functional unit, equipment or system that can be individually considered' (p. 14).

- **Preventive maintenance**, i.e. maintenance carried out at predetermined intervals or according to prescribed criteria intended to reduce the probability of failure or the degradation of the functioning of an item [2]. In this case, actions are scheduled, proactive and intended to control the deterioration process leading to failure of a system. They are carried out to either reduce the likelihood of a failure or prolong the life of the component [5] by, for example, performing replacement, lubrication, cleaning and inspection [6].

A third type of maintenance can also be added to this list. This concerns large-scale maintenance. This type of maintenance is carried out to allow an item to accomplish new or additional functions, or the same function in better conditions. It is frequently carried out during shutdown (an outage scheduled in advance) of the item [7]. The actions performed concern, for example, modification, rebuilding, modernisation or renovation of the equipment or system [8].

2.2. Maintenance workers

2.2.1. General employment

It is difficult to obtain statistics on the employment of maintenance workers for various reasons:

- Maintenance does not correspond to just one occupation but to several. Mechanics, electricians, car mechanics, electronics engineers, maintenance supervisors and other workers might perform maintenance tasks as a part of their job;
- Maintenance concerns all sectors of activity. The type of maintenance will be different depending on the sector in which the maintenance worker is employed;
- Maintenance is a role that can be assumed by different operators in a principal or subsidiary way. Maintenance organisations are various and have undergone profound modifications (e.g. total productive maintenance; autonomous maintenance; shared, integrated or specialised maintenance; subcontracting maintenance; and remote maintenance) leading for example to the allocation of maintenance tasks to production operators [9]. Thus, maintenance operations may be carried out by a specialised operator, a user or an operator who is external to the company owning the items being maintained.

The data presented below relate to employees whose occupation is explicitly related to maintenance. As no data were found for Europe in general, data from France and Spain are presented as an indication of employment of maintenance workers in Europe.

According to AFIM (Association of Maintenance Engineers and Technicians),maintenance (which includes industrial and tertiary[2] maintenance as well as private services) represents more than 450,000 jobs in France, including 15,000 managers [10–13].

[2] The tertiary sector covers activities such as trade, administration, transport, financial and property activities, services to companies and people, education, health and social action.

The SUMER 2003 survey[3] [14] also allowed the number of maintenance employees in France to be estimated. The professional families[4] distinguished in the survey and related to maintenance are as follows:

- 'Skilled maintenance workers'. They undertake maintenance work, and the repair and renovation of mechanical, electromechanical, electrical and electronic equipment;
- 'Automotive repair workers'. These employees are mainly (about 75%) car mechanics and electronics workers, and (to a lesser extent) coachbuilders;
- 'Maintenance and organisation technicians and supervisors'. This group includes middle managers, who plan maintenance work, and qualified technicians, fitters and temporary repair workers in electricity, electronics and mechanics. Environmental engineers, managers and technicians are grouped with maintenance technicians and supervisors, which may affect the results as their activities are different.

On the basis of the results of the SUMER 2003 survey, the number of maintenance employees coming under these three maintenance professional families (the maintenance domain) in France can be assessed at 889,400 (see Table 1). Hence, they represent some 5% of the salaried employees of the general social security system and of the public hospitals, French post office, French electricity board, French railways, French air transport (Air France) and the agricultural social insurance system [14]. However, the three maintenance families examined here probably do not represent all maintenance employees. Moreover, these numbers are related to the occupations of the employees and not to their role.

Table 1: Number of professional families in France in the 'maintenance domain', SUMER 2003 survey [14]

Professional family	Number*	Percentage**
Skilled maintenance workers	304,600	1.76%
Automotive repair workers	202,000	1.17%
Maintenance and organisation technicians and supervisors	382,800	2.21%
Total	**889,400**	**5.13%**
All professional families (76 families)	17,334,200	100%

* Extrapolated numbers of salaried employees from the survey sample.

** Ratio of the employees of the professional family concerned to the total number of employees of the survey (i.e. employees of the 76 professional families, bearing in mind that 10 were not included because their number was insufficient or because they were too heterogeneous).

Two groups from the Spanish social security database were considered as maintenance workers:

- maintenance, repair, adjustment and working out (code 52);
- industrial or manual cleaning of spaces and machines (code 53).

The data show that, in 2006, about 6% of the working population in Spain was concerned with maintenance tasks. From 2003 to 2006 the percentage of workers involved in maintenance fell

[3] The SUMER (SUrveillance MEdicale des Risques professionnels) survey is an evaluation tool of the exposure of employees to the main workplace risks in France. It is organised by the French Ministry of Labour and was conducted in 2003 in conjunction with the French Department of Work Relations and the Ministry's Research and Statistics Department (DARES, Direction de l'Animation de la Recherche, des Etudes et Statistiques). The survey is based on interviews conducted by company doctors and questionnaires to a representative sample of 56,345 randomly chosen salaried employees.

[4] 'Professional families' is one of the main occupational nomenclatures based on the grouping used by INSEE (French National Institute of Statistics and Economical Studies) and ANPE (French National Agency for Employment). Professional families relate to occupations which require common knowledge and similar physical strains [15].

slightly (from 8% in 2003 to 6,1% in 2005, see Table 2) [17]. However, these figures do not necessarily cover all maintenance workers.

Table 2: Employment in maintenance work in Spain, Ministry of Labour and Immigration, 2003–2006 [17]

Maintenance					
Year	Yes		No		Total
	No.	%	No.	%	
2003	76,152	8.0	878,695	92.0	954,847
2004	61,880	6.5	893,864	93.5	955,744
2005	61,146	6.2	920,649	93.8	981,795
2006	61,367	6.1	942,073	93.9	1,003,440

2.2.2. Employment by gender

The data from the French SUMER 2003 survey indicate that almost all maintenance employees are men (Table 3); this is the case for 95% of all such employees, ranging from 91% for maintenance and organisation technicians and supervisors to 99% for automotive repair workers. Women represent 5% of these three professional families.

Table 3: Distribution of maintenance employees in France as a function of gender, SUMER 2003 survey

Gender	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain*
Male	97%	99.3%	91.2%	95%
Female	3%	0.7%	8.8%	5%
Total	**304,600**	**202,000**	**382,800**	**889,400**

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

In Spain the percentage of female maintenance workers is higher than in France; in 2006, 63% were men compared to 37% women (Table 4). This is comparable to the total employment figures, although the total percentage of male workers in 2006 was 77% making the percentage of women undertaking maintenance work higher than the average percentage of women in employment. This is quite a remarkable situation.

Table 4: Employment of maintenance workers by gender in Spain, Ministry of Labour and Immigration, 2003–2006 [17]

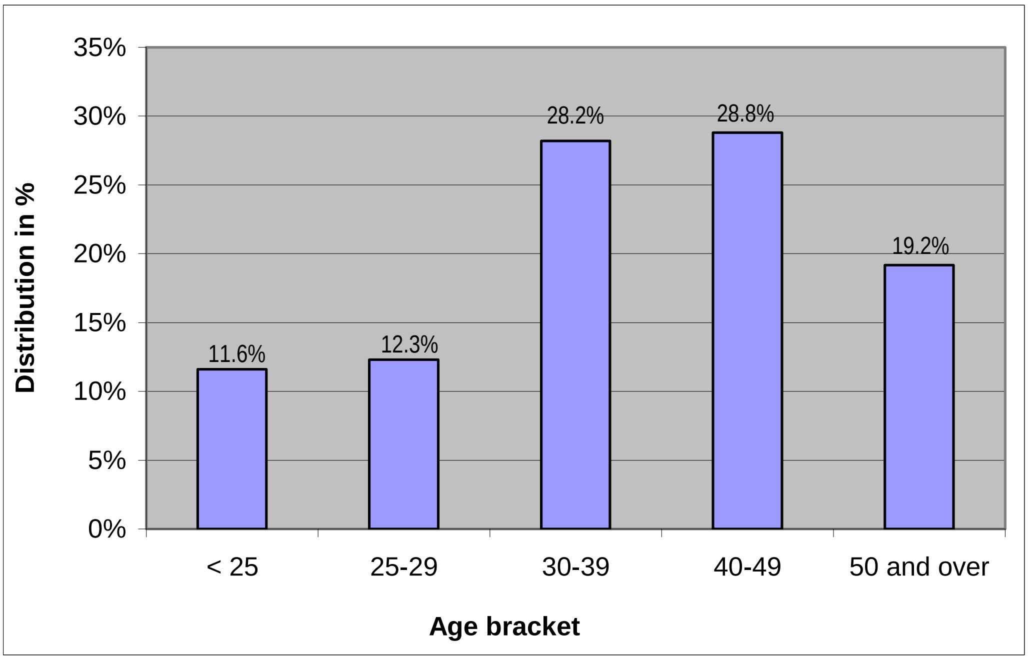
Year	Maintenance					Total				Total
	Men		Women		Total	Men		Women		
	No.	%	No.	%		No.	%	No.	%	
2003	49,167	64.6	26,985	35.4	76,152	745,265	78.1	209,582	21.9	954,847
2004	39,691	64.1	22,189	35.9	61,880	741,162	77.5	214,582	22.5	955,744

Year	Maintenance					Total				Total
	Men		Women		Total	Men		Women		
	No.	%	No.	%		No.	%	No.	%	
2005	38,846	63.5	22,300	36.5	61,146	761,032	77.5	220,763	22.5	981,795
2006	38,877	63.4	22,490	36.6	61,367	773,991	77.1	229,449	22.9	1,003,440

2.2.3. Employment by age

According to the SUMER survey [14], 57% of employees in the maintenance professional domain in France in 2003 were between 30 and 49 years old (see Figure 1).

Figure 1: Distribution of maintenance employees in France as a function of age bracket, SUMER 2003 survey [14]



However, there are large variations in this distribution in relation to professional family; 21% of the automotive repair workers were under 25 in 2003, whereas this percentage is only 6.6% for the maintenance and organisation technicians and supervisors. On the other hand, employees aged at least 50 represented more than one skilled maintenance worker in five (23%), but only 12% of the automotive repair workers. Furthermore, the SUMER 2003 survey does not allow comparison with all French employees (data are only relative to age per professional category).

According to the SUMER 2003 survey, 5.5% of the maintenance staff had been doing this work for less than one year (variations between maintenance professional families were slight – from 4.9% to 7.1%), and 94.5% had been working for at least a year in the job.

In Spain the largest proportion (around 65%) of the maintenance workers in 2003–2006 were between 25 and 49 years old (Table 5). This is comparable to the figures for total employment in Spain, though compared to the total employment, there are less young workers involved in maintenance work and a larger proportion of older workers.

Table 5: Employment of maintenance workers in Spain, by age, Ministry of Labour and Immigration, 2003–2006 [17]

(a) Maintenance							
Year	15–24		25–49		50 and more		Total
	N	%	N	%	N	%	
2003	11,496	15.1	47,620	62.5	17,036	22.4	76,152
2004	8,801	14.2	39,607	64.0	13,455	21.7	61,863
2005	8,160	13.3	39,292	64.3	13,694	22.4	61,146
2006	7,898	12.9	39,558	64.5	13,911	22.7	61,367

(b) Total							
Year	15–24		25–49		50 and more		Total
	N	%	N	%	N	%	
2003	218,132	22.8	593,616	62.2	143,099	15.0	954,847
2004	208,079	21.8	614,011	64.3	133,426	14.0	955,516
2005	202,362	20.6	639,242	65.1	140,191	14.3	981,795
2006	196,431	19.6	662,976	66.1	144,033	14.4	1,003,440

2.2.4. Employment by sector

Table 6 shows the distribution of maintenance employees as a function of four activity sectors – agriculture, industry, building, tertiary (service) – in the SUMER 2003 survey [14]. In 2003, maintenance staff worked essentially in the service sector (62%). They were also well represented in the industry sector (34%), but seem to be less numerous in the building and agricultural sectors.

Some variations are observed in relation to professional family, as almost every automotive repair worker (97%) worked in the service sector, whereas a third of the maintenance and organisation technicians and supervisors (34%) and more than half of the maintenance skilled worker (54%) worked in industry.

The high proportion of maintenance staff in the service sector is noteworthy. This distribution of maintenance employees according to sector is likely to have undergone major change in recent years (from industry to service sector). As maintenance activities are increasingly subcontracted, maintenance staff who used to work for industrial companies may now work for companies specialising in maintenance (which are part of the service sector). Indeed, maintenance was the most subcontracted function in industry according to a survey conducted in 2005 in France [19].

Table 6: Distribution of maintenance employees in France as a function of four activity sectors, SUMER 2003 survey [14]

Activity sector	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain
Agriculture	0.6%	0.6%	0.1%	0.4%
Industry	54.1%	2.2%	33.8%	33.6%
Building	5.9%	0.2%	3.9%	3.7%
Service	39.3%	97.0%	62.2%	62.3%

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

In Spain maintenance workers are best represented in 2003–2006 in the service sector (70%), followed by industry (19%) and construction (10%). The service sector is also best represented (46%) in the total working population (see Table 7).

Table 7: Employment by economic activity in Spain, Ministry of Labour and Immigration, 2003-2006 [18]

Activity sector	2003				2004			
	Maintenance		Total workers		Maintenance		Total	
	N	%	N	%	N	%	N	%
Agriculture	864	1.1	34,830	3.6	709	1.1	36,246	3.8
Industry	15,901	20.9	247,050	25.9	12,362	20.0	244,411	25.6
Construction	7,084	9.3	238,360	25.0	5,498	8.9	236,475	24.7
Service	52,303	68.7	434,607	45.5	43,311	70.0	438,612	45.9
Total	76,152		954,847		61,880		955,744	

Activity sector	2005				2006			
	Maintenance		Total workers		Maintenance		Total	
	N	%	N	%	N	%	N	%
Agriculture	622	1.0	35,438	3.6	692	1.1	36,005	3.6
Industry	11,715	19.2	241,550	24.6	11,605	18.9	241,371	24.1
Construction	5,792	9.5	251,505	25.6	5,968	9.7	263,359	26.2
Service	43,017	70.4	453,302	46.2	43,102	70.2	462,705	46.1
Total	61,146		981,795		61,367		1,003,440	

2.2.5. Size of company

In 2003, almost half of maintenance staff (49%) in France worked in companies with less than 50 employees (Table 8). Nearly a third belonged to companies with 50–499 employees and 18.5% to companies with 500 or more employees. Nevertheless, there are considerable variations in relation to professional family (see Table 8). Indeed, over half the automotive repair workers worked for companies with less than 10 employees, and more than 80% for companies with less than 50 employees. On the other hand, the corresponding figures are 13% and 34% respectively for skilled maintenance workers (more than a quarter worked in companies with 500 employees and more), and 18% and 43% respectively for maintenance and organisation technicians and supervisors. The subcontracting of maintenance may result in increasing numbers of maintenance workers working in small companies, whereas maintenance technicians and supervisors tend to stay in user companies to prepare and plan subcontracted interventions.

Table 8: Distribution of maintenance staff in France according to size of company, SUMER 2003 survey [14]

No. of employees	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain
1–9	13.2%	52.8%	17.6%	24.1%
10–49	21.1%	31.4%	25.3%	25.3%
50–199	23.5%	11.1%	23.6%	20.7%
200–499	15.3%	1.6%	13.5%	11.4%
500 and over	26.9%	3.1%	19.9%	18.5%

2.3. Maintenance companies

As explained above (i.e. maintenance is a transverse activity which concerns all activity sectors), it is very difficult to evaluate the number of maintenance companies.

In France, numerous risk codes used by the CNAM (Caisse Nationale d'Assurance Maladie – National Health Insurance Fund) to characterise company activity are explicitly related to maintenance. This is the case in the following examples:

- 'reconstruction and repair of machine tools';
- 'repair of agricultural equipment';
- 'repair of household equipment'.

However, data concerning these companies are grouped together with data related to those whose main activity does not concern maintenance.

Although existing sources do not allow an evaluation of the number of companies specialising in maintenance in France, some indicators are provided by AFIM (Association of Maintenance Engineers and Technicians). AFIM has identified 300 companies and training organisations certified in maintenance, including 169 maintenance service providers [12]. In addition, 5,485 French establishments containing the term 'maintenance' can be found by searching the website http://www.societe.com. Furthermore using a directory of French companies, 'France Prospect 2008',[5] the Chamber of Commerce and Industry of Meurthe-et-Moselle identified [84] companies specialising in maintenance in the Lorraine region alone. Thus, assuming that there is no difference between the 22 various French regions, there could be an estimated 1,848 companies specialising in maintenance in France.

2.4. Subcontracting maintenance

Maintenance is one of the most subcontracted functions in industry [18,19]. Indeed, many industrial companies have decided to focus on their core business and have outsourced some functions or departments that were previously integrated into their structure. For example, this is the case for transport and research, but also maintenance. The aim of transferring activities to external companies can be 'to set up a small network of interdependent companies that will make production, maintenance and services more flexible' [20] and consequently to reduce costs; in our case, maintenance costs.

According to SESSI (Department of Industrial Studies and Statistics), maintenance and general services represent 20% of the purchases of services by industrial companies in France [21], with

[5] See http://www.france-prospect.fr

some variations according to the size of the company and its sector of activity.[6] In 2005 according to SESSI [21]:

- 50% of French industrial companies with at least 20 employees bought maintenance and general services, but also had internal maintenance and general services;
- 44% only had external (subcontracting) maintenance and general services;
- 4% had no maintenance and general services at all;
- 2% only had internal maintenance as well as general services.

More than 60% of French service companies had recourse to a service provider for maintenance and cleaning activities in 2001. According to INSEE (National Institute of Statistics and Economical Studies), the reasons are primarily linked to the specific abilities needed and the cost of maintenance [22].

AFIM estimates that maintenance represents 2.5–3% of industrial turnover in France, i.e. EUR 22 billion of expenditure, of which EUR 7.1 billion is dedicated to subcontracting [12]. Hence, almost a third (32%) of maintenance expenditure may be dedicated to subcontracting. Internal subcontracting in France (i.e. user company allocating work to an external company on the user company's site and within the scope of its own business) is particularly concerned with industrial maintenance and accounts for a turnover of about EUR 6 billion [23]. This subcontracting maintenance covers different industries such as chemical, petrochemical, steel and nuclear [23].

The subcontracting trend in Spain seems to be less developed than observed in France. It even seems that the percentage of outsourcing of maintenance work in Spain is still declining; in 2003 25% of the maintenance work was outsourced while in 2006 it was only 14% (see Table 9).

Further studies are necessary to better estimate the importance of subcontracting maintenance in Europe.

Table 9: Subcontracting maintenance work in Spain, Ministry of Labour and Immigration, 2003–2006 [18]

Year	Subcontracting maintenance			
	Yes		No	
	N	%	N	%
2003	19,126	25.1	57,026	74.9
2004	12,852	20.8	49,028	79.2
2005	11,625	19.0	49,521	81.0
2006	8,430	13.7	52,937	86.3

[6] Industrial companies may offer their customers certain services. These services mainly concern maintenance and services related to installation and startup [21].

3. Occupational safety and health risks related to maintenance

In recent years, maintenance has been the subject of fundamental change and is now regarded as an essential function within companies. However, maintenance-related risks continue to receive limited attention and little research has been devoted to the impact of maintenance on the safety of those who work in maintenance and their co-workers [24]. Maintenance tasks can be carried out in permanent installations (i.e. maintenance workshops) with appropriate machines and tools, but also where a breakdown occurs. In this latter case, incidents and accidents are more frequent because workers may use inappropriate or improvised equipment, may be working under time pressure, etc. [25]. Moreover, maintenance activities are rarely taken into account in the design of equipment.

Maintenance workers are exposed to many and varied risks when carrying out their job due to very different activities of maintenance, maintenance environment, varied equipments concerned, etc. [26]. Maintenance covers different conditions:

- working outdoors exposed to changing climatic conditions (e.g. maintenance of radiotelephone antenna) or to vibrations, noise and chemical substances (e.g. maintenance of roads, bridges, tunnels, rail tracks);
- working indoors exposed to high levels of noise in industrial facilities (e.g. repair of machines, vehicles, etc.).

Thus, risks are related mainly to:

- environment where the work is carried out;
- machines and tools used;
- type of energy used (e.g. electric, pneumatic or hydraulic);
- working conditions;
- chemical and/or biological agents that workers handle during the work.

In most cases there is a combination of risks.

3.1. Physical hazards

3.1.1. Noise

Many maintenance workers do their job or remain for many hours in noisy environments. This is the case, for instance, for those maintaining roads/tunnels/bridges/railway tracks, aircraft mechanics, car mechanics, metal workers, etc.

Noise can be caused by machinery, equipment or motor vehicles. The levels of noise can exceed the established limit values and continuous exposure to such high sound levels may have several undesirable impacts on the health of operators, causing them hearing loss and other non-auditory effects (see Table 10).

Table 10: Classification of noise effects [27]

Type	Effects of noise
Auditory effects	Temporary hearing loss
	Permanent hearing loss; Acoustical trauma; Hearing loss induced by noise.
	Effects of very intense noise

Non-auditory effects	Physiological non-auditory effects; Increase in blood pressure; Increase in respiratory frequency; Gastric ulcers; Sleep disorders.
	Difficulties in oral communication
	Difficulties in mental concentration
	Discomfort
	Reduction in performance
	Increase in work accidents

Maintenance employees working with heavy earth-moving machinery are considered particularly at risk, with the sound levels experienced by these workers reported to range from 95 to 105 dB [28].

Another study aimed to characterise respirable dust, crystalline silica, diesel and noise exposure of construction workers on a large highway construction project (including maintenance tasks) [29]. The study focused primarily on operating engineers and labourers, and to a lesser extent on ironworkers and carpenters during the tunnel finish and cut and cover stages. With regard to noise exposure, full and partial shift noise dosimeter measurements were collected. Of the 40 noise measurements, 80% were at or above 85 dBA, with the operating engineers averaging 91 dBA. The results indicate that high exposure to noise is common in the road construction industry.

Aircraft mechanics are also considered to be particularly exposed to impact noise [30] and fatigue has been shown to be an effect of noise exposure in this group of workers [31]. According to this latter study, mechanics would feel sleepier and less energetic during the week of work on the runaway after repair work at their base; this effect was most evident in the afternoon after work and increased during the week. The mechanics reported that, when working between two aeroplanes with engines running, they could not only hear the sound but also feel it as vibrations, especially in the chest. This effect might have contributed to the fatigue.

3.1.2 Vibration

- **Hand-arm vibration**

Many of the hand-held power tools used by maintenance workers (e.g. grinding, polishing or riveting tools, impact wrenches, percussion hammers, vibrating compactors, mowers, and chain saws) can transmit vibrations to the worker's hand [32]. The exposure to certain levels of hand–arm vibrations can cause different worker disorders (see Table 11) depending on the doses received, the environmental conditions and the individual characteristics.

Table 11: Disorders caused by exposure to hand–arm vibrations [27]

Type of disorder	Symptoms
Vascular	White finger or Raynaud's phenomenon
Neurological	Decline in touch, manual dexterity and sensitivity to heat
Musculoskeletal	Wrist or elbow osteoarthritis, arthralgia in hands or arms, muscular weakness

- **Whole-body vibrations**

Whole-body vibrations occur when a major part of the body rests on a vibrating surface. In most cases, this exposure takes place while sitting, and vibrations are transmitted through the seats, or while standing and then vibrations are transmitted through the feet. As a consequence, whole-body vibrations are basically from driving commercial vehicles such as earth-moving machinery, tractors, fork-lift trucks, lorries and buses [32]. The exposure to certain levels of whole-body vibrations can cause different disorders depending on the doses received, the environmental conditions and the individual characteristics (see Table 12).

Table 12: Disorders caused by exposure to whole-body vibrations [27]

Type of disorder	Symptoms
Back	Backache, disc lesions, spinal degeneration
Digestive	Gastrointestinal problems
Female sexual organs	Menstruation disorders, internal inflammation, pregnancy disorders
Circulatory	Haemorrhoids, varicose veins
Hearing loss	Hearing loss due to noise exposure can be increased by simultaneous exposure to vibrations.

Many studies demonstrate the exposure of maintenance workers to vibrations. In particular these studies highlight the risk from machinery used during the maintenance of roads, bridges and tunnels. The main conclusions of a study conducted in the Asturias region of Spain were that [33]:

- in almost all civil engineering machines, vibration levels exceeded the action level fixed by Council Directive 2002/44/EC [34] at 0.5 m/s2 for an eight daily hours reference period;
- in some of the machines, measured vibration values were higher on the seat than on the base.

A study [35] based on a systematic literature review to assess risk factors for carpal tunnel syndrome (CTS) summarised 38 primary reports, with analyses based either on a comparison of job titles (22) or of physical activities in the job (13) or both (3). The study found:

- reasonable evidence that regular and prolonged use of hand-held vibratory tools increases the risk of CTS two-fold;
- substantial evidence for similar or even higher risks from prolonged and highly repetitious flexion and extension of the wrist, especially when allied with a forceful grip.

3.1.3. Heat atmosphere

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Studies show the particular hazard of maintenance workers in nuclear power stations due to their exposure to heat [36]. The hazard is particularly present in maintenance operations during the nuclear reactor rundown. The circuit is then under high temperature (300ºC) and pressure (150 bar). Work teams are normally made up of two operators; one takes the necessary measurements in a different circuit and the other notes the results [36].

A 1992 study examined a case of heat exposure in an aluminium foundry [37].

The maintenance worker's task consisted of lifting the aluminium ingots with a shovel and throwing them into basket.

The height to which the ingots were removed from their moulds and collected by the shovel was approximately 90 cm. The basket where the ingots were thrown was placed to the right of the worker. The authors concluded that this was a pure maintenance task where the thermal strain was linked to the radiating temperature of the ingots, placed first on the chain and then in the basket [37].

3.1.4. Radiation

Radiation is a method of transmitting energy, which when interacting with matter, can alter it. Health effects can occur when this interaction affects human organs, and will depend on the radiation type and its intensity [38].

According to their energy level, radiations can be classified as **not ionising** or **ionising.** Not all ionising radiations have less energy than ionising radiations; nevertheless they can also have negative effects on human health (see Table 13).

Table 13: Examples of disorders caused by exposure to non-ionising radiation [27]

Type of radiation	Symptoms
Ultraviolet (UV)	Erythema, conjunctivitis and, in the long term, skin cancer
Visible and infrared	Thermal effects: irradiated surface warming
	Ocular injuries: corneal and retina injuries
Laser	Ocular and skin effects depending on the power severity, duration and wavelength of the laser source
Microwave and radiofrequency	Thermal effects: internal organs warming. Stronger effects in organs with low vascularisation
	Non-thermal effects: interference with biological membranes and bioelectrical activities (EEG, EMG); genetic transmission disorders; interference with pacemakers.
Magnetic and static electrical fields and extremely low frequency (ELF) radiation (>30 kHz)	Photosensitivity Some studies link exposure to these types of radiation to certain types of cancer, but evidence is not conclusive

The energy of ionising radiation is high enough to wrench electrons from the orbits of atoms, causing their ionisation. Such radiation is classified as α, β, γ and X-ray. Biological cellular damage is due to the action of the ionising radiation on DNA molecules. Radiation can produce fragmentations in DNA molecules, leading to chromosomal aberrations and even cellular death. It can also transform the chemical structure of molecules, causing mutations that affect the genetic message. Damages are unspecific and can be somatic (affecting the individual) or genetic (affecting offspring). Effects can appear immediately after exposure (immediate effects) or after a period of time (deferred effects) [27, 38].

Studies indicate that some maintenance workers (e.g. welders) are particularly at risk of radiation. Arc welders are exposed to ultraviolet and visible light from the electric arc. The personal UV radiation exposure levels of a group of welders and nearby workers were estimated in a research using a photosensitive polymer film, polysulphone [39]. The polysulphone film was attached to the inner and outer surfaces of eye protection, the workers' clothing, and also placed throughout the work area. The estimated average ocular exposures (inside the helmets) for welders and boilermakers were between four and five times the maximum permissible exposure (MPE) limit and the estimated exposures at the spectacles of non-welders were around nine times MPE. Body exposures (at the clothing surface) for welders were estimated to be around 3,000 times MPE and for non-welders around 13 times MPE. The ambient UV radiation levels in the factory were found to exceed the MPE by an average of 5.5 times, even in non-welding areas. The results suggest that [39]:

- welders require additional ocular protection to supplement conventional welding helmets;
- any exposed skin areas of workers in this environment should also be protected.

It has also been shown that the interaction of the arc and the metal being welded generates UV radiation, metallic oxides, fumes and gases [40].

Incorporation of radioactive elements to some welding sticks additionally puts workers at risk of cancer due to their exposure to ionising radiation [41]. The risks of cancer due to exposure to radiation are the subject of many epidemiological studies, especially in workers in the nuclear industry. In a cohort of 4,563 nuclear workers followed retrospectively from 1950 to 1994, one study found that the age at exposure modified the effects of external radiation dose on cancer mortality [42]. After adjustment for confounding factors, it was found that workers exposed to external radiation after the age of 50 years experienced exposure-related elevations in mortality from cancer at any site, with radiosensitive solid cancer and lung cancer substantially greater than seen in co-workers exposed at all earlier ages. In contrast, all the radiation doses contributing to mortality from cancers of the blood and lymph system were received before the age of 50 [42]. The results for cancer of any site from this study were considered consistent with the results of previous studies examining the effects of exposure age in nuclear workers. Thus, in the opinion of the authors, the effects of low-level radiation doses may depend on exposure age, and furthermore, patterns of effect modification by age may differ by type of cancer [49].

Much attention has been paid to the health effects of exposure to electromagnetic fields. One study examined exposure to magnetic fields of maintenance workers on electrified railway lines [43]. The maintenance of radiotelephony antenna may also be a source of exposure to electromagnetic fields [44,45].

3.1.5. Exposure to physical hazards among Spanish maintenance workers

An analysis of the results of the Spanish National Survey of Working Conditions [46] revealed some interesting data on the exposure to physical hazards among Spanish maintenance workers. The general sample of the survey, made up of 11,073 workers, represented all occupations and all economic activities.

For this project, two groups were created from the sample in order to exploit the data:

- maintenance workers (n = 1,280);
- other workers in the sample (n = 9,793).

The following occupations were considered as related to maintenance:

- bricklayer or bricklayer’s mate (n = 626);
- painter, varnisher/lacquerer, paperhanger (n = 114);
- plumber, heating operator (n = 68);
- electrician (n = 138);
- parquetry worker, tile or floor layer, glazier, roofer, installer of insulating material, installer of air conditioning (n = 112);
- cleaners of building façades (n = 6);
- machinist, machine adjuster (n = 164);
- electrical or electronic equipment repairer (n = 52).

The results (see Figure 2) indicate higher exposure of maintenance workers to:

- loud noise (16% vs. 8%);

- very loud noise (3% vs. 2%);
- hand–arm vibrations (24% vs. 9%);
- whole-body vibrations (12% vs. 5%);
- radiation – UV light (8% vs. 4%);
- radiation – radiofrequencies (4% vs. 2%).

As shown in Figure 3, maintenance workers are also more exposed to:
- heat in summer (44% vs. 19%);
- cold in winter (44% vs.17%);
- very humid atmospheres (25% vs. 13%);
- very dry atmospheres (5% vs. 4%)

Figure 2: Exposure to noise, vibration and radiation among Spanish maintenance workers, 2007 [46]

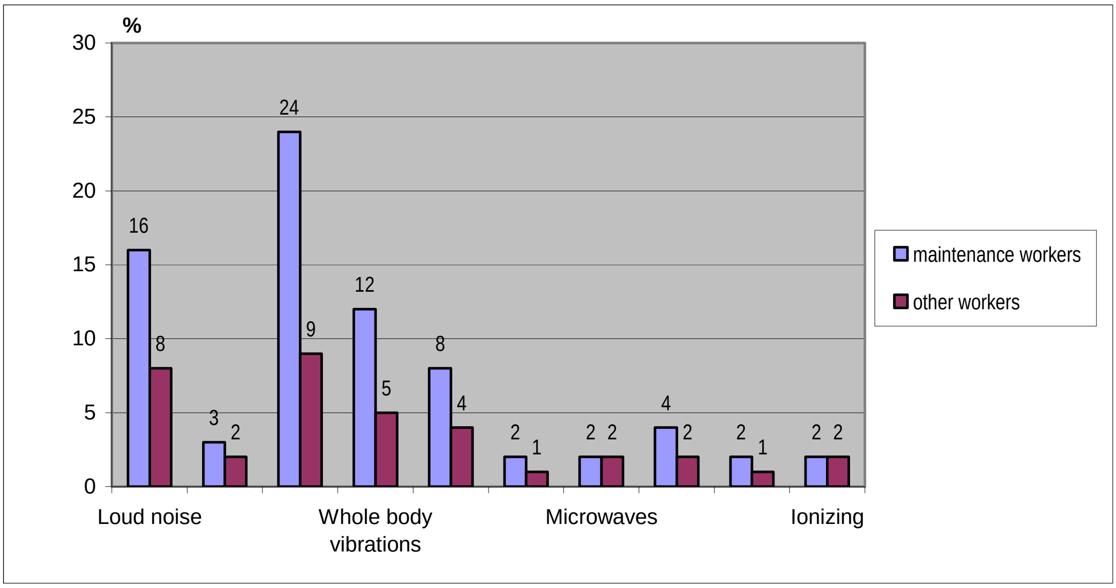
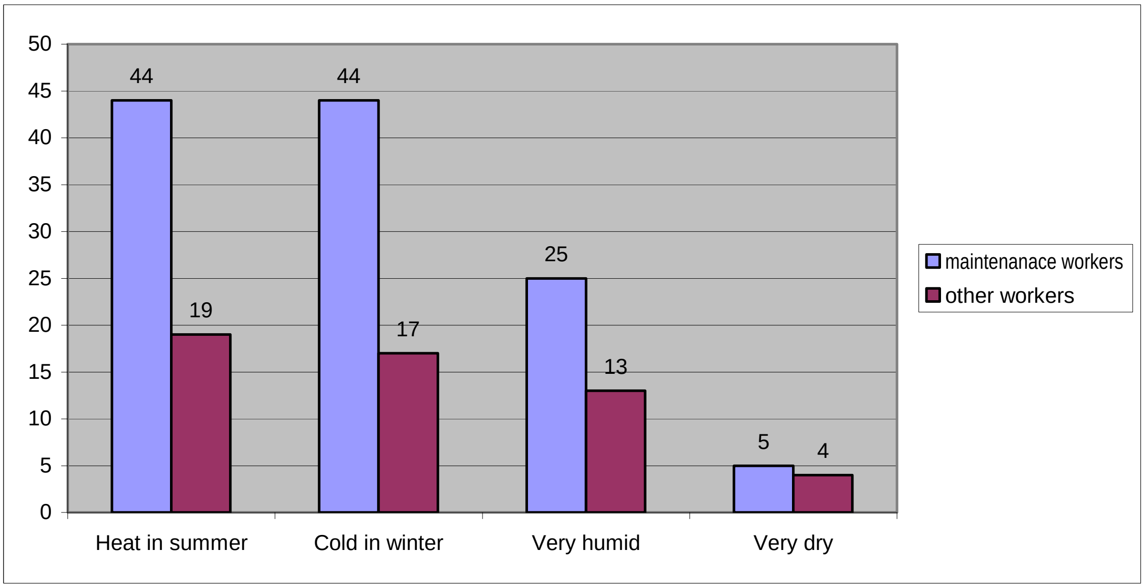


Figure 3: Exposure to cold, hot, and humid environment among Spanish maintenance workers, 2007 [46]



3.2. Physical workload

Maintenance workers often perform physically demanding work which causes high strain on the limbs and the back. Movements that cause this job to be strenuous include:

- carrying and placing heavy materials;
- bending;
- kneeling;
- reaching;
- pushing and pulling;
- working in small spaces;
- maintaining the arms in the air;
- twisting position.

Examples identified by Prevent (Belgian Institute for Prevention and Well-being at Work)[7] of activities that can lead to possible back problems or upper limb disorders include:

- lifting loads (e.g. parts of machines, tools, equipment) in awkward postures due to bad design (parts not in reach, lack of access or space to move, working under knee height or above shoulders). Maintenance tasks are often unexpected or infrequent so that no lifting devices are provided to help maintenance staff – maintenance staff often receive no help from colleagues to lift heavy loads, or to hold or manipulate parts of machines;
- carrying (heavy) loads on stairs or in narrow spaces;
- repetitive movements due to locking and unlocking screws;
- tasks where tools or parts of the installation have to be held for a certain period of time, which can lead to serious static muscular workload and local fatigue;
- unexpected physical risks due to situations where the operators are not familiar with the movements or need force to manipulate or lift parts of machines, installations, etc;
- working in narrow spaces, on slippery floors, with cables, steps, working at height;
- use of tools with a non-ergonomic design.

Musculoskeletal disorders (MSDs) are frequents among ship maintenance workers performing various manual operations such as sandblasting, high-pressure water cleaning and spray painting [47]. Back pain accompanying improper biomechanics is observed also among automobile body repair shop workers [48].

Analysis of a number of reported work-related musculoskeletal disorders and risk factors among workers in Norway's offshore petroleum industry from 1992 to 2003 found that 53% of the disorders were upper limb disorders, 20% back disorders and 16% lower limb disorders [49]. Of all the cases analysed, 40% were maintenance workers. Among these workers, upper limb and back problems were the most frequently reported, mainly because of high physical workload and repetitive work [49].

Useful information about the risks faced by a range of professions encountered in the construction industry is available on the website of the Dutch organisation, Arbouw.[8]

Arbouw reports that 70% of workers who repair concrete found their job physically demanding; 27% complained about often being tired. Standing up (19%), working in the same position (34%) and bending regularly (35%) were especially mentioned as being hard; lugging material, hacking, drilling and beaming were also considered hard. Among workers who maintain machines, about 52% reported that the work is hard [50]. Lifting the tools, placing and lifting machine parts, pushing and

[7] http://www.prevent.be
[8] http://www.arbouw.nl/werknemer/beroepen-en-risicos/

pulling during screwing down, and unscrewing machine parts are all activities during which workers are exposed to high physical strain. Workers often have to work on machines with difficult access, usually in awkward body positions [50].

Workers maintaining sewers complained about bending regularly (37%), problems with their back (45%), arms (45%), legs (39%), knees (27%) and wrists, hands and fingers (22%). Almost all (97%) of these workers stated that their work was very physically demanding [51]. The motional space is very small, causing them to work in forced body positions and therefore the static strain is very high. When descending to the sewer and leaving it, workers have to climb and clamber which produces additional strain [51].

About 51% of maintenance painters believed their work is physically hard and 21% reported often being tired. Painters suffer especially from having to stand up for long periods (22%), working in the same position for a long time (28%), and bending regularly (25%). There were also a lot of complaints concerning the muscles and joints in the neck (27%), back (38%), shoulders (27%) and knees (24%) [52]. Removing old paint and polishing the surface is heavy on hands, arms, shoulders, back and neck, especially when working near the ground or above eye level. Twisting, bending and kneeling are also very frequent during maintenance painting work [52].

Work was reported as physically strenuous (especially on the back) by 50–60% of workers positioning rails on railway lines. When trains are approaching, workers need to replace materials and tools very quickly, which produces an additional strain on the body [53]. Two-thirds (66%) of carpenters performing maintenance and reparation work reported that their work is physically demanding; bending regularly was especially found to be annoying (24%) [54]. Carpenters often have to work above eye level, kneeling, bending, and twisting, and in small spaces and on slanting roofs. Supplying, placing and assembling heavy pieces are tasks also considered very strenuous [54].

Results from the French SUMER 2003 survey [14] also indicate high exposure to physical load, particularly to postural and joint constraints (see Table 14).

The proportion of maintenance workers who reported being exposed to such constraints is higher than that observed for all the professional families (87% vs. 72%). This trend can be observed for each of the three maintenance professional families featuring in the survey, but particularly for skilled maintenance workers and automotive repair workers.

Table 14: Percentage of maintenance employees reporting being exposed to postural and joint constraints, SUMER 2003 survey [14]

Type of constraint	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain*	Total of all the professional families
Postural and joint constraints (all)	**93.8%**	**98.1%**	**76.1%**	**87.16%**	**71.80%**
Standing position or standing about	73.3%	87.8%	50.4%	66.74%	48.90%
Displacement of feet during work	75.0%	69.6%	56.5%	65.81%	43.50%
Kneeling position	55.7%	75.0%	30.4%	49.19%	14.90%
Fixed position of the head and neck	23.6%	25.4%	24.2%	24.27%	22.50%
Maintaining the arms in the air	45.7%	65.1%	2.5%	40.12%	15.20%
Other postural constraints (e.g. squatting or twisting position)	61.1%	81.2%	36.8%	55.21%	24.90%
Highly repetitive gesture	10.6%	16.9%	6.4%	10.22%	16.90%
Number	304,600	202,000	382,800	889,400	17,334,200

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

These results suggest that:

- the majority of those examined in the survey are subject to the postural and joint constraints to which maintenance staff are subjected, i.e. standing position and standing about; displacement of feet; kneeling position; fixed position of the head and neck; maintaining the arms in the air; other postural constraints (e.g. squatting or twisting position);
- the proportion of maintenance employees who stated being exposed to these constraints is, for almost all of them, much higher than that observed for all employees. Highly repetitive gestures are the only constraint for which a lower percentage for maintenance staff than all the employees is observed;
- particular constraints affecting maintenance employees that are more numerous than all the professional families are as follows:
- kneeling position (almost half of these employees vs. 15% of all the professional families);
- maintaining the arms in the air (more than 2.5 times more statements for maintenance employees);
- other postural constraints (e.g. squatting or twisting position) were reported over two times more often among maintenance employees (55% vs. 25%);
- displacement of feet while working (66% vs. 44%).

These trends are observed for each of the three maintenance professional families, and more particularly for skilled automotive workers, followed by skilled maintenance workers.

Table 15 shows the ratios of maintenance employees who reported in the SUMER 2003 survey [14] being exposed to constraints related to the manual handling of loads during their last week of work. More than half of the maintenance employees (55%) stated that they handled loads manually, whereas the corresponding percentage for all the professional families is 43%. The professional family of maintenance and organisation technicians and supervisors does not differ greatly from that observed for the professional families as a whole. On the other hand, automotive repair workers (68%), and to a lesser degree skilled maintenance workers (63%), are more often exposed to this type of constraint compared with all salaried employees surveyed (43%).

Table 15: Percentage of maintenance employees reporting being exposed to constraints related to the manual handling of loads, SUMER 2003 survey [14]

Exposure	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain *	Total of all the professional families
Manual handling of loads	63.0%	67.9%	40.8%	54.56%	42.8%
Numbers	304,600	202,000	382,800	889,400	17,334,200

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

3.3. Chemical hazards

3.3.1. Work with asbestos

Even though use of asbestos is prohibited, exposure to asbestos during maintenance work is still highly possible. Studies show that nowadays the highest level of exposure to asbestos may happen during maintenance activities. Typical activities by craftsmen include removal of floor covering with asbestos-containing backings or the removal of friction linings [55].

Asbestos has been widely used due to its physicochemical properties which make it highly resistant to fire, alkali and acid, and very suitable as a thermal and acoustic insulating material. Examples of its widespread use in the construction industry include [56]:

- as protection against fire in metal structures;
- in acoustic panels;
- in thermal insulation of pipelines;
- in the manufacture of tiles;
- in pipes made of cement-asbestos;
- in paint, asphalts and putties.

Asbestos has also been used as an insulating material in ships, train coaches, aeroplanes, thermal and nuclear plants, in domestic appliances, in boilers and pipelines, and in a multitude of other applications [56].

Some varieties of asbestos, principally chrysotile asbestos, can be woven. This feature has enabled the use of asbestos fabrics in fireproof curtains, insulating suits, fire extinction hoses and gloves. This means that, although the asbestos is not used in the production process itself, it may be found as a part of the building material, structure, devices or facilities.

Whenever it is necessary to carry out demolition, rehabilitation, maintenance, repair and other operations that imply manipulation of asbestos materials, there are hazards for workers' health. The design and application of a specific work plan to protect workers is obligatory [57, 58].

Specific operations generating a risk for maintenance workers include:

- demolition of structures where asbestos is present and their refurbishment;
- works and operations designed to remove asbestos or those involving materials, buildings, structures, devices and facilities that contain asbestos;
- disposal of ships or units in which asbestos materials are present;
- maintenance and repair work in buildings, facilities or units in which there is a risk of releasing asbestos fibres.

Maintenance operations in which asbestos fibres might be released are as follows:

- **Working on sprayed asbestos or thermal insulation materials**: maintenance work in places containing sprayed asbestos (electricity, heating, air conditioning, plumbing, placement or retreat of false roofs, etc.) where piercing and scraping operations are performed, or there is a possibility of contact with sprayed asbestos;
- Working on materials that contain asbestos:
- Asbestos board: operations involving partial placement, cutting and mechanisation of the fireproof plates of false roofs made of asbestos or which contain asbestos, etc.
- Coatings: maintenance and renovation works in places where adhesives/plasters containing asbestos are present (e.g. preparation of supports, sanding, piercing, demolition of partitions);
- Jointing and filters: disassembly or jointing (plumbing, heating) by scraping off, brushing, sanding, etc.
- Friction products: interventions on friction linings (brakes, clutches) such as dusting, removing, machining (sawing, rectifying, piercing, sanding) and assembling;

- **Working with and manipulation of woven asbestos**: intervention (placement, cutting, elimination) on asbestos ribbons, cords or plaiting asbestos, etc.
- Working on elements of asbestos:
- Cement: repair of roofs and other elements constructed of asbestos, which implies operations such as cutting, slicing, piercing and sanding;
- Diverse work including the storage and manipulation of asbestos:
- Storage, maintenance and transport of objects containing asbestos;
- Transport, storage and elimination of the waste containing asbestos.
- Cleaning activities (i.e. maintenance of equipment used to work with asbestos).

Epidemiological data prove that there has been, and may continue to be, a significant risk to maintenance workers who come in contact with asbestos-containing materials (ACM) through their work. The sampling and assessment of the exposure of maintenance workers is a particular problem because they may not know that they are working with ACM. In a study among industrial plumbers in the UK, their awareness of working with asbestos was investigated and compared with the monitored, actual level of exposure. The results showed that workers' expectations and awareness of work with asbestos were far lower than found during monitoring [59, 60].

Studies have been also carried out to evaluate the respiratory effects on maintenance workers of asbestos exposure. For example, it has been shown that asbestos exposure of custodians and maintenance employees in buildings with friable asbestos-containing materials might be associated with a frequency of pleural thickening as seen on chest X-rays [61].

A series of studies have analysed the exposure of car mechanics to asbestos:

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One such study [62] presents a historical analysis of published data regarding the exposure of brake mechanics to asbestos as a result of carrying out their work. Concerns about this possible hazard were first raised in the late 1960s. This analysis focused on 30 years of data collected during the repair of car brakes and eight-hour time-weighted average (TWA) personal samples. Nearly 200 jobs and eight-hour TWA airborne asbestos samples were analysed to assess how asbestos concentrations varied by:

- type of vehicle serviced;
- country in which the mechanics worked;
- time period;
- brake cleaning method used.

Based on the results from this analysis, it seems that mechanics repairing brakes from heavy trucks and buses experienced higher daily asbestos exposures than automobile and light truck mechanics. The increased use of brake dust control measures in some garages resulted in at least a 10-fold decrease in the TWA airborne concentrations of asbestos from the 1970s to the late 1980s [62].

3.3.2. Working in confined spaces

A 'confined space' means an enclosed or partially enclosed space that is at atmospheric pressure when anyone is in the space. There could have restricted entry to, or exit from, this space, and although it is not intended or designed primarily as a workplace, it is likely to be entered by someone to work. A confined space at any time contains, or is likely to contain, any of the following [63]:

- an atmosphere that has potentially harmful levels of a contaminant;
- an atmosphere that does not have a safe oxygen level;
- anything that could cause engulfment.

Examples of confined spaces include [63]:

- storage tanks, tank cars, process vessels, pressure vessels, boilers, silos and other tank-like compartments;
- pits and degreasers;
- pipes, sewers, sewer pump stations including wet and dry wells, shafts and ducts;
- shipboard spaces entered through small hatchways or access points, cargo tanks, cellular double bottom tanks, duct keels, ballast or oil tanks and void spaces.

The presence of gases and toxic vapours in confined spaces makes the atmosphere very dangerous for workers' health. Gases such as carbon disulphide, carbon monoxide, hydrogen cyanide or hydrogen sulphide combined with lack of oxygen might be a cause of death. A study of construction poisoning fatalities from 1990 to 1999 found that majority of the cases occurred in confined spaces [64].

Accidents in confined spaces are generally characterised by the presence of two factors:

- an ignorance of the risks present in the workplace and during the accomplishment of the work by those in charge of the work;

- a lack of communication between production and maintenance departments.

Some work practices inside confined spaces may also generate risks [65].

3.3.3. Welding work

Maintenance workers involved in electrical arc welding are at risk of inhalation of the smoke and toxic gases produced by the electrical arc. The inhalation is variable depending on the type of the electrode coating or protective gas, and on the base or contribution materials. Workers can be exposed to metal fumes (oxides of iron, chrome, manganese, copper, etc.) and gases (oxides of carbon, of nitrogen, etc.). Phosgene poisoning can also occur when welding works are carried out in the proximities of degreasing tanks with chlorinated products or on humid pieces with the above mentioned products [66].

One study was unable to prove a clear relationship between exposure to welding fumes and lung cancer, but welders with the longest experience had a relative risk of 1.9 for lung cancer [67]. Another study sought to determine the prevalence of coexisting welding related systemic symptoms indicative of metal fume fever (MFF) and welding related respiratory symptoms suggestive of occupational asthma (OA) in a sample of welders, and the strength and significance of any association between these two groups of symptoms [68]. The authors concluded that there is a strong association between welding related MFF and welding related respiratory symptoms suggestive of OA. As such, MFF could be viewed as a pre-marker of welding related OA (a hypothesis which requires further investigation) [68]. Occupational exposure to welding fumes among welders disturbs the homeostasis of trace elements in systemic circulation and induces oxidative stress [69].

3.3.4. Maintenance of public swimming pools

Maintenance personnel at swimming pools are exposed during their work by inhalation or by skin contact to a series of chemical products. There are risks of inhalation of chlorine, ozone and substances released by reaction between the chemical agents added to the water of the swimming pool (principally disinfectants) and organic matter (of human origin) [70,71]. Relatively high concentrations of trihalomethanes (THMs) have been found in some indoor swimming pools in London [72]. Another study observed an excessive risk of respiratory symptoms indicative of asthma among swimming pool workers [73].

3.3.5. Working in car repair shops

The main chemical risks for workers carrying out maintenance in car repair shops are [74–76]:

- inhalation of irritating gases and welding fumes derived from the application of blowpipes to metallic surfaces with surface treatment;
- inhalation/skin contact of vapours from spray painting, e.g. organic solvents, isocyanates;
- inhalation of dust during sanding;
- inhalation of asbestos fibres (see section 3.3.1) in operations such as maintenance of brake shoes and wheel removal;
- contact with oils and greases in mechanical repairs;
- inhalation of petrol fumes during mechanical repairs;
- inhalation of exhaust gases, especially carbon monoxide and diesel particulate matter during the running of Otto (four-stroke) and diesel engines respectively.

3.3.6. Maintenance work at solid waste treatment plants

Alongside the standard operations at solid waste treatment plants, there are supporting services such as maintenance and cleaning.

A transfer station is a site where solid wastes are collected and stored until they can be transported elsewhere for assessment or destruction, with or without prior segregation. The procedure at this type of facility consists of unloading waste from trucks, compressing it and then shipping the material to the corresponding treatment unit.

Maintenance work at transfer stations consists of maintaining the compression system, control panels and air ventilation filters [77]. A study to evaluate workers' exposure to dioxin-like substances[9] confirmed that workers may be exposed to these substances during the performance of cleaning operations at municipal solid waste (MSW) incinerators [78].

Maintenance workers at solid waste treatment plants can be exposed to:

- exhaust gases from vehicle engines (trucks and power shovels), especially in the unload zone;
- steam or harmful gases generated by waste materials accepted by those plants where waste entry is uncontrolled;
- toxic gases generated in certain work zones due to the use of products such as disinfectants and cleaning agents.

There is also exposure to waste itself during the maintenance of compression equipment and transfer lines and/or equipment.

3.3.7. Exposure to hazardous substances during maintenance of industrial installations

Workers may be exposed to dangerous substances during the maintenance of industrial installations either producing or applying chemical substances. Such exposure often happens when systems are opened.

The intake of the substances can occur through skin or respiration. For example, high exposure to chemical pollutants was reported during the shutdown of a plant synthesising toluene di-isocyanate (TDI) [79].

During maintenance work investigated by BAuA (German Federal Institute for Occupational Health and Safety) [80], the efficiency of protection barriers was found to decline when normally closed systems were opened. Workplace measurements (personal air sampling and stationary sampling) were also made. In relation to personal protective equipment (PPE), the quality of the equipment provided, sizing/fitting and the use of protective devices was recorded and assessed. The enterprises included in the investigation programme produced a range of chemicals such as chlorine, organic solvents and vinyl chloride.

The occupational exposure limits (OELs) were exceeded in about a quarter of the total of around 170 workplace measurements performed as part of the investigation programme. Most cases in which OELs were exceeded occurred during cleaning, followed by changing of fittings and valves, and other work at the opened system [80].

As well the respiratory exposure, the dermal route of exposure was also studied. In contrast to the normal operation mode, the dermal route exposure occurred to a larger extent during maintenance. In addition, PPE was incorrectly used in more than 75% of all cases. A special problem was repair work for which PPE was neither correctly provided nor fitted nor used [80].

3.3.8. Maintenance of buildings

Maintenance workers carrying out their job in public buildings built in the 1960s and 1970s might be affected by polychlorinated biphenyls (PCBs). These substances were used [81]:

- as isolating fluids in transformers and condensers;
- as a softening agent in plastics and joint packings;

[9] Polychlorinated dibenzo-*p*-dioxins (PCDDs), dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs)

- in ceiling linings;
- in cleaning cables;
- as flame retardants in wall paints, finishes, adhesives and hydraulic oils.

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PCBs are now classified as carcinogenic and have not been produced since 1983.

Formaldehyde (HCHO) is another chemical sometimes found in buildings. It is a toxic, colourless, flammable gas which is used in a manifold of ways. It can be found in, for example, glued products from derived timber products, insulating material, painting material, colours, finishes and parquet floor sealers

Formaldehyde is also present in glass and mineral wool, textiles and floor coverings [82].

Exposure to formaldehyde can lead to type-IV allergies and sensitisations among the workforce [81].

This in turn may lead to asthma, allergies, irritated mucous membranes and difficulty in breathing. Formaldehyde is categorised as carcinogenic by the World Health Organization (WHO). Under EU legislation it is categorised as a Category 3 carcinogen (Dangerous Substances Directive 67/548/EEC) [103].

3.3.9. Road maintenance

As well as exhaust fumes from traffic, road construction and maintenance workers are potentially exposed to a range of hazardous substances including [83]:

- asphalt fumes containing asphaltenes and polycyclic hydrocarbons (PAHs);
- carbon monoxide;
- diesel exhaust;
- organic solvents;
- biological agents;
- dust;
- herbicides;
- benzene;
- lead;
- silica;
- asbestos.

3.3.10. Exposure to chemical hazards among Spanish maintenance workers

The numbers and percentages of maintenance employees handling dangerous substances in the workplace and those exposed to vapours and fumes by inhalation relative to the remainder of workers are shown in Tables 16 and 17 respectively. These figures come from the Spanish National Survey of Working Conditions 2007 [46] (see section 3.1.5).

Table 16: Handling dangerous substances in the workplace, 2007 [46]

Rest				Maintenance workers			Total
				Industry	Construction	Services	
Handling dangerous substances in the workplace	Yes	N	1,571	109	237	33	1,950
		%	16.1%	43.3%	25.6%	31.1%	17.6%
	No	N	8,160	142	684	73	9,059
		%	83.5%	56.3%	74.0%	68.9%	81.9%
	NS *	N	32	1	2	0	35
		%	0.3%	0.4%	0.2%	0.0%	0.3%
	NR **	N	10	0	1	0	11
		%	0.1%	0.0%	0.1%	0.0%	0.1%
Total		**N**	**9,773**	**252**	**924**	**106**	**11,055**
		%	**100%**	**100%**	**100%**	**100%**	**100%**

* Doesn't know.

** No response

Table 17: Inhalation of vapours and fumes in the workplace, 2007 [46]

Rest				Maintenance workers			Total
				Industry	Construction	Services	
Inhalation of vapours and fumes	Yes	N	1,682	145	462	33	2,322
		%	17.2%	57.5%	50.0%	31.4%	21.0%
	No	N	8,030	106	456	72	8,664
		%	82.2%	42.1%	49.4%	68.6%	78.4%
	NS *	N	34	0	5	0	39
		%	0.3%	0.0%	0.5%	0.0%	0.4%
	NR **	N	27	1	1	0	29
		%	0.3%	0.4%	0.1%	0.0%	0.3%
Total		**N**	**9,773**	**252**	**924**	**105**	**11,054**
		%	**100%**	**100%**	**100%**	**100%**	**100%**

* Doesn't know.

** No response

The data indicate higher exposure of maintenance workers to dangerous substances compared with other workers. Noteworthy figures are as follows:

- The percentage of maintenance employees stating that they handle dangerous substances in the workplace is almost twice that by the rest of workers as a whole in case of services (31% vs. 16%) and more than two times higher in case of industry (43% vs.16%).
- The percentage of maintenance employees exposed to vapours and fumes through inhalation in the workplace is almost two times higher than reported by the rest of workers as a whole in case of services (31% vs. 17 %), but three times higher and more in case of construction (50% vs. 17%) and industry (58% vs. 17%).

3.4. Biological hazards

Maintenance workers exposed to biological agents are those especially from the following sectors [84]:

- healthcare;
- waste management;
- agriculture;
- biotechnology;
- pharmacological plants;
- clinical, veterinary and diagnostic laboratories;
- swimming pools.

3.4.1. Legionella

Legionella is a gram-negative bacterium of which more than 48 species have been identified, including *Legionella pneumophila*. Ideal conditions for Legionella for reproduction are fresh or salt water, and a temperature between 25 and 50°C.

There is evidence that *Legionella pneumophila* can be spread at least 6 km from its source [85]. The uptake of Legionella via inhalation (aerosols) is harmful and causes legionellosis – either the more severe Legionnaires' disease or the milder Pontiac fever.

Water supply and building air conditioning systems are the two sources most frequently linked to epidemics caused by Legionella. Among them the following areas can be highlighted [86]:

- warm water distribution circuits;
- air conditioning and refrigeration towers;
- thermal waters in rehabilitation and play centres;
- medical equipment using aerosol-based therapeutics;
- decorative fountains.

Two cases of death due to Legionnaires' diseases on a ship were reported in 2001 [87]. The two mechanics had carried out maintenance work on the cargo ship, which had been moored up in Tunisia for two years; the origin of infection was probably a water pump that they repaired.

Cases of Pontiac fever due to maintenance of a steam turbine condenser have also been reported [87].

An outbreak of Pontiac fever occurred in 2000 among workers performing high pressure cleaning in a sugar beet plant [88].

Legionella has also been found in dental clinics. For example, 20% of the investigated technicians in a dental office in 1988 showed antibodies against *Legionella pneumophila* [89].

Legionellosis is also possible after changing filters contaminated with Legionella in cooling towers or air conditioning system. A study on a group of workers who became ill with fever and flu-like symptoms after repairing a decanter for sludge concentration at a sewage treatment plant during a hot and humid summer period concluded that the fever was caused by *L. pneumophila* emitted to the environment by the uncovered decanter [90].

3.4.2. Hepatitis A virus and Leptospira

Controversy exists on the possible exposure to hepatitis A virus (HAV) of maintenance workers at sewage treatment works. To assess whether the scientific literature supports the hypothesis that workers exposed to sewage are at higher risk of hepatitis A, all original papers describing epidemiological studies examining on the risk of hepatitis A infection in workers exposed to sewage were reviewed [90]. This systematic review did not confirm an increased risk of clinical hepatitis A in workers exposed to sewage. An increased risk of subclinical hepatitis A (defined only by the presence of anti-HAV antibodies) cannot be excluded, but the association between being seropositive and exposure to sewage was not strong and became weaker still if publication bias was taken into account [90].

A study of the prevalence of *Leptospira interrogans* and HAV antibodies in serum samples from sewer workers and controls concluded that leptospirosis continues to be a problem to sewer workers but that hepatitis A is apparently no longer a risk [91]. The most likely explanation is that Leptospira are still abundant in the sewage system in contrast with HAV, which is only rarely found in sewage as a result of the general decline in the incidence of hepatitis A over the past three decades [91].

3.4.3. Maintenance work in water supply installations and wastewater treatment plants

Wastewater treatment plants employ physical, chemical and/or biological processes to remove contaminants. Workers can be exposed to a range of hazardous substances and biological agents from these processes. The composition of the microflora in wastewater treatment plants varies with respect to spectrum of species and wastewater concentration (factors such as microorganism input, chemical substances in the wastewater, climatic conditions and procedures influence these parameters) [93].

Factor analysis as part of a study to investigate work-related symptoms in workers at wastewater treatment plants yielded three clusters of correlated symptoms [94]:

- ‘lower respiratory and skin symptoms’;
- ‘flu-like and systemic symptoms’;
- ‘upper respiratory symptoms’.

Symptoms appeared to be more prevalent in workers exposed to endotoxin levels higher than 50 endotoxin units per m^3 (EU/m^3). A significant dose–response relationship was found for ‘lower respiratory and skin symptoms’ and ‘flu-like and systemic symptoms’. It was concluded that [94]:

- wastewater treatment workers reported a wide range of symptoms that may be work-related;
- microbial exposures including those to endotoxins seem to play a causal role.

3.4.4. Maintenance work in solid waste treatment plants

Workers in solid waste treatment plants can be exposed to a wide range of biological risks. Bacteria, fungi, spores, viruses, parasites as well as degradation products such as endotoxins occur as aerosols or biological agents that adhere to biodegradable waste. These agents may cause diverse respiratory diseases (allergies, bronchitis, severe diseases of the mucosa like organic dust toxic syndrome) but also hemorrhagic fevers, brucellosis, diphtheria, Q fever, tuberculosis, viral hepatitis, leprosy, bacterial dysentery, meningitis, and cholera [95,96].

3.4.5. Maintenance of public swimming pools

Workers can be exposed to different types of biological agents when maintaining swimming pools. The biological agents present in these humid environments include:

- Protozoa – these can be saprophyte (i.e. obtain nourishment from decomposing vegetables and animals) such as the paramecium, or parasites such as amoebae;
- Fungi (including moulds) – these proliferate in humid zones such as changing rooms, walls and floors, and can cause cutaneous or deep injuries;

- Bacteria – these multiply rapidly in cases of incorrect maintenance of the swimming pool and they may cause infectious diseases such as legionellosis;
- Viruses – in this case, there are major risks from poliomyelitis and those viruses causing plantar warts.

3.4.6. Maintenance of public buildings – exposure to pigeon droppings and moulds

Pigeons are present everywhere in urban surroundings. An analysis in 1997 of the number of pigeons in several German cities gave the estimated pigeon population in, for example, Berlin or Munich as around 40,000. Each pigeon produces about 2.5 kg of dry droppings per year, making a total of 100 tons each year in a city like Berlin or Munich. The droppings damage stone and steel constructions (buildings, bridges) [97]. Furthermore, they may contain microorganisms such as bacteria (e.g. *Campylobacter jejuni*, *Salmonella enteritidis*, *Clamydophila psittaci*), yeasts (e.g. *Crytococcus neoformans*), fungi (e.g. *Histoplasma capsulatum*) and viruses, which are to some extent pathogenic for human beings. Infections might occur via oral (insufficient hygiene), airways or skin/mucosa path of infection [98].

For maintenance activities cleaning of contaminated parts is necessary. In doing so, dust and liquid aerosols are produced, which might be taken up via different paths [98]. However, the contamination of dropping with microorganisms is, in the majority of cases, unknown [99]. Appropriate measures are therefore necessary to minimise exposure to these biological agents.

Moulds and their spores can generally be regarded as natural components of the environment. However, moulds producing toxic substances such as carcinogenic mycotoxins can be released indoors and reach the air via the respiratory system, mouth, skin and mucous membranes. This is especially true for areas such as bathrooms, kitchens and basements [100]. Moulds grow by degrading nutrients from organic substrates such as wood and wood products, fabrics, foodstuffs, plants and plant debris, and soil [101].

Workers may be exposed to moulds in any indoor workplace (offices, schools, hospitals, other public buildings). High exposure to moulds is especially observed among construction workers, in solid waste or wastewater treatment plants, in cotton mills, and in agriculture. Health effects include [101]:

- asthma, or exacerbation of asthma in a mould-sensitive asthmatic;
- allergic diseases;
- increased rates for upper respiratory disease;
- infection (people with suppressed immune system are especially susceptible to fungal infections);
- nose, throat or eye irritation;
- runny nose, cough, congestion, headache and flu-like symptoms;
- skin irritation.

3.5. Psychosocial hazards

According to Prevent (Belgian Institute for Prevention and Well-being at Work), the following psychosocial issues may impose a problem for maintenance workers [102]:

- Complex problems have to be solved under time pressure. During maintenance work, the productivity of an organisation is cut back. There is an urgency to restart activities as soon as possible because production has to go on and people are waiting to resume their work. This can put a lot of pressure on maintenance workers, causing stress and increasing the probability of making mistakes and accidents [104]. In additionally, unfavourable working conditions such as, for example, excessive heat may increase the level of stress [105];
- Shift work, weekend work, night work, on-call work and irregular working hours can lead to stress, or mental health problems sleeping problems, fatigue, lack of work-life balance, obesity, etc. [106];
- Workers have to deal with complex problems in non-routine situations. Nowadays technologies are very complex and require specific knowledge by the workers who manipulate and repair them. Maintenance workers also often work on dangerous machines that do not have an adapted human-machine interface (e.g. information from displays is not clear, unreadable scales, controls not known or not in reach);
- Working with workers from contractors can lead to communication difficulties;
- Lone work/isolated work can lead to uncertainty and fear, lack of coaching and social support. When an accident happens, maintenance workers have to rely on their ability to help themselves. In case of serious accidents, it may take time until a colleague discovers the worker. When working alone, no-one knows where the worker is located exactly in the machine or installation. So if the nature, planning and location of the work are not well communicated to the operators, the chance of an accident is high;
- Exposure to unexpected/unknown safety and health risks;
- Maintenance activities can often be found at the bottom of the hierarchy in terms of respect, influence and authority (e.g. at nuclear power plants) [107–109]. Furthermore, maintenance work is often considered as mostly manual labour, which requires little or no mental work. This may give maintenance workers the impression that their work is not acknowledged enough, affecting job satisfaction and work-related stress.

3.5.1. Working time characteristics

With respect to working time characteristics (work duration, night work, flexibility of working hours, weekend work, etc.), the SUMER 2003 survey [14] in France did not highlight higher constraints for maintenance employees in comparison with professional families as a whole. However, examination of the survey's findings by this study (see Table 18) has revealed that:

- maintenance employees stated more frequently than the professional families as a whole that they had to stay available in case of emergency10 (24% vs. 11%). This is more particularly the case for skilled maintenance workers and for maintenance and organisation technicians and supervisors;
- the proportion of skilled maintenance workers (22%) and maintenance and organisation technicians and supervisors (15%) who work at night between midnight and 5 am is higher than that observed for the professional families as a whole (9%).

[10] Period of time (usually outside normal working hours) during which somebody has to remain fully available in case an event occurs; for example, a technician who is free to stay at home during the weekend (i.e. not working) but must nevertheless remain easily contactable and available in case an event requiring their attention occurs.

Table 18: Some characteristics of the working time of maintenance employees, SUMER 2003 survey [14]

Working time characteristic	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain *	Total of all the professional families
Availability in case of emergency	27.3%	12.2%	28.5%	24.39%	10.5%
Occasional night work (between midnight and 5am)	22.3%	_**	15.2	_	9.3%
Numbers	304,600	202,000	382,800	889,400	17,334,200

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

** Insufficient numbers for significant statistical results.

3.5.2. Constraints related to pace of work

As shown in Table 21 with respect to constraints related to pace of work, the SUMER 2003 survey [14] in France highlights that:

- the proportion of maintenance employees who stated they had to abandon a task in order to undertake another unscheduled one was higher than that for the professional families as a whole (67% vs. 58%). This trend is particularly high for automotive repair workers (73%);
- the constraints related to pace of work were slightly higher for maintenance employees compared with all the salaried employees surveyed. The constraints also had the following elements:
- production standards or deadlines of one hour or more (27% vs. 20%);
- the need to answer outside requests that did not require an immediate answer (60% vs. 59%);
- the need to rotate around different workstations in order to overcome absences (31% vs. 27%).

Frequent work interruptions have also been shown to mainly concern operators whose function is related to maintenance [110] and are considered as a potential source of stress. The considerabletemporal constraints related to maintenance interventions and the time pressure generated by clients (e.g. in the case of subcontracted maintenance) may also increase stress levels [111].

Table 19: Constraints related to the pace of work of maintenance employees, SUMER 2003 survey [14]

Constraints related to pace of work	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain *	Total of all the professional families
Abandon a task to undertake another unscheduled one	66.1%	73.1%	65.2%	67.3%	58.10%

Constraints related to pace of work	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain *	Total of all the professional families
Outside request that does not require an immediate answer	53.9%	65%	62.5%	60.12%	58.9%
Production requirements or deadlines to achieve in one hour or more	27.2%	28.7%	25.1%	26.64%	19.9%
Rotate around different workstations in order to overcome absences	29.5%	29.9%	31.8%	30.58%	27.10%
Numbers	304,600	202,000	382,800	889,400	17,334,200

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

3.5.3. Job control and autonomy

With respect to work autonomy and job control (see Table 20), the results of the SUMER 2003 survey [14] in France show that:

- almost one third (32%) of maintenance employees stated that their work was subject to control or a computerised follow-up, whereas this percentage was 27% for the professional families as a whole;
- half of maintenance employees (51%) had to give a written account of their activities at least once a week, whereas the percentage required to do this for the salaried employees surveyed as a whole was 31%;
- a lower proportion of maintenance employees (7.5%) compared to the professional families as a whole (15%) stated that they were not in a position to modify the order of tasks to be accomplished.

Table 20: Some characteristics related to the autonomy and job control of maintenance employees, SUMER 2003 survey [14]

Characteristic of job control and autonomy	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain *	Total of all the professional families
Control or computerised follow-up of work	33.3%	20.6%	37.4%	32.18%	27.2%
Give a written account of activity at least once a week	59.3%	41.6%	49.2%	50.93%	30.8%

Characteristic of job control and autonomy	Skilled maintenance workers	Automotive repair workers	Maintenance and organisation technicians and supervisors	Total maintenance domain *	Total of all the professional families
Not being in a position to modify the order of tasks to be accomplished	6.5%	14.3%	4.8%	7.54%	14.8%
Numbers	304,600	202,000	382,800	889,400	17,334,200

* Data recalculated by taking into account the numbers of each of the three maintenance professional families.

The maintenance employees interviewed during the survey raised the question of difficulties related to inadequacies slightly more frequently than professional families as a whole:

- insufficient work information (22% vs. 19%);
- inadequate number of colleagues (27% vs. 26%);
- insufficient or inadequate materials (24% vs. 20%);
- insufficient training (24% vs. 20%).

3.5.4. Difficulties related to subcontracting maintenance

Subcontracting maintenance is often considered an aggravating factor in terms of safety and health [112–114].

Working away from one's usual place of work (e.g. at a customer's premises) or frequent changes of working environment may cause additional occupational hazards as 'employees have to adapt to different working environments, which has an impact on their exposure to occupational hazards, and they frequently travel from place to another, thereby subjecting themselves to road-related risks' [23].

The workplace diversity may increase health risks: 'subcontracting employees who intervene in facilities only from time to time are unable to manage their work environment like the permanent employees' [23].

The subcontracting of maintenance can also lead many subcontracting companies to operate simultaneously on sites where the conditions in terms of work organisation and time pressure are determined by the user company [23].

4. Outcomes related to occupational safety and health

4.1. Occupational accidents

Analyses of EUROSTAT data based on the 'European statistics on accidents and work' (ESAW) methodology [1] can help to identify accidents related to maintenance operations in a number of European countries.

Within the variable 'working process' used by ESAW to classify the causes and circumstances of accidents, it is possible to select four subcategories that are related to maintenance operations:

- setting up, preparation, installation, mounting, disassembling, dismantling;
- maintenance, repair, tuning, adjustment;
- cleaning working areas, machines (industrial or manual);

- monitoring, inspection of manufacturing procedures, working areas, means of transport, equipment (with or without monitoring equipment).

In this study, the number of accidents related to these subcategories was compared to the total number of accidents related to any other subcategory within 'working process'.

As shown in Table 21, the data show that the proportion of occupational accidents related to maintenance operations compared with total accidents was:

- 19–21% in Belgium (2005–2006);
- 18–19% in Finland (2003–2006);
- 14–17% in Spain (2003–2006);
- 10–14% in Italy (2003–2006).

In Austria (2003–2006), significantly fewer (3%) accidents related to maintenance.

Table 21: Number of occupational accidents related to maintenance activities in selected European countries (data from EUROSTAT)

		2003	2004	2005	2006
Spain	**Total**	792,565	766,460	780,433	769,657
	Maintenance operations	136,608 **17%**	107,068 **14%**	107,014 **14%**	105,886 **14%**
Belgium	**Total**	No data	No data	72,541	74,868
	Maintenance operations			15,292 **21%**	14,567 **19%**
Austria	**Total**	88,790	88,397	85,500	86,326
	Maintenance operations	3,002 **3%**	3,027 **3%**	2,808 **3%**	2,722 **3%**
Finland	**Total**	58,498	58,123	62,959	63,462
	Maintenance operations	11,103 **19%**	10,688 **18%**	11,810 **19%**	11,993 **19%**
Italy	**Total**	599,711	588,151	564,167	551,659
	Maintenance operations	60,856 **10%**	80,621 **14%**	72,458 **13%**	71,977 **13%**

4.1.1. Occupational accidents by seriousness

Data from a number of European countries indicate that around 10–15% of all fatal occupational accidents in 2006 were related to maintenance operations (see Figure 4).

The numbers of fatal accidents related to maintenance in selected European countries for period 2003–2006 are shown in Figure 5.

Figure 4: Fatal accidents related to maintenance operations in selected European countries, 2006 (data from EUROSTAT)

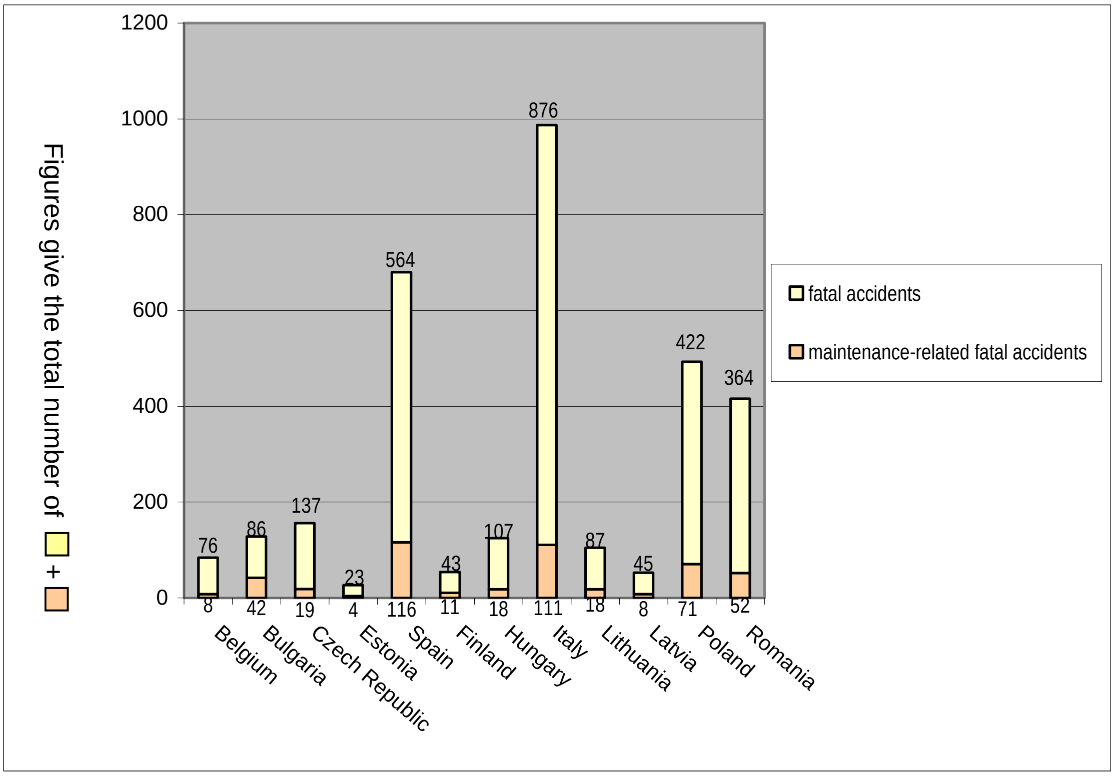
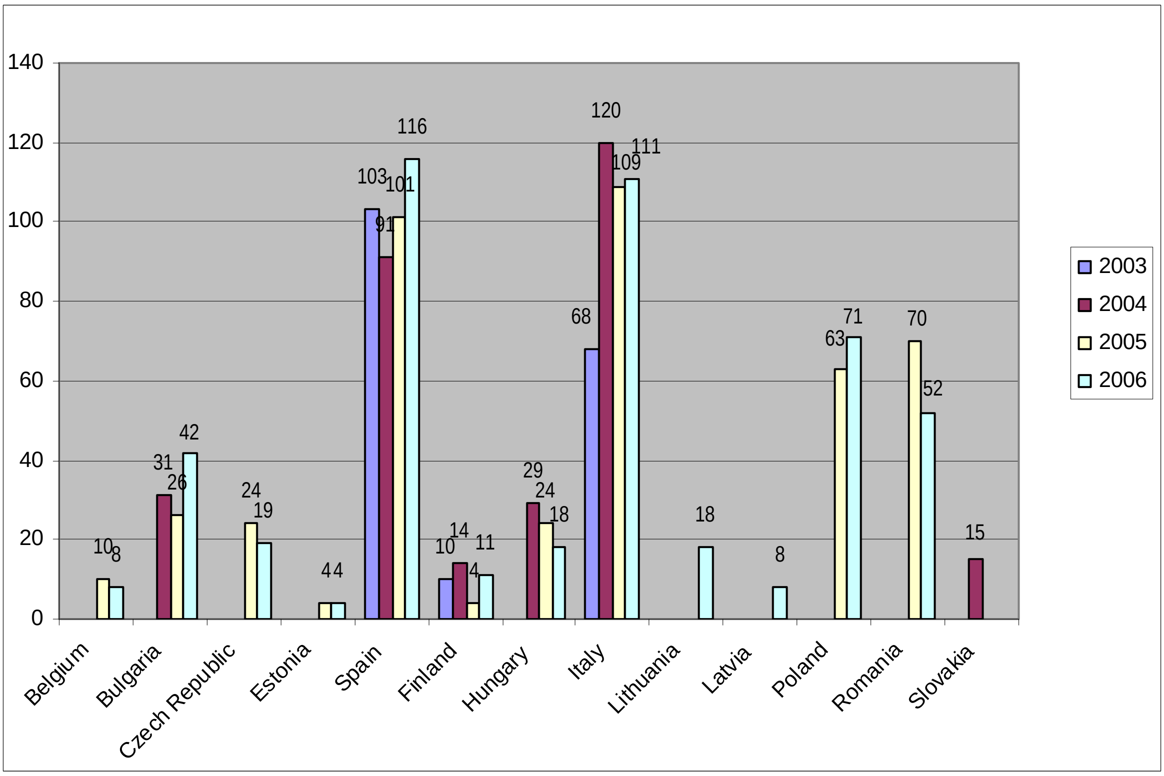
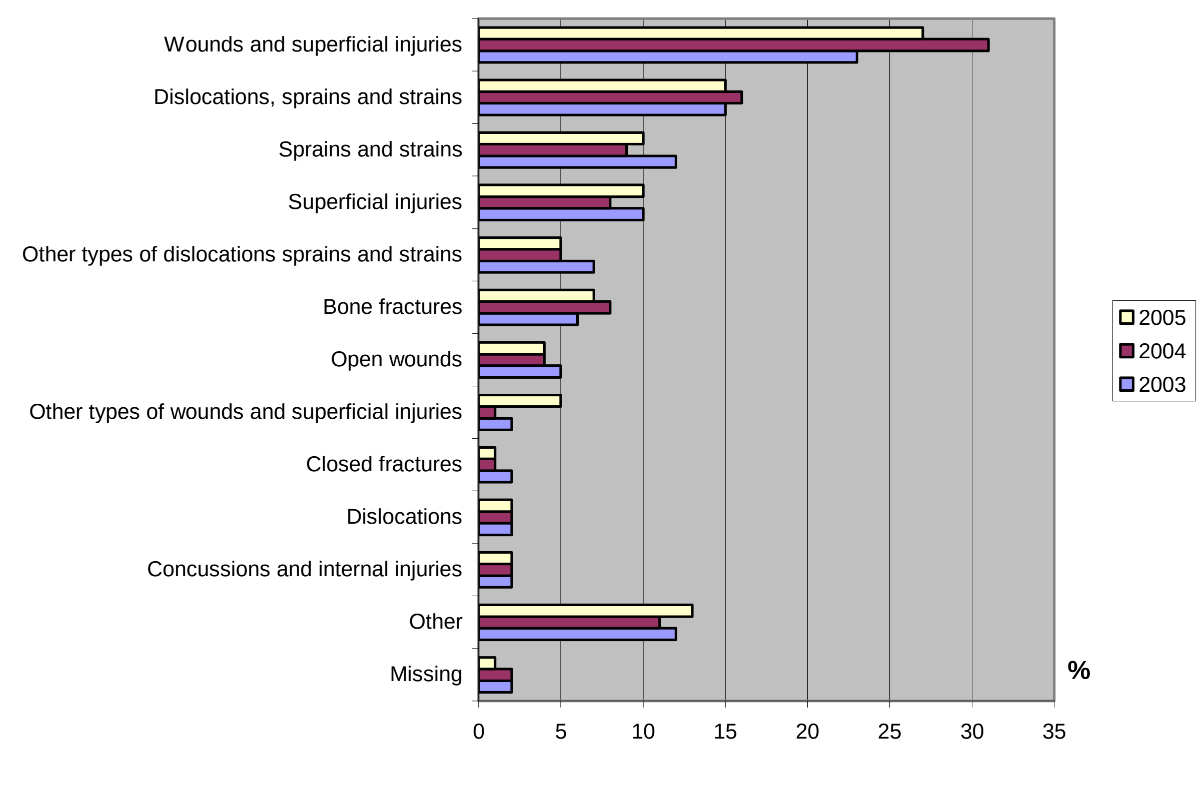


Figure 5: Fatal accidents related to maintenance operations in selected European countries, 2003–2006 (data from EUROSTAT)



According to the EUROSTAT data published in 2007, the most prevalent types of injuries stemming from maintenance-related accidents are wound and superficial injuries, dislocations, sprains and strains (see Figure 6)

Figure 6: Accidents related to maintenance operations and type of injury, 2003–2005 (data from EUROSTAT)



4.1.2. Reports of occupational accidents related to maintenance activities

An examination by HSE (Health and Safety Executive) of the 1,531 fatal occupational accidents in the United Kingdom between 1980 and 1982 from all sectors of activity taken together showed that 21% were related to maintenance [115]. A later HSE study of the 2,146 critical events in the chemical industry between 1982 and 1985 underscored the fact that about 30% (i.e. almost 700 critical events) were related to maintenance [116]; it was estimated that 125 people per year were injured fatally or otherwise in the chemical industry as a result of maintenance work [115,116].

A HSE study of 1,971 incidents occurring on drilling installations over a three-year period from 1989 to 1991 showed that 14.7% occurred during maintenance activities [117]. These kinds of accidents involved over 100 people per year (i.e. 326 fatal accidents in total or two fatal accidents per week) [117].

According to a Dutch study [118], about 38% of chemical accidents are caused by dangerous materials released from on-site plant taking place during maintenance. Similar percentages could be found with regard to accidents involving pipework failure in chemical plants originating in the maintenance phase of plant operations [119]. Moreover, examination of a French work accidents database (EPICEA) showed that 14% of all fatal accidents which occurred in 2000 and were recorded in the database were related to work equipment and machine maintenance [8].

A US study showed that maintenance employees figure highly in occupational accident statistics. An analysis carried out in a company manufacturing automotive components in Alabama revealed that the proportion of accidents of maintenance employees was, in absolute terms, much lower than that of employees of two operational departments (14% vs. 27% and 18% respectively), but that this trend was reversed when numbers of accidents were related to the number of employees [120].

A study of 1,604 occupational injuries with sick leave occurring between January 1998 and December 1999 among approximately 20,000 male workers from the French railway, SNCF, showed that railway maintenance operators and mechanical maintenance operators received the most injuries of the sample [121].

Analyses of work accident records (accident claims and reports) in a company producing mechanical transport refrigeration units and another performing the after-sales service for these systems indicate that the maintenance workers are probably more frequently involved in accidents than all other types of employees [8].

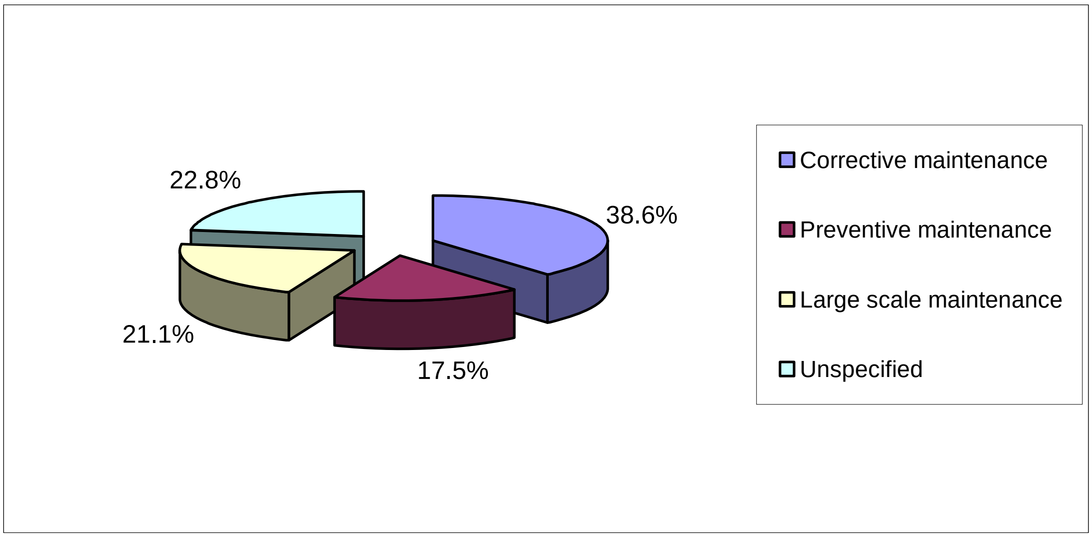
4.1.3. Occupational accidents by type of maintenance activity

The HSE analysis of 502 critical events related to maintenance in the chemical industry indicated that most of the critical events occurred during corrective maintenance activities [116]. This result underlined the findings of the earlier HSE review of the 106 work accidents related to the maintenance of work equipment and installations [115]:

- 66% of the occupational accidents occurred when a fault arose or a planned repair was carried out, i.e. during corrective maintenance activities;
- 25% of the occupational accidents occurred during cleaning activities;
- 9% of the occupational accidents occurred during examination or lubrication activities.

The French analysis of 57 accidents related to work equipment and machine maintenance [8] also found the highest proportion of the critical events (39%) occurred during corrective maintenance activities vs. 17.5% during preventive maintenance and 21% during large-scale maintenance (see Figure 7).

Figure 7: Distribution of 57 maintenance related accidents in France as a function of maintenance type [8]



According to the HSE study published in 1985 [115], accidents related to the maintenance of work equipment and installations as well as to the maintenance of roofs were the most numerous; the maintenance of work equipment and installations represented one third of all the fatal accidents and 19% of these accidents were related to the maintenance of roofs. A much more recent study indicated that numerous railway accidents and incidents were related to maintenance of equipment and to subcontracting maintenance [122].

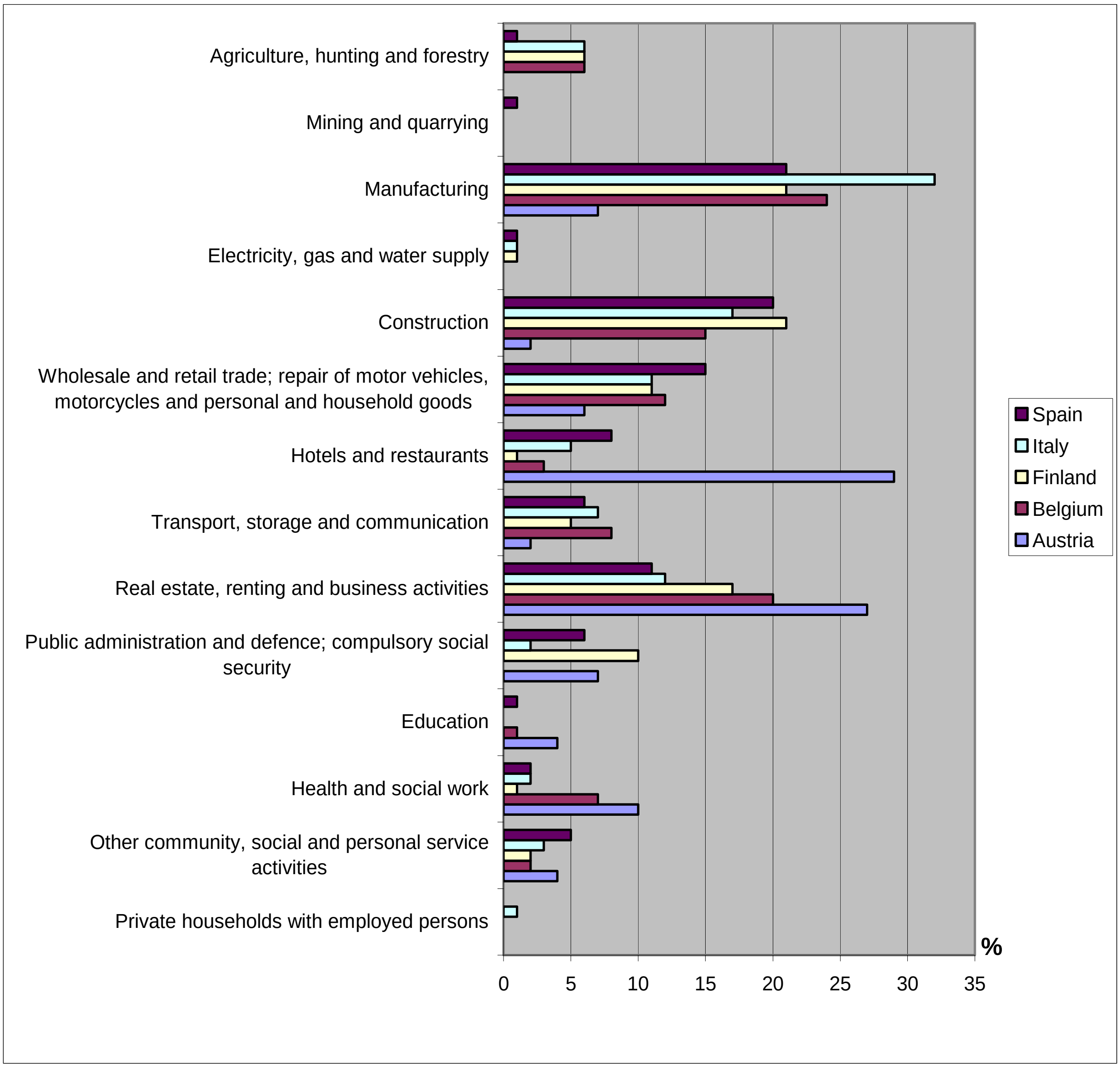
4.1.4. Occupational accidents by sector

As shown in Figure 8, EUROSTAT data for 2006 from five European countries indicate that most maintenance-related accidents occur in:

- manufacturing sector;
- construction sector;
- real estate, renting and business activities;[11]

However, in Austria 29% of all maintenance related accidents occurred also in hotels and restaurants.

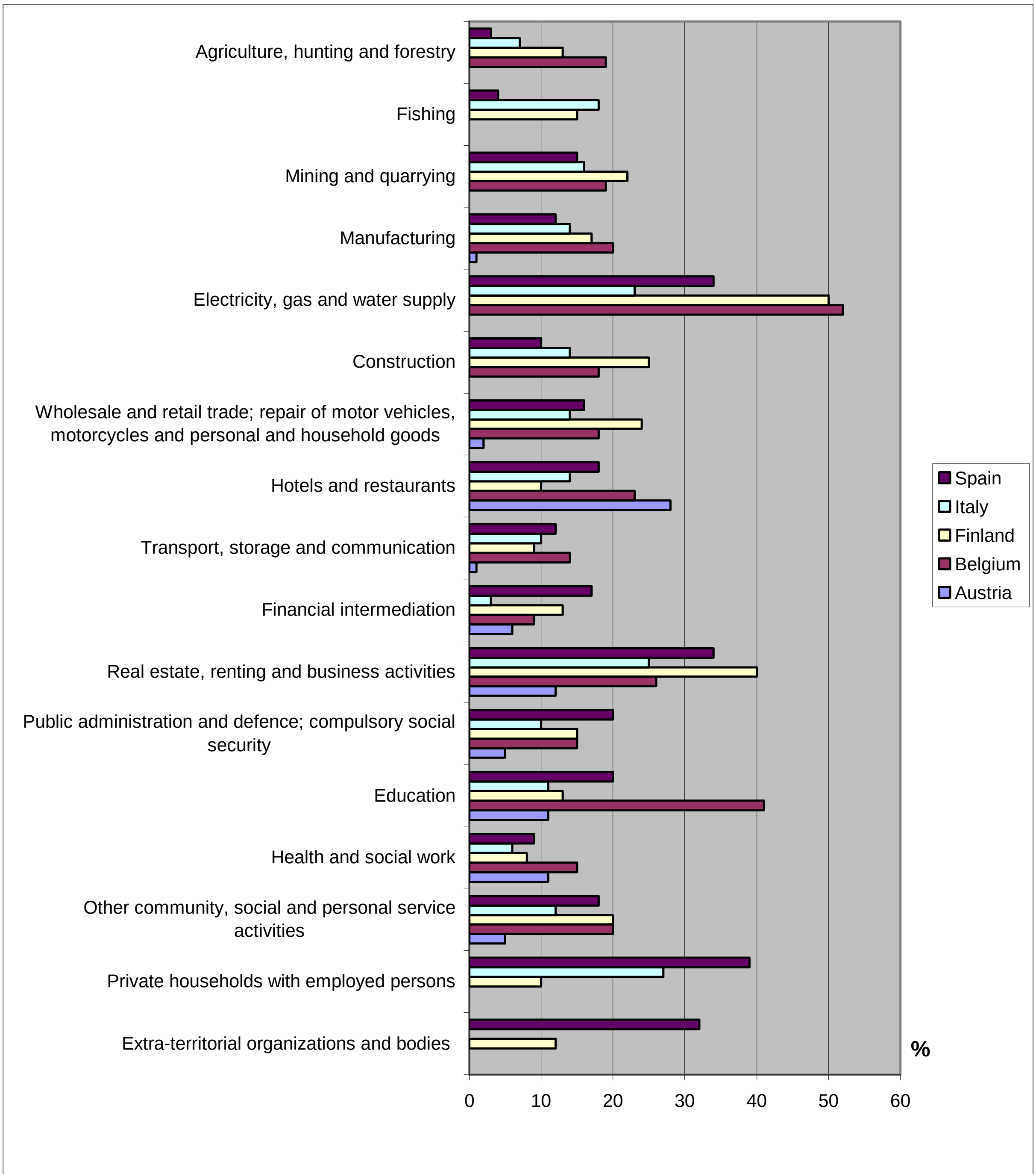
Figure 8: Percentage distribution of accidents related to maintenance operations by sector in selected European countries, 2006 (data from EUROSTAT)



[11] 'Real estate, renting and business activity' consists of subcategories such as 'maintenance and repair of office, accounting and computing machinery' as well as 'industrial cleaning'.

Figure 9 highlights some further high instances of accidents relating to maintenance operations in 2006. In the electricity, gas and water supply sector, 50% of accidents in Finland and Belgium, 34% in Spain and 23% in Italy were related to maintenance operations. In the real estate, renting and business activities sector, 40% of accidents in Finland, 34% in Spain, and 26% in Belgium related to maintenance. In Belgium, 41% of accidents in the education sector were maintenance-related. In other sectors, depending on the country, 10–20% of accidents related to maintenance operations (see Figure 9).

Figure 9: Accidents (%) related to maintenance operations within sector in selected European countries, 2006 (data from EUROSTAT)



The industrial and building sectors represented 30% and 36% respectively of the 326 fatal occupational accidents between 1980 and 1982 analysed by HSE [115]. In the construction sector, the major causes of fatal accidents among maintenance workers are due to workers being struck by heavy equipment or trucks and being struck by equipment loads or parts. In most of the cases, the accidents were due to failing to set brakes, leaving vehicles in gear, or other failures to lock out vehicles when either getting off or working around them [123].

In Germany, the highest numbers of fatal accidents reported in the BAuA (German Federal Institute for Occupational Health and Safety) database occurred during 'transport' and 'assembly' tasks. For this report, the specific tasks of 'service/inspection', 'fault clearance' and 'repair/maintenance' were combined and called 'fatal maintenance accidents'.[12] From 2000 to 2006, more or less the same number of fatal accidents happened during these activities. While the total number of fatal occupational accidents declined, the number of fatal maintenance accidents in Germany increased between 2000 and 2003 (92 fatal accidents in 2003) and then decreased until 2006 (56 fatal accidents in 2006) (see Table 22) [124].

Between 2000 and 2006, the highest total number of fatal maintenance accidents occurred in micro-sized enterprises (1–9 employees, in total 125 fatal accidents), followed by 71 fatal maintenance accidents related to maintenance in enterprises with 10–19 employees. In general, the highest number of fatal accidents was found in small and medium-sized enterprises (1–200 employees) [124].

Table 22: Number of fatal accidents in relation to accident-related tasks in Germany, 2000–2006 [124]

	2000	2001	2002	2003	2004	2005	2006	Total
Transport	123	122	118	121	102	109	110	805
Setup/rigging	8	12	12	5	13	5	9	64
Assembly	75	63	55	43	47	54	51	388
Service/inspection	21	26	30	34	23	21	20	175
Fault clearance	24	20	22	25	20	18	17	146
Maintenance	25	23	27	33	26	25	19	178
Disassembly	31	24	23	13	29	11	11	142
Surveillance/inspection/control	12	14	15	14	19	12	11	97
Administrative work	2	2	0	2	1	0	1	8
Travel accident	27	25	25	16	17	16	6	132
Task-unspecific	2	6	2	2	0	0	4	16
Other	3	4	3	4	2	1	5	22

4.1.5. Occupational accidents by age

EUROSTAT data show that accidents related to maintenance operations are the most prevalent among middle-aged workers (25–34 and 35–44 years) (see Table 23).

Table 23: Accidents related to maintenance operations by age in selected European countries (data from EUROSTAT)

Age range	2002 *		2003 **		2004 ***		2005 ****	
	N	%	N	%	N.	%	N.	%
0–17	661	1	1,519	1	1,624	1	1,849	1

[12] The German database distinguishes between different tasks: 'Wartung/Inspektion' (translated into 'service/inspection'), 'Störungsbeseitigung' (translated into fault clearance') and 'Instandsetzen' (translated into 'repair/maintenance'). All three refer to 'maintenance.

Age range	2002 *		2003 **		2004 ***		2005 ****	
	N	%	N	%	N.	%	N.	%
18–24	6,000	12	29,579	14	26,972	13	32,471	13
25–34	14,297	29	61,951	29	59,409	28	69,890	28
35–44	13,717	28	56,420	27	57,371	27	68,050	27
45–54	10,703	22	43,021	20	43,152	21	54,015	22
55–64	3,616	7	18,004	8	18,732	9	22,331	9
65+	434	1	1,076	1	1,226	<1	1,246	<1
Total	49,428		211,570		208,486		249,852	

* Austria, Finland, Italy

** Austria, Spain, Finland, Italy

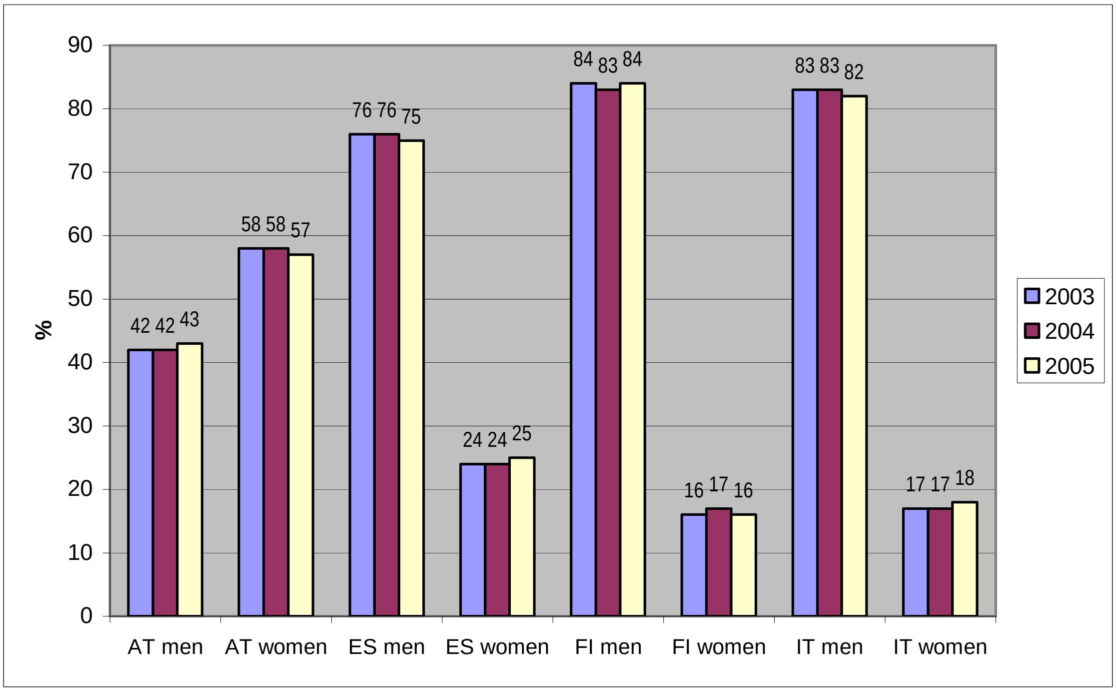
*** Austria, Bulgaria, Spain, Finland, Hungary, Italy, Lithuania, Slovakia

**** Austria, Belgium, Bulgaria, Czech Republic, Estonia, Spain, Finland, Hungary, Italy, Lithuania, Poland, Romania

4.1.6. Occupational accidents by gender

According to EUROSTAT data, accidents related to maintenance are significantly more prevalent among men than women in Finland and Italy (around 80% vs. 20%) as well as in Spain (around 70% vs. 30%), whereas in Austria they are more common among women (around 60% vs. 40%) (see Figure 10). This may be explained by the fact, compared with other countries, maintenance-related accidents in Austria are more common in private households with employees and in the hotels and restaurants sector where a relatively high percentage of staff are women. Moreover, only around 2% of accidents are related to maintenance in electricity, gas and water supply (see section 4.1.4), where majority of workers are men.

Figure 10: Accidents related to maintenance operations by gender in selected European countries, 2003–2005 (data from EUROSTAT)



In Germany, most of the fatal accidents happened among men (e.g. 54 fatal accidents among men and two among women in 2006) (see Table 24) [124].

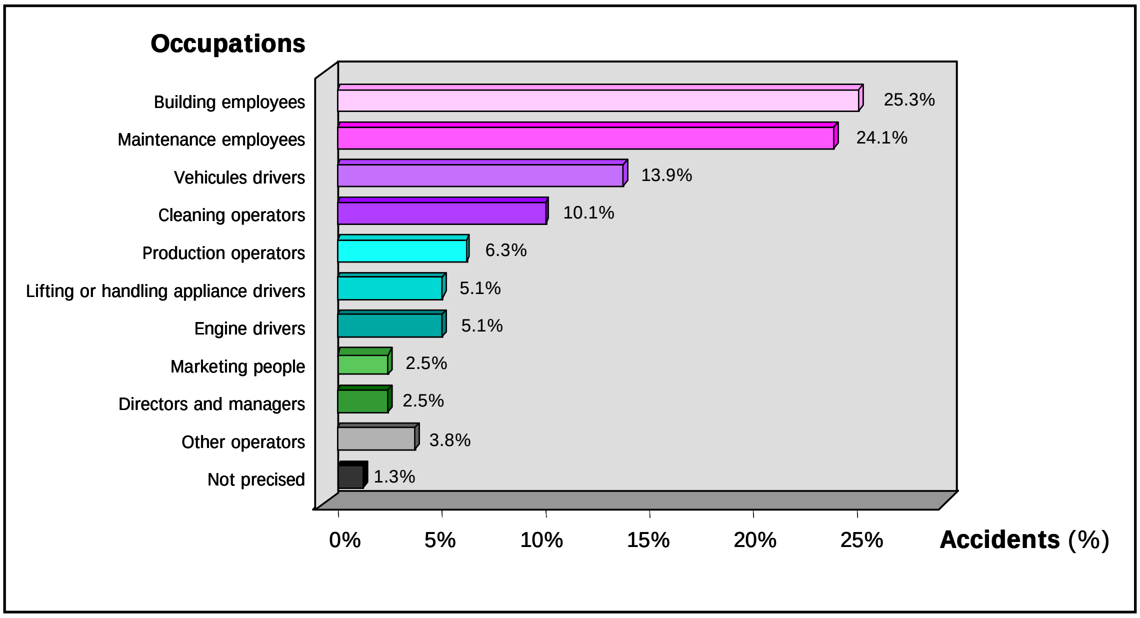
Table 24: Number of fatal maintenance accidents in relation to sex in Germany, 2000–2006 [124]

	2000	2001	2002	2003	2004	2005	2006
Men	69	66	79	92	69	62	54
Women	1	3	0	0	0	2	2

4.1.7. Occupational accidents related to subcontracting maintenance

Examination of a French work accidents database (EPICEA) identified 79 accidents related to subcontracting in 2002 and showed that maintenance staff was the second most common group of victims of these accidents, just behind construction employees [125]. Indeed, maintenance staff were the victims of almost one in four of the accidents relating to subcontracting (24%; see Figure 11) [125].

Figure 11: Distribution of 79 subcontracting related accidents in France as a function of the occupation of the victim [125]



4.2. Occupational diseases and health problems

Studies indicate that industry maintenance workers might be especially at risk of contracting occupational diseases [12]. According to a study by AFIM (Association of Maintenance Engineers and Technicians) carried out in the Provence Alpes Côte d'Azur region of France with maintenance subcontracting companies, industrial maintenance employees have an occurrence of occupational diseases 8–10 times greater than the average population [126,127]. This represents 1,100 victims per year of occupational disease in industrial maintenance.

The seven main occupational diseases that concern industrial maintenance employees are [12]:

- diseases related to the inhalation of asbestos dust;
- respiratory diseases;
- hearing impairment;

- musculoskeletal disorders (MSDs);
- diseases of the peripheral nervous system;
- diseases of the circulatory system;
- skin diseases.

In France, almost 1% of maintenance technicians are victims of a permanent disability each year [127].

Increased morbidity and/or mortality rates related to asbestos exposure can be found for marine maintenance engineers [128] and building maintenance workers [129]. Plumbers, gas fitters, carpenters, electricians, ventilation engineers, cleaners and other work groups maintaining buildings and disturbing asbestos-containing materials are also at risk [130,131].

Maintenance workers exposed to asbestos may suffer from cancers such as lung cancer and mesothelioma; 24% of the deaths from mesothelioma were found in maintenance worker occupations [132]. Aircraft maintenance workers have also been found to have an increased risk of cancer [133], indicating that they are exposed to a variety of chemicals of which some were known or possible carcinogens. Minor symptoms include headaches, dizziness, irritated eyes, abdominal cramps, body odour, contact dermatitis, diarrhoea and vomiting [133]. In addition, neuropsychiatric and neurological symptoms (e.g. memory loss, irritability and poor sleep) may be observed [133].

An HSE study [134] found that musculoskeletal disorders, representing 40% of all the occupational diseases in the air transport industry, mainly concerned baggage handlers and ground maintenance staff.

Likewise, a study of work-related musculoskeletal disorders reported over a 12-year period (1992–2003) in Norway's offshore petroleum industry showed that there were 3,131 new cases of musculoskeletal disorders during this period [49]. About 40% of all the cases reported (i.e. disorders of the upper limbs, back pain, and less often neck disorders and disorders of the lower limbs) were maintenance workers, and more particularly mechanics, electricians and scaffolders. The activities reported as the cause of work-related musculoskeletal disorders were high physical workload, repetitive work, but also fixed position, walking, climbing stairs or kneeling. According to the authors, 'workers in maintenance represented the largest group of cases, upper limb and back were the most frequently reported anatomical regions and high physical workload and repetitive work dominated as the reported causes' (p. 114) [49].

Moreover, musculoskeletal disorders are important diagnostic causes of sick leave among maintainers in the offshore petroleum industry [135] as well as onshore in Norway [135,136].

4.3. Poor maintenance

Lack of maintenance or inadequate maintenance can also lead to dangerous situations, accidents and health problems. This may be related to lack of, or poor maintenance of:

- vehicles;
- industrial or agriculture machines;
- electric facilities;
- fire-extinguishers;
- buildings;
- water facilities.

Maintenance failures may contribute to large-scale disasters with serious damaging consequences for humans and the environment. The first two examples below from the UK illustrate the possible scenarios of such accidents. A further example from the German labour inspectorates highlights the importance of maintenance procedures in relation to (fatal) occupational accidents. However, many accident communications remain unpublished.

4.3.1. Example: Park Environmental Services Ltd, Newport, UK

On 16 July 2001, an estimated 186 m^3 of hydrogen sulphide gas were released from a 500 m^3 treatment tank at Park Environmental Services Ltd, which operated a treatment plant for processing chemical waste at Newport in South Wales [137].

Approximately 20 tonnes of waste alkali solution were transferred from a road tanker to a treatment tank. Mixed waste acids were added to the treatment tank with a view to controlling the pH level. During processing, the acid reacted with the polysulphide contaminants in the waste alkali solution. Hydrogen sulphide gas was produced, which escaped from the treatment tank. The gas then settled at ground level.

Due to inadequate maintenance, the lid collapsed into the treatment tank. Furthermore, the analysis of the waste chemicals to determine the nature and volume of toxic gas was insufficient. In addition, the extraction system was neither adequate for use with, nor designed for, an open vessel. It could therefore not prevent the loss of containment of the toxic gas formed.

The incident had the following impacts [137]:

- one fatality from asphyxiation;
- three injuries to on-site personnel from exposure to hydrogen sulphide gas;
- serious danger to human health involving the release of one dangerous substance;
- fines imposed by the courts totalling £250,000;
- a nationwide enforcement initiative to look more closely at the chemical waste industry and its safety/environmental standards.

4.3.2. Example: Fehrer (GB) Ltd, Smethwick, West Midlands, UK

Fehrer Ltd manufactured polyurethane resins for moulding into car seat cushions. On 24 July 2002, a fire in an area around a curing oven spread to the process and manufacturing areas, and destroyed the factory [138].

The incident occurred during a factory shutdown while various maintenance works were being undertaken including cutting out redundant pipework with an oxy-propane torch. A spark from the cutting operation ignited combustible material.

The incident had the following impacts [138]:

- no injuries sustained;
- property damage of over EUR 2 million;
- 110 people had to be evacuated from their homes;
- destruction of the factory.

4.3.3. Example: compost storage facility, Germany

An industrial fitter working at a compost storage facility in Germany in 2003 was killed during the maintenance of a machine used to mix different compost fractions. The machine had paddles fixed on two shafts. Some days previously the fitter had repaired one broken paddle. However, the repair was inappropriate and the fitter had to repeat the maintenance work. In the morning, the fitter entered the mixing machine via a ladder. The ignition key was plugged in the ignition lock and the main control switch was not locked. Another employee did not know about the maintenance procedure and started the mixing machine. The industrial fitter was pulled in by the shafts. Although the employee immediately pushed the emergency stop switch, the fitter could not be saved [124].

5. Prevention measures

Given the wide range of hazards and risks associated with maintenance, it is necessary to include it in a company's comprehensive management system.

- **Structured approach.** Maintenance may mean stopping a production process and requiring workers to operate in hazardous locations (e.g. inside machinery and plant). As outlined in this report, there are many associated hazards and risks. Therefore, a system has to be in place to ensure that:
- maintenance can be carried out safely;
- the workers involved in an ongoing production process remain safe during the process;
- equipment can be started up safely afterwards.

A risk assessment record should be included in typical task documentation.

- **Organising work.** Maintenance is often performed under pressure – to restart a stalled production process or to complete scheduled work before a deadline. Workers who are under this kind of pressure – and possibly putting in long hours to complete the task – may not work as safely as they should. Taking shortcuts can end up actually prolonging the task, as well as risking injuries and damage to equipment.

- **Training.** The competence of the people carrying out maintenance, including inspection and testing, is vital to safety. Most workers carry out some maintenance tasks. Even though workers are frequently multi-skilled and routine maintenance may be part of their job description, activities that are not performed regularly must to be included in their training. Accidents may occur if workers try to do tasks they are not trained for or experienced in.

Employers must ensure that workers:

- have the skills to carry out the necessary tasks;
- are informed about safe work procedures;
- know what to do when a situation exceeds the scope of their skills.

- **Procurement of equipment.** Maintenance activities can require workers to operate in dangerous locations. This may involve the use of equipment that is not routinely used in the workplace, including personal protective equipment (PPE). Procurement procedures must be in place to ensure that the necessary tools and PPE (along with the necessary training and care of this equipment) are available for safe maintenance. For example, temporary lighting may need to be explosion protected, and appropriate PPE provided (e.g. respiratory protection for use when cleaning filters). During the procurement of new machinery and buildings, ease of access for performing maintenance should be considered: risks during maintenance can be minimised or even eliminated through good design of work equipment and the provision of relevant information by the supplier or manufacturer.

Artists: Magda Szymeczko, Andrzej Leraczyk. Courtesy of the Occupational Safety Poster Competition organised by the Central Institute for Labour Protection – National Research Institute, Poland

- **Subcontracting.** Companies are increasingly outsourcing their maintenance activities, resulting in a major impact by procurement and management of contracts between companies on occupational safety and health. Maintenance carried out by a contractor must be well integrated into the ongoing activities of the company to safeguard the safety and health of all workers involved. Good practice examples where the needs of both the contractor and host company are taken into consideration include 'good neighbour schemes', 'safety passports' and induction procedures. During the procurement process, issues of cultural and language differences should be considered, as well as issues resulting from the sometimes uncertain employment of some subcontractors.

5.1. Maintenance as a process

It is essential to take a structured approach to maintenance, seeing it as a process rather than a task.

The process starts with the **planning** phase, when risk assessment is carried out. The scope of work is decided upon and the required resources are identified (e.g. range of skills of workers and their roles, tools needed), as well as the hazards and precautions to be taken. It is advisable to involve the maintenance workers in the planning process.

Only then can the location of the task be **made safe** – power locked off, moving parts of machinery secured, temporary ventilation installed, access and egress routes established, etc.

Appropriate tools (including PPE) must be made available.

Procedures decided on in the planning stage must be followed, but provision must also be made for managing unexpected problems.

Once the actual maintenance has taken place, the **work is checked** to make sure:

- the item worked on is safe to use again;
- all isolations are removed;
- all tools are retrieved;
- any waste is removed.

The process should be documented and **records** of tasks performed, as well as the sign-off condition, should be verified and approved.

Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances (Seveso II Directive) aims to prevent major accidents which involve dangerous substances. Furthermore, the Directive promotes the exchange of information among the Member States on accidents and near misses that occur within sites that fall under the Directive in order to prevent similar occurrences in the future [139]. The Major Accidents Hazards Bureau[13] at the European Commission's Joint Research Centre operates a system for the distribution of information concerning these major accidents as well as the lessons learned from them:

- Major Accident Reporting System (MARS);
- Seveso Plants Information Retrieval System (SPIRS).

This information can be used in order to make procedures – also in relation to maintenance – safer.

[13] http://mahbsrv.jrc.it/

6. Conclusions

Literature studies indicate that significant numbers of maintenance workers may be exposed to a variety of risks when doing their job. In addition, a significant number of accidents are related to maintenance activities and especially to corrective maintenance. Thus it is vital for maintenance workers to be well informed about occupational risks. They should be provided with the appropriate work equipment, protection equipment, and work procedures.

The process of maintenance should start at the design and planning stage and before maintenance workers enter the workplace.

Implementing appropriate risk assessment procedures related to maintenance operations, as well as employing adequate preventive measures to ensure the safety and health of workers involved in maintenance activities are essential.

After maintenance operations are completed, special checks (inspections and tests) should be carried out to ensure that:

- maintenance has been carried out properly;
- new risks have not been created.

During the whole process, good maintenance management should ensure that:

- maintenance is co-ordinated, scheduled and performed correctly as planned;
- the equipment or workplace is left in a safe condition for continued operation.

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ANEXO VI

MANUAL DE PREVENÇÃO DE RISCO ELÉCTRICO

EDIÇÃO DE OUTUBRO DE 2006

Título:

MANUAL DE SEGURANÇA

♦

PREVENÇÃO DO RISCO ELÉCTRICO

nNatureza	*Versão*	*Data*	*Autor*
Documento homologado	*Inicial*	*24/01/2002*	*SPSI – Serviço Prevenção e Segurança Interempresas*

Lista de Distribuição:

- *Adjuntos e Assessores do CA*
- *Directores da Holding*
- *CA´s das Empresas do Grupo EDP*

Lista de Anexos:

Sem anexos

Observações:

- *Elaborado e revisto em colaboração a EDP Distribuição, EDP Produção, LABELEC, MRH e SÃVIDA*

Autorização para Edição	***Acessibilidade***	
Aprovado por: *Comissão Executiva da EDP*	Livre	
Data: *24-01-2002*	Grupo EDP	X
Substitui: *"Prescrições de Segurança para Trabalhos e Manobras nas Instalações Eléctricas da EDP" (homologadas pelo DP 31/85/CG, de 14/03/85);*	Restrita	
"Prescrições de Segurança para Trabalhos em Tensão" (homologadas por Despacho da Direcção Geral, de 18/07/80).	Confidencial	

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1. GENERALIDADES

1 — GENERALIDADES

1.1 OBJECTO

→ O "Manual de Prevenção do Risco Eléctrico" estabelece as prescrições de segurança com vista a assegurar a protecção das pessoas contra os riscos de origem eléctrica, sempre que realizem trabalhos:

- Em instalações eléctricas em exploração (condução, manutenção, modificação, ampliação...) ou na sua vizinhança;
- Em instalações eléctricas ou não eléctricas em construção ou demolição, quando estiverem na vizinhança de instalações eléctricas em exploração.

Uma instalação eléctrica considera-se em exploração desde a sua primeira colocação em tensão, total ou parcial, mesmo que para ensaios

→ Sempre que necessário estas prescrições deverão ser completadas com regulamentos, protocolos ou instruções locais.

1.2 DOMÍNIO DE APLICAÇÃO

→ O "Manual de Prevenção do Risco Eléctrico" aplica-se a todas as empresas do Grupo EDP:

- Nas instalações afectas à produção de energia eléctrica;
- Nas instalações afectas ao transporte e à distribuição;
- Nas instalações eléctricas e equipamentos de instalações de utilização;
- Nas instalações e equipamentos exteriores à EDP, sobre os quais o pessoal da EDP é chamado a intervir.

→ Por via contratual, as prescrições do presente Manual aplicam-se aos trabalhos realizados em instalações da EDP por empresas exteriores, bem como a trabalhos a cargo da EDP realizados em instalações de terceiros.

→ No caso de existirem diversas empresas exteriores na mesma obra, antes do início dos trabalhos, e por iniciativa do coordenador de segurança na obra, devem ser definidas em conjunto as medidas a tomar para evitar os riscos profissionais que possam resultar do exercício simultâneo das actividades das diversas empresas (riscos de interferência).

As prescrições do presente Manual aplicam-se desde a primeira colocação da instalação em tensão, total ou parcial, ou desde a sua construção se as condições de vizinhança a uma outra instalação em tensão dão origem a riscos eléctricos

1.3 PRINCÍPIOS GERAIS

→ O respeito pelas obrigações legais exige que as responsabilidades dos diferentes intervenientes sejam claramente definidas e plenamente percebidas e assumidas por cada um. Neste sentido, as delegações de competências para a exploração das instalações eléctricas devem ser claramente definidas por escrito e mantidas actualizadas.

→ Nos termos da legislação em vigor, qualquer trabalhador pode invocar o direito de se recusar a executar determinado trabalho se não estiverem preenchidas as condições de segurança adequadas.

→ Nas redes de transporte e distribuição de energia eléctrica, instalações de produção e seus anexos, os trabalhos podem ser realizados em tensão ou fora de tensão.

→ Nas instalações de utilização, os trabalhos devem ser realizados sem tensão, excepto se:

- Existirem razões de exploração ou de utilização;
- A própria natureza das operações impuser a permanência da tensão (reparação de avarias, por exemplo).

→ Os trabalhos em tensão devem ser realizados em conformidade com os métodos de trabalho aprovados, com excepção de trabalhos experimentais executados por um departamento competente, para testar novos métodos ou novas ferramentas.

→ Os trabalhos devem ser objecto:

- De preparação e de análise no local (trabalhos de construção e de conservação);
- De análise no local (reparação de avarias).

→ Se a execução dum trabalho exigir a participação de várias equipas, deverá ser designado um responsável pela coordenação.

1.4 NATUREZA DOS TRABALHOS

→ As prescrições a respeitar são determinadas pela natureza dos trabalhos.

↘ **Trabalhos eléctricos**

- São os trabalhos efectuados nas partes eléctricas da instalação.
- Devem ser confiados a pessoas qualificadas.

↘ **Trabalhos não eléctricos**

- São os trabalhos de natureza não eléctrica realizados em instalações eléctricas ou próximo destas.
- Podem ser confiados a pessoas não qualificadas no domínio eléctrico, desde que tenham recebido instrução sobre prevenção de riscos eléctricos e estejam autorizadas para esse efeito, ou estejam sob a vigilância de uma pessoa qualificada.

2. DEFINIÇÕES

2 — DEFINIÇÕES

2.1 GENERALIDADES

No quadro do presente documento, os termos seguintes são usados com a acepção especificada.

2.1.1 Condução

Conjunto das actividades (da exploração) de vigilância, de controlo e de comando asseguradas por um centro de comando relativamente a uma ou mais instalações.

2.1.2 Disponibilidade

Situação em que um grupo gerador, linha, transformador, painel, barramento, equipamentos e aparelhos se encontram aptos a responder em exploração às solicitações de acordo com as suas características técnicas e parâmetros considerados válidos.

2.1.3 Exploração

Conjunto de actividades necessárias ao funcionamento de uma instalação eléctrica, incluindo as manobras, o comando, o controlo, a manutenção, bem como os trabalhos eléctricos e não eléctricos.

As actividades da exploração competem:

- À entidade responsável pela condução no que concerne nomeadamente à decisão, operação e autorização prévia para a execução de trabalhos ou manobras nas redes em exploração;
- Aos centros locais de exploração no que respeita às acções técnicas e administrativas da exploração, compreendendo nomeadamente as operações de controlo, manutenção, reparação destinadas a manter uma instalação num estado que lhe permita cumprir a sua função.

2.1.4 Indisponibilidade

Situação em que um grupo gerador, linha, transformador, painel, barramento, equipamentos e aparelhos não se encontram aptos a responder em exploração às solicitações de acordo com as suas características técnicas e parâmetros considerados válidos.

2.1.5 Manutenção

Combinação de acções técnicas e administrativas (da exploração) que compreendem as operações de vigilância destinadas a manter uma instalação eléctrica num estado que lhe permita cumprir a sua função.

A manutenção pode ser preventiva (conservação), com o objectivo de reduzir a probabilidade de avaria ou degradamento do funcionamento da instalação, ou correctiva (reparação), realizada depois da detecção de uma avaria e destinada a repor o funcionamento da instalação.

2.1.6 Perigo eléctrico

Fonte de possíveis danos corporais ou prejuízos para a saúde devidos à presença de energia eléctrica numa instalação eléctrica.

2.1.7 Regulamento específico

Descritivo de procedimentos ou regras específicas de uma instalação eléctrica ou de um conjunto de instalações similares, destinadas a orientar os profissionais que efectuam manobras de rede.

2.1.8 Risco eléctrico

Associação da probabilidade com o grau de possíveis danos corporais ou prejuízos para a saúde para uma pessoa exposta a um perigo eléctrico.

2.2 DEFINIÇÕES RELATIVAS ÀS PESSOAS OU GRUPOS DE ACTIVIDADE

2.2.1 Agente de condução

Profissional qualificado para operar na condução de instalações eléctricas.

2.2.2 Centro de condução (CC)

Órgão de condução da rede encarregue da vigilância e condução das instalações e equipamentos das redes de distribuição.

2.2.3 Delegado de consignação

Profissional qualificado, que estando numa instalação diferente daquela em que se encontra o responsável de consignação, se responsabiliza perante este pelo estabelecimento e permanência de todas as medidas de segurança necessárias para colocar e manter as suas instalações na situação definida pelo responsável de consignação.

2.2.4 Empregador

Pessoa que, directamente, ou por delegação, assume a responsabilidade legal por uma empresa ou por um estabelecimento.

O empregador pode delegar as suas prerrogativas numa pessoa por si escolhida para assegurar a responsabilidade hierárquica de uma instalação cujos limites estão perfeitamente definidos.

Nesta qualidade a pessoa a quem é dada a delegação é responsável, nomeadamente:

- Pela organização dos processos de trabalho e das diversas relações de exploração;
- Pela aplicação dos diversos regulamentos existentes, bem como pelo respeito pelas regras técnicas;
- Pela aplicação das regras de segurança.

2.2.5 Empresa exterior

Empresa que efectua trabalhos ou que presta serviços em instalações da empresa utilizadora.

2.2.6 Empresa utilizadora

Empresa do Grupo EDP que utiliza os serviços de uma empresa exterior.

Entende-se que os termos "empregador", "responsável pela empresa utilizadora" e "responsável pela empresa exterior" se aplicam igualmente às pessoas em quem aqueles delegaram o poder de os representar.

2.2.7 Entidade requisitante

Entidade interessada na realização de trabalhos a quem está atribuída a responsabilidade de solicitar por escrito:

- A consignação de um elemento de rede (ou instalação) para a realização de trabalhos ou ensaios fora de tensão;
- A realização de trabalhos em tensão, num elemento de rede (ou numa instalação).

2.2.8 Executante

Pessoa qualificada, ou não, e designada pelo seu empregador para efectuar trabalhos no cumprimento de uma ordem escrita ou verbal.

Esses trabalhos podem ser:

- Eléctricos, e neste caso o executante deve possuir a qualificação adequada;
- Não eléctricos, podendo neste caso o executante ser ou não electricista.

O executante está sob a autoridade dum único responsável de trabalhos ou de um único responsável de ensaios.

O executante deve:

- Cumprir as instruções do responsável de trabalhos ou do responsável de ensaios;
- Iniciar um trabalho só depois de ter recebido ordem para tal;
- Respeitar os limites da zona de trabalhos que lhe foi definida e respeitar as disposições de segurança estabelecidas no interior da referida zona;
- Usar os equipamentos de protecção individual;
- Utilizar apenas ferramentas adequadas ao trabalho a efectuar;
- Respeitar as características técnicas dos equipamentos e as regras de segurança e da técnica aplicáveis a cada tarefa;
- Verificar os equipamentos e ferramentas antes da sua utilização.

O executante zela pela sua própria segurança

2.2.9 Pessoa comum

Pessoa que não é nem qualificada nem instruída.

2.2.10 Pessoa instruída

Pessoa devidamente informada por pessoas qualificadas com vista a permitir-lhe evitar os perigos que possam advir da electricidade.

2.2.11 Pessoa qualificada

Pessoa que possui conhecimentos técnicos ou com experiência que lhe permitam evitar os perigos que possam advir da electricidade.

2.2.12 Responsável de condução

Pessoa a quem está atribuída a responsabilidade pela coordenação de todos os actos de condução duma instalação cujos limites estão perfeitamente definidos.

Pode ser autorizado a delegar as suas competências noutro agente da condução.

2.2.13 Responsável de consignação

É o profissional qualificado sob cuja exclusiva responsabilidade é colocado, durante todo o período da consignação, um elemento de rede (ou uma instalação) onde se vão realizar os trabalhos ao abrigo da consignação.

O responsável de consignação assume a responsabilidade das instalações consignadas onde se vão realizar trabalhos, até à finalização da desconsignação.

2.2.14 Responsável de ensaios

É o profissional qualificado designado para assumir a direcção efectiva dos ensaios abrangidos por uma consignação para ensaios, competindo-lhe estabelecer as medidas de segurança necessárias e velar pela sua aplicação, de acordo com as normas e regulamentos aplicáveis.

2.2.15 Responsável de exploração

Pessoa designada por escrito, pelo empregador, para assumir a responsabilidade efectiva pela exploração duma instalação ou dum conjunto de instalações eléctricas, cujos limites estão perfeitamente definidos.

O responsável de exploração pode ser autorizado a delegar toda ou parte das suas competências num outro agente de exploração. Esta delegação deve ser objecto de um documento escrito ou de uma troca de mensagens registadas.

São, nomeadamente, atribuições do responsável de exploração tomar decisões respeitantes ao acesso às instalações e coordenar esses acessos a fim de evitar qualquer interferência de riscos eléctricos entre estaleiros onde se desenvolvam trabalhos em simultâneo.

2.2.16 Responsável de manutenção

Pessoa a quem está atribuída a responsabilidade pela coordenação de todas as operações de manutenção duma instalação cujos limites estão perfeitamente definidos.

Pode ser autorizado a delegar as suas competências noutro agente da manutenção.

2.2.17 Responsável de trabalhos

É o profissional qualificado designado ou indicado para assumir a direcção efectiva dos trabalhos, competindo-lhe estabelecer as medidas de segurança necessárias e zelar pela sua aplicação de acordo com as normas e regulamentos aplicáveis.

O responsável de trabalhos é responsável pela segurança na zona de trabalhos

2.3 DEFINIÇÕES RELATIVAS A INSTALAÇÕES ELÉCTRICAS

2.3.1 Canalizações eléctricas

Este termo designa o conjunto constituído por um ou mais condutores eléctricos nus ou isolados e pelos elementos que asseguram a sua fixação e a sua protecção mecânica, se existirem.

2.3.2 Equipamento de segurança

Equipamento utilizado para proteger o pessoal, individual ou colectivamente. O referido equipamento deve responder a características precisas de norma ou de especificação técnica.

2.3.3 Linhas eléctricas aéreas

Conjunto de condutores nus ou isolados, fixados em elevação sobre apoios (postes, torres, postaletes, galerias acessíveis ao público,...), por meio de isoladores ou de sistemas de suspensão adequados. Podem estar agrupados em feixes de condutores isolados electricamente uns dos outros e mecanicamente solidários.

2.3.4 Linhas eléctricas subterrâneas

Canalizações eléctricas estabelecidas abaixo do nível do solo. Estas canalizações são de tipo isolado e podem estar colocadas:

- Em plena terra (invólucro exterior em contacto directo com a terra), sendo então designadas enterradas;
- Em caleiras, em manilhas ou em galerias técnicas.

2.3.5 Iluminação exterior

Conjunto das instalações que asseguram a iluminação, a sinalização de locais exteriores privados ou públicos. A iluminação exterior compreende não só as redes mas também os materiais que equipam, por exemplo, candeeiros da via pública, cabinas telefónicas, abrigos de transportes públicos, sanitários públicos, painéis de indicação e semáforos.

2.3.6 Instalação colocada fora de tensão

É o estado em que se encontra uma instalação quando a tensão foi suprimida. Este estado, por si só, não permite iniciar trabalhos.

2.3.7 Instalações de comunicação de dados

Instalações destinadas à transmissão, emissão ou recepção de símbolos, sinais, imagens, sons ou informações de natureza semelhante.

2.3.8 Instalações de distribuição — Redes

Conjunto dos equipamentos (linhas aéreas, canalizações subterrâneas, subestações e postos de transformação...) explorados pelas empresas de distribuição de energia eléctrica.

2.3.9 Instalação eléctrica

Conjunto dos equipamentos utilizados na produção, no transporte, na conversão, na distribuição e na utilização da energia eléctrica, incluindo as fontes de energia, como as baterias, os condensadores e todas as outras fontes de armazenamento de energia eléctrica.

Neste documento o termo genérico "instalação" é utilizado sempre que não for necessário precisar o seu tipo, ainda que se trate de partes duma instalação ou de equipamentos. O qualificativo "eléctrico" é omitido desde que não haja ambiguidade.

2.3.10 Instalações de produção

Conjunto dos equipamentos eléctricos (máquinas rotativas, aparelhagens, canalizações e postos de transformação anexos), destinados a produzir energia eléctrica.

2.3.11 Instalações de transporte — Redes

Conjunto dos equipamentos (linhas aéreas e subterrâneas e subestações) explorados pela empresa de transporte de energia eléctrica.

2.4 DEFINIÇÕES RELATIVAS ÀS GRANDEZAS ELÉCTRICAS

2.4.1 Tensões

Todas as instalações e equipamentos, qualquer que seja o fim a que se destinem, são classificados em função da mais elevada das tensões nominais existentes:

- Entre quaisquer dois dos seus condutores (ou peças condutoras);
- Entre qualquer um dos condutores (ou peças condutoras) e a terra (ou as massas).

Para efeito deste documento as tensões são classificadas por domínios de tensão (Quadro 1).

Quadro 1 - Domínios de tensão

Domínios de tensão	Níveis de tensão	Valor da tensão nominal	
		Em corrente alternada (1)	Em corrente contínua (2)
BT I	Tensão Reduzida	$U_n \leq 50$ V	$U_n \leq 120$ V (2)
BT II	Baixa Tensão	$U_n \leq 1000$ V	$120 < U_n \leq 1\ 500$ V
AT	Média Tensão	1 kV $< U_n \leq 45$ kV	$U_n > 1\ 500$ V
	Alta Tensão	$45 < U_n \leq 110$ kV	
	Muito Alta Tensão	$U_n > 110$ kV	

(1) Valor eficaz

(2) Corrente contínua lisa

2.4.2 Tensões reduzidas (TR)

No âmbito dos trabalhos e intervenções em instalações e equipamentos de tensão reduzida, há a distinguir os que são realizados:

- Em Tensão Reduzida de Segurança (TRS);
- Em Tensão Reduzida de Protecção (TRP);
- Em Tensão Reduzida Funcional (TRF).

2.4.2.1 Instalações de TRS

São instalações de TRS aquelas em que, simultaneamente:

- Todas as partes activas estão separadas das partes activas de qualquer outra instalação por um isolamento duplo ou reforçado;
- As partes activas estão isoladas da terra, assim como de qualquer outro condutor de protecção pertencente a outras instalações.

2.4.2.2 Instalações de TRP

São instalações de TRP aquelas em que todas as partes activas estão separadas das partes activas de qualquer outra instalação por um isolamento duplo ou reforçado.

2.4.2.3 Instalações de TRF

São classificadas nesta categoria as instalações de tensão reduzida que não podem ser classificadas nem em TRS nem em TRP.

2.5 DEFINIÇÕES RELATIVAS AOS DIFERENTES TIPOS DE TRABALHOS

2.5.1 Consignação eléctrica de uma instalação

Conjunto de operações que consiste em isolar (por corte ou por seccionamento), bloquear, verificar a ausência de tensão, estabelecer ligações à terra e em curto-circuito e proteger contra peças em tensão adjacentes e delimitar um elemento de rede (ou uma instalação) previamente identificado e retirado da exploração normal, destinado a garantir as condições de segurança necessárias à realização de trabalhos fora de tensão nesse elemento de rede (ou nessa instalação).

2.5.1.1 Bloqueio de um aparelho de corte ou de seccionamento

Conjunto de operações destinadas a impedir a sua manobra por comando local (utilizando fechaduras, cadeados, etc.) ou por comando à distância (cortando os circuitos auxiliares) mantendo-o numa situação determinada.

2.5.1.2 Corte (de uma instalação)

Consiste em efectuar a interrupção de todos os condutores activos das suas fontes de alimentação por meio de equipamentos com poder de corte adequado, por exemplo desligar um disjuntor ou um interruptor.

2.5.1.3 Isolamento (de uma instalação)

Conjunto de operações que consiste em separar electricamente uma instalação de todas as possíveis fontes de tensão, por meio de seccionadores abertos ou por qualquer outro método equivalente de seccionamento que dê iguais garantias de separação permanente.

2.5.1.4 Seccionamento (de uma instalação)

Consiste em assegurar uma posição de abertura com uma distância de separação entre os contactos eléctricos que satisfaça as condições de isolamento predeterminadas e capazes de garantir a segurança das pessoas, por exemplo abertura de seccionadores, de arcos ou fiadores de corte visível, retirada de aparelhos extraíveis.

2.5.2 Consignação para paragem de uma máquina ou de um aparelho

Conjunto de operações que permite a consignação para paragem de uma máquina ou de um aparelho e que consiste em efectuar uma ou mais manobras de segurança para interromper o seu funcionamento e impedir a presença e, eventualmente, a manutenção de qualquer fonte possível de energia.

Em geral, desta tarefa são apenas incumbidos os trabalhadores qualificados de empresas especializadas.

2.5.3 Desconsignação eléctrica de uma instalação

Conjunto de operações que permitem restabelecer as condições necessárias para a devolução à exploração normal de um elemento de rede (ou uma instalação) que se encontrava consignada.

Compreende a identificação do elemento de rede (ou instalação), a retirada das ligações à terra e em curto-circuito, o desbloqueio dos órgãos de corte ou seccionamento e a reposição em serviço da instalação.

> As manobras para a desconsignação só podem ser iniciadas depois de autorizadas pelo centro de condução, a pedido do responsável de consignação.

2.5.4 Ensaio

Acção destinada a verificar o funcionamento ou o estado eléctrico ou mecânico ou outro de uma instalação podendo esta estar total ou parcialmente em tensão.

2.5.5 Manobras

São operações que conduzem a uma mudança da configuração eléctrica de uma rede, de uma instalação ou da alimentação eléctrica de um equipamento. Estas operações são realizadas com o auxílio de aparelhos ou de dispositivos especialmente concebidos para o efeito, tais como interruptores, disjuntores, seccionadores, arcos ou fiadores de continuidade, etc. Em regra a ordem de sucessão das manobras não é indiferente.

Há a distinguir:

- Manobras de consignação, efectuadas para realizar a consignação de uma rede, de uma instalação ou de um equipamento, para permitir a realização de trabalhos fora de tensão;
- Manobras de desconsignação, efectuadas numa determinada sequência visando desconsignar uma rede, uma instalação ou um equipamento, previamente consignados.
- Manobras de exploração, que conduzem à modificação do estado eléctrico de uma rede ou de uma instalação, no âmbito do seu normal funcionamento;
- Manobras de urgência/emergência, impostas pelas circunstâncias para salvaguarda de pessoas e bens.

2.5.6 Medições

Acções que permitem medir grandezas eléctricas, mecânicas, térmicas, etc..

2.5.7 Operações

Acções desencadeadas localmente ou por telecomando que visam modificar o estado de um órgão ou sistema.

2.5.8 Regime especial de exploração (REE)

Situação em que é colocado um elemento de rede (ou uma instalação) durante a realização de trabalhos em tensão, ou na vizinhança de tensão, de modo a diminuir o risco eléctrico ou a minimizar os seus efeitos. As disposições a tomar em cada caso são as indicadas nas condições de execução dos trabalhos em tensão.

2.5.9 Trabalho

Qualquer tipo de intervenção (eléctrica ou não) cujo fim seja o de realizar, modificar, conservar ou reparar uma instalação eléctrica, onde haja a possibilidade de ocorrer um risco eléctrico.

2.5.9.1 Trabalho eléctrico

Trabalho que respeite às partes activas ou seus isolamentos, à continuidade das massas ou outras partes condutoras dos equipamentos, assim como aos condutores de protecção das instalações.

Inclui os trabalhos fora de tensão, em tensão ou na vizinhança de tensão, em instalações eléctricas como por exemplo, ensaios e medições, reparações, substituições, modificações, ampliações, construções e verificações.

2.5.9.2 Trabalho em Tensão (TET)

Trabalho em que o trabalhador entra em contacto com peças em tensão ou entra na zona de trabalho em tensão com partes do seu corpo ou com ferramentas, equipamentos ou com dispositivos que ele manipule.

2.5.9.3 Trabalho fora de tensão (TFT)

Trabalho realizado em instalações eléctricas, após terem sido tomadas todas as medidas adequadas para se evitar o risco eléctrico, e que não estejam nem em tensão nem em carga.

2.5.9.4 Trabalho na vizinhança em Tensão (TVT)

Trabalho em que o trabalhador entra com parte do seu corpo, com uma ferramenta ou qualquer outro objecto que manipule, dentro da zona de vizinhança mas sem entrar na zona de trabalhos em tensão.

2.5.9.5 Trabalho não eléctrico

Trabalho efectuado noutras partes de instalações eléctricas, que não as indicadas no §2.5.9.1; inclui trabalhos, como por exemplo, construções, escavações, limpezas, pinturas, etc.

2.5.9.6 Trabalho de reparação

Trabalho que tem por fim solucionar rapidamente um defeito susceptível de causar danos a pessoas e bens ou ao funcionamento normal de uma parte da instalação de alimentação.

2.5.10 Verificações

Acções destinadas a confirmar se uma instalação está conforme com as disposições previstas.

2.6 DEFINIÇÕES RELATIVAS ÀS DISTÂNCIAS, ZONAS E LOCAIS

2.6.1 Delimitação da zona de trabalhos

Materialização dos limites de uma zona de trabalhos por meio de fita ou correntes delimitadoras, redes, barreiras, … .

2.6.2 Distância mínima de aproximação (D)

Distância mínima no ar, medida em relação a peças condutoras (condutor activo ou qualquer estrutura condutora) cujo potencial seja diferente do potencial do executante, considerado como estando ao potencial da terra, e que é resultado da soma da distância de tensão e da distância de guarda.

Na Média e na Alta Tensão a distância mínima de aproximação representa o limite interior da zona de vizinhança (**D_L**).

2.6.2.1 Distância de tensão (D_T)

Distância no ar, destinada a proteger os trabalhadores contra disrupções que possam ocorrer durante os trabalhos em tensão.

$$D_T = 0{,}005\ Un, \text{ em metros,}$$

em que Un é o valor da tensão nominal em kV.

O resultado é arredondado por excesso para o decímetro mais próximo, nunca inferior a 0,10 m para Un > 1 kV.

Se o operador se encontra a um potencial diferente do da terra, esta distância deve ser modificada em conformidade. Em particular em AT, deve ser aumentada quando for necessário ter em conta fenómenos de sobretensão. Este aumento será definido de acordo com a entidade que explora a instalação.

Em corrente contínua, as distâncias de tensão não estão especificadas. No entanto, para valores de tensão ≤ 1500 V, esta distância é praticamente nula. Para valores superiores de tensão, por prudência, tomam-se as distâncias das tensões alternadas.

2.6.3 Distância de guarda (D_G)

Distância no ar, destinada a libertar o trabalhador da preocupação permanente de manter a distância de tensão e da atenção aos gestos involuntários.

Esta distância toma os seguintes valores:

- 0,30 m para a BT, excepto TR;
- 0,50 m para U_n > 1.000 V.

Para as tensões reduzidas ($U_n \leq 50$ V) a distância de guarda não é considerada.

2.6.4 Distância de vizinhança (D_V)

Distância no ar que define o limite exterior da zona de vizinhança, e é estabelecida em função da tensão (Quadro 2).

Esta distância tem em conta os riscos de contacto ou de escorvamento com peças nuas em tensão, mas não tem em conta os riscos eventuais devidos aos fenómenos de indução a que podem ficar submetidas as instalações sem tensão.

Quadro 2 - Distâncias para os valores nominais de tensão mais frequentes

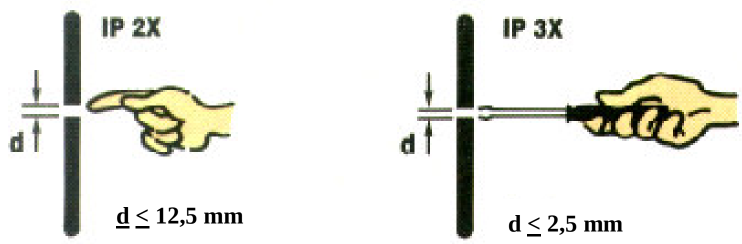
Tensão nominal da rede (U_n) kV (valor eficaz)	Distância de tensão (t) m	Distância de guarda (g) m	Limite exterior de trabalhos em tensão (D_L) ≡ (DMA) m	Distância vizinhança (D_V) m
< 1	0 (sem contacto)	0,30	0,30	0,30 (*)
10	0,10	0,50	0,60	1,5
15	0,10	0,50	0,60	1,5
20	0,10	0,50	0,60	1,5
30	0,20	0,50	0,70	2,0
60	0,30	0,50	0,80	2,0
110	0,50	0,50	1,10	3,0
150	0,80	0,50	1,30	3,0
220	1,10	0,50	1,60	4,0
400	2,00	0,50	2,50	5,0

(*) Na baixa tensão a zona entre a superfície nua da peça em tensão (sem contacto) e a distância de vizinhança (D_V) é considerada:

- Zona de trabalhos em tensão, se não tiverem sido tomadas medidas para afastar ou impedir o contacto com a peça nua em tensão;
- Zona de vizinhança BT, se foram tomadas medidas adequadas para impedir qualquer contacto com a peça nua em tensão.

2.6.5 Locais de acesso reservado a electricistas ∗

Pela designação "local de acesso reservado a electricistas" deve entender-se todo o volume fechado (armário, compartimento, cela,...), podendo conter peças nuas em tensão, cujo grau de protecção, definido pela norma à data em vigor (NPEN 60 529) é inferior ao índice de protecção IP 2X em BT, e IP 3X no domínio AT.



Nota: IP 2 … s com diâmetro igual ou sup…

IP 3X – protecção contra a penetração de objectos sólidos com diâmetro igual ou superior a 2,5 mm.

Os apoios de linhas aéreas que tenham peças nuas em tensão, sempre que haja ascensão, são considerados como locais de acesso reservado a electricistas.

∗ Entenda-se pessoa qualificada para a realização de trabalhos eléctricos

2.6.6 Zona protegida

Em trabalhos fora de tensão (TFT): zona delimitada pelas ligações à terra e em curto-circuito, colocadas entre os pontos de isolamento (separação) e normalmente na proximidade destes;

Em trabalhos em tensão (TET): zona em que todos os elementos da rede têm os seus automatismos programados e as suas protecções reguladas para o regime especial de exploração (REE).

2.6.7 Zona de trabalhos

Local(ais) ou área(s) onde os trabalhos são ou serão realizados. A zona de trabalhos situa-se no interior da zona protegida.

No interior desta zona, que deve estar delimitada, só devem penetrar pessoas autorizadas ou as designadas para o trabalho a efectuar.

2.6.8 Zona de trabalhos em tensão

Espaço em volta das peças em tensão, no qual o nível de isolamento destinado a evitar o perigo eléctrico não é garantido se nele se entrar sem serem tomadas medidas de protecção.

2.6.9 Zona de vizinhança

Espaço delimitado e situado em volta da zona de trabalhos em tensão. A zona de vizinhança fica compreendida entre o limite exterior da zona de trabalhos em tensão (D_L) e o limite exterior da zona de vizinhança (D_V) – ver figura 1.

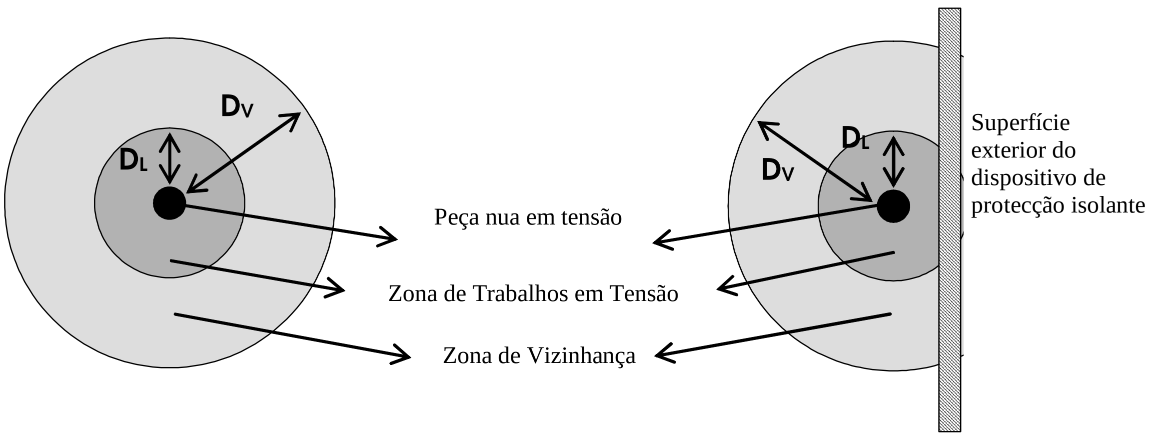


Figura 1

Na baixa tensão, a zona entre a superfície da peça nua em tensão (sem contacto) e a distância mínima de aproximação é considerada zona de trabalhos em tensão, a menos que tenham sido tomadas medidas para afastar ou impedir o contacto com a peça nua em tensão.

2.7 DEFINIÇÕES RELATIVAS AOS DOCUMENTOS ESCRITOS

2.7.1 Autorização para intervenção em tensão (AIT)

Documento escrito, com validade limitada, por meio do qual o responsável pela condução autoriza um responsável de trabalhos – pertencente quer à própria empresa quer a uma empresa exterior – a executar em tensão uma tarefa definida, em condições precisas de data e de lugar, especificando, se for caso disso, as disposições particulares de exploração, nomeadamente a duração previsível.

Excepcionalmente, quando a distância geográfica e as necessidades de exploração o justificarem, a AIT pode tomar a forma de uma mensagem registada do responsável de condução para o responsável de trabalhos. Neste caso, cada correspondente deve preencher um impresso numerado e anotar nele o número de identificação do impresso preenchido pelo outro correspondente, assim como os números de ordem da mensagem.

A autorização para intervenção em tensão fica concluída com o aviso de fim de trabalho em tensão, redigido no mesmo documento. A redacção e a transmissão são efectuadas nas mesmas condições que a autorização de trabalho em tensão.

2.7.2 Autorização para trabalhos não eléctricos

Documento que autoriza, em particular, a execução de trabalhos de natureza não eléctrica em instalações eléctricas ou na sua vizinhança.

É preenchida em dois exemplares, sendo um entregue à pessoa a quem é confiada a direcção dos trabalhos, pelo:

- Responsável pelas instalações (ou pessoa por ele designada) no caso de vizinhança;
- Responsável de consignação, caso haja lugar à consignação para trabalhos;
- Responsável de trabalhos, caso a consignação seja feita no local.

A autorização de trabalho deixa de ser válida a partir do momento da sua restituição, seja a título de interrupção, seja de fim de trabalhos.

2.7.3 Boletim de Consignação

Documento emitido pela entidade responsável pela condução e distribuído ao responsável de consignação e aos delegados de consignação, no qual será efectuado o registo das operações de consignação e das comunicações entre o centro de condução e o responsável de consignação e delegados de consignação, e entre o responsável de consignação e os delegados de consignação.

Neste boletim é feito o registo das comunicações entre o responsável de condução e o responsável de consignação e entre este e os delegados, se existirem.

2.7.4 Boletim de trabalhos/ensaios (fora de tensão)

Documento, em dois exemplares, preenchido pelo responsável de consignação, e entregue cópia ao responsável de trabalhos, atestando que uma instalação se encontra num estado tal que o seu acesso é autorizado para a execução dos trabalhos fora de tensão.

Comporta a data e a hora da consignação, é assinado por ambos, ficando um dos exemplares em poder do responsável de consignação e o outro entregue ao responsável de trabalhos/ensaios.

Excepcionalmente, quando a distância geográfica e as necessidades de exploração o justificarem, o boletim de trabalhos/ensaios pode tomar a forma de uma mensagem registada do responsável de consignação para o responsável de trabalhos/ensaios.

O boletim de trabalhos/ensaios fica concluído com o aviso de fim de trabalhos redigido sobre o mesmo documento e cuja redacção e transmissão são efectuadas nas mesmas condições que o boletim de consignação para trabalhos/ensaios.

O boletim de trabalhos/ensaios perde a validade a partir do momento em que é restituído pelo responsável de trabalhos/ensaios ao responsável de consignação, quer seja a título de interrupção, quer de fim de trabalhos/ensaios.

2.7.5 Licença para intervenção em tensão (LIT)

Documento escrito de carácter permanente, estabelecido pelo responsável de manutenção das instalações, para uso do(s) responsável(eis) de trabalhos, em que são fixadas as operações BT habituais que pelo seu carácter podem ser executadas sem uma autorização para intervenção em tensão.

Para tal, o responsável de manutenção recebe uma lista dos trabalhadores em condições de intervir no âmbito de uma LIT, da própria empresa e das empresas exteriores que podem actuar nas instalações a seu cargo.

2.7.6 Mensagem registada

Comunicação transmitida palavra a palavra pelo emissor ao receptor, via rádio ou telefone, registada por escrito pelos dois, comportando sempre a data, a hora e a identificação dos intervenientes, e relida pelo receptor ao emissor.

Podem também ser utilizados para suporte de emissão o correio electrónico ou fax. Em qualquer dos casos a recepção deve ser sempre confirmada pelo receptor.

2.7.7 Pedido de indisponibilidade

Pedido formulado pela entidade requisitante, normalmente por escrito, à entidade responsável pela condução, para colocar uma instalação ou elemento de rede indisponível com vista à realização de trabalhos ou ensaios fora de tensão.

Em condições excepcionais, se este pedido não puder ser feito por escrito, o mesmo deverá ser feito por mensagem registada entre a entidade requisitante e a entidade responsável pela condução da instalação.

2.7.8 Pedido de intervenção em tensão (PIT)

Documento escrito pelo qual a entidade interessada na realização dos trabalhos dá a conhecer ao responsável pelos trabalhos em tensão na empresa, ou de uma empresa exterior, a sua intenção de lhe confiar a execução de trabalhos em tensão.

Depois de confirmada a exequibilidade do trabalho em tensão, o responsável de manutenção remete ao centro de condução uma cópia do PIT, com a indicação do responsável de trabalhos, para emissão da AIT respectiva.

Um pedido de intervenção em tensão pode ser geral, isto é, válido para um conjunto de trabalhos escalonados num período de tempo limitado ou estabelecido para um trabalho limitado.

2.7.9 Plano/Ordem de manobras

Documento que explicita, segundo a ordem de realização, todos os procedimentos a respeitar para a execução de manobras complexas ou múltiplas. São exemplo as ordens de manobras para a realização de consignações ou de desconsignações.

A ordem de manobras constitui um elemento fundamental na preparação de consignações.

2.7.10 Plano de prevenção

Documento escrito, estabelecido pelo empregador para uso do responsável de trabalhos, que fixa, para um ou para diversos tipos de trabalhos (fora de tensão, em tensão ou na vizinhança) habituais ou repetitivos:

- Os riscos mais frequentes;
- As condições de execução, incluindo as medidas de prevenção;
- As condições relativas ao pessoal (designação, habilitação, vigilância);
- As condições relativas aos equipamentos e às ferramentas.

Em certos casos, o plano de prevenção é estabelecido quando da preparação do trabalho.

2.7.11 Ordem de trabalho escrita

Documento que precisa a natureza, a situação e a duração do trabalho a realizar.

Todos os documentos necessários à compreensão dos trabalhos a realizar são entregues ao responsável de trabalho.

2.8 DEFINIÇÕES QUANTO ÀS CONDIÇÕES ATMOSFÉRICAS

2.8.1 Nevoeiro espesso

Considera-se que há nevoeiro espesso quando a visibilidade é reduzida de forma perigosa para a segurança do executante, nomeadamente quando o responsável de trabalhos não pode distinguir nitidamente os executantes do seu grupo ou os condutores sobre os quais estes deverão intervir.

2.8.2 Precipitações atmosféricas

Considera-se que há precipitação atmosférica quando há queda de chuva, de neve ou granizo ou a presença de brumas, neblina ou gelo.

A precipitação atmosférica diz-se pouco importante quando não perturba a visibilidade do executante e do responsável de trabalhos. Diz-se importante no caso contrário.

2.8.3 Trovoada

Considera-se que há trovoada quando houver:

- Percepção de relâmpagos;
- Ou percepção de trovões.

2.8.4 Vento violento

Considera-se que há vento violento se implicar uma insuficiente precisão do executante na utilização das suas ferramentas, ou torne impraticável a utilização dos meios necessários à execução do trabalho.

3. TRABALHOS FORA DE TENSÃO

3 — TRABALHOS FORA DE TENSÃO

Este capítulo trata das prescrições essenciais para assegurar que a instalação eléctrica, na zona de trabalhos, fica fora de tensão e assegurar que esta condição se mantém durante a realização dos trabalhos.

3.1 PRINCÍPIOS FUNDAMENTAIS DA CONSIGNAÇÃO ELÉCTRICA DE UMA INSTALAÇÃO PARA A REALIZAÇÃO DE TRABALHOS FORA DE TENSÃO

→ Após a identificação clara das instalações eléctricas afectadas pelo trabalho, devem ser observadas as seguintes regras essenciais:

1. **Separar completamente** (isolar a instalação de todas as possíveis fontes de tensão);
2. **Proteger contra religações** (bloquear na posição de abertura todos os órgãos de corte ou seccionamento, ou adoptar medidas preventivas quando tal não seja exequível);
3. **Verificar a ausência de tensão**, depois de previamente identificada no local de trabalho a instalação colocada fora de tensão;
4. **Ligar à terra e em curto-circuito**;
5. **Proteger contra as peças em tensão adjacentes e delimitar a zona de trabalho.**

Em certos casos a verificação da ausência de tensão é necessária para a identificação da instalação.

3.1.1 Separar (isolar) a instalação das fontes de tensão

→ Esta separação deve ser efectuada por meio dos órgãos previstos para este efeito, em todos os condutores activos, incluindo o neutro (contudo, em BT, no caso do esquema TNC (terra e neutro comuns) o neutro não deve ser interrompido).

A separação deve ser visível ou com garantia de que a operação foi efectivamente realizada; por exemplo, a abertura de arcos ou o retirar de fusíveis constituem formas correctas de isolamento.

→ A confirmação do isolamento, que deve ser sempre feita, pode ser obtida de várias maneiras:

- Por observação directa da abertura dos contactos;
- Pelo retirar das peças de contacto;
- Pela interposição de anteparos entre os contactos.

→ Nos aparelhos em que o corte efectivo não pode ser visível, a confirmação deve ser feita:

- Localmente, pela posição de cada contacto móvel dos dispositivos de seccionamento, sinalizada por um dispositivo indicador fiável (*), por exemplo:
  - A indicação do estado de abertura dos contactos do aparelho;
  - A elevação das hastes dos contactos.
- Por telecomando, na condição de que o receptor local da informação da posição dos contactos responda à condição da alínea anterior e que a transmissão da informação (sinalização óptica, telessinalização,...) seja fiável.

→ Em BT a certeza da separação pode ser igualmente obtida pela utilização dos seguintes dispositivos de seccionamento: seccionadores, bornes de ligação dos aparelhos amovíveis, porta-fusíveis de corta-circuitos, fichas e tomadas especialmente concebidas para este fim,....

→ As partes da instalação que possam ficar com tensão residual após terem sido desligadas da rede, como os condensadores e cabos, devem ser descarregadas por meio de dispositivos próprios.

3.1.2 Proteger contra religações ou Bloquear na posição de abertura

→ O bloqueio (ou encravamento) tem por objectivo impedir a manobra dos órgãos de isolamento. Consta de:

a) Imobilização do órgão de corte ou seccionamento

Esta imobilização é realizada por bloqueio mecânico ou outro equivalente que ofereça as mesmas garantias e deve neutralizar todos os comandos, locais ou à distância, assim como, se necessário, desligar as fontes auxiliares de energia necessárias para o seu funcionamento.

b) Sinalização

Os comandos locais ou à distância dum órgão de corte ou seccionamento assim bloqueado devem conter uma indicação, sinal ou qualquer outro tipo de registo, referindo explicitamente que este órgão está bloqueado e não deve ser manobrado.

Quando não existirem ou não for possível imobilizar os órgãos de manobra, as placas ou outros dispositivos de aviso (eléctricos, mecânicos,...) constituem a protecção mínima obrigatória de interdição de manobra.

As placas de aviso devem ser bem visíveis e explícitas, como por exemplo:

ATENÇÃO Bloqueado por motivo de trabalhos **PROIBIDO MANOBRAR** **Nome:** **Contacto:**

(*) *Com eficácia comprovada pela Direcção Geral de Energia (§ 2.º do art.º 38.º do Decreto Regulamentar 56/85, de 6 de Setembro).*

Quando forem usados dispositivos de controlo remoto para proteger contra a religação, a sua manobra deve ficar inibida.

3.1.3 Verificar a ausência de tensão

Antes de efectuar a verificação de ausência de tensão, deve ser feita a identificação da instalação confirmar que os trabalhos serão efectuados na instalação ou parte da instalação previamente separada e bloqueada

3.1.3.1 Identificar a instalação no local de trabalho

→ A identificação pode ser obtida pela combinação de diversos processos, por exemplo:

- O conhecimento da localização geográfica da instalação;
- A consulta de esquemas ou cartas geográficas actualizados;
- O conhecimento das instalações e das suas características;
- A leitura das chapas de avisos, etiquetas, números dos apoios, etc.;
- A identificação visual, quando se pode seguir a linha ou o cabo desde o lugar onde foi realizado o corte visível ou a ligação à terra e em curto-circuito até à zona de trabalhos;
- Para os cabos, a identificação com a utilização de um aparelho especial (por exemplo, injectando uma frequência particular) ou, na sua falta, obrigatoriamente por um meio destrutivo (por exemplo com o pica-cabos);

Nota: o cabo, depois de ser identificado por meios não destrutivos e antes de ser cortado, deverá ser obrigatoriamente picado com o pica-cabos.

→ Uma vez feita a identificação deve ser colocada uma marcação sobre a instalação identificada, a menos que as ligações à terra e em curto-circuito sejam visíveis de qualquer ponto na zona de trabalhos ou que não exista qualquer risco de confusão.

A forma de identificação deve constar da preparação do trabalho

3.1.3.2 Verificar a ausência de tensão (VAT)

→ A ausência de tensão deve ser verificada em todos os condutores activos, o mais próximo possível do local de trabalho e precederá sempre o estabelecimento das ligações à terra e em curto-circuito. Para a verificação da ausência de tensão:

- Utilizar um "detector de tensão" adequado à tensão de serviço;

  1.º Imediatamente antes de proceder à verificação confirmar o bom funcionamento do detector;

  2.º Proceder à verificação da ausência de tensão actuando como se a instalação estivesse em tensão, respeitando por isso as distâncias de segurança e usando o equipamento de protecção adequado;

  3.º Imediatamente após a operação confirmar o bom funcionamento do detector.

Em certas instalações, a verificação directa da ausência de tensão não é possível (material protegido, por exemplo). Neste caso são aplicadas as disposições particulares que devem ser indicadas pelo fabricante do material.

3.1.4 Ligar à terra e em curto-circuito

A ligação à terra e em curto-circuito não é permitida sem ser precedida da verificação da ausência de tensão

→ A ligação à terra e em curto-circuito, que deve ser feita imediatamente após a verificação da ausência de tensão, visa:

- Manter a instalação sem tensão depois de se ter verificado a ausência de tensão;
- Proteger contra:
  - Manobras intempestivas que possam pôr a instalação em tensão;
  - Realimentações provenientes de fontes autónomas;
  - Tensões indutivas, induzidas residuais e capacitivas;
  - Descargas atmosféricas.

→ Os equipamentos e dispositivos a utilizar para ligação à terra e em curto-circuito devem ser adequados e de secção apropriada para a corrente máxima de curto-circuito no local, e devem ser ligados primeiro ao ponto de ligação à terra e só depois às peças a ligar à terra.

A vareta de terra deve ser implantada no solo afastada da base de apoio e do local onde permaneçam pessoas, para evitar o perigo da tensão de passo.

→ As ligações à terra e em curto-circuito devem ser efectuadas o mais próximo possível do local de trabalho, de um e de outro lado da zona de trabalhos, e pelo menos uma das ligações à terra e em curto-circuito deve ser visível a partir do local de trabalho.

→ Nos cabos isolados ou linhas aéreas em condutores isolados, as ligações à terra e em curto-circuito são efectuadas nas partes nuas acessíveis nos pontos de separação do lado onde vão ser realizados os trabalhos, ou o mais próximo possível de um lado e de outro da zona de trabalhos. Com efeito, na maior parte dos casos as ligações à terra e em curto-circuito não podem ser feitas no local de trabalho.

→ Nas linhas aéreas de BT e AT em condutores nus e para uma zona de trabalhos pontual, se não houver interrupção dos condutores durante a realização do trabalho, admite-se que no local de trabalho seja efectuada apenas uma única ligação à terra e em curto-circuito.

→ Se durante um trabalho os condutores tiverem de ser cortados ou serem separadas fisicamente partes da instalação, devem ser previamente tomadas as medidas indispensáveis e apropriadas para assegurar as continuidades das ligações à terra e em curto-circuito.

→ Quando se prevejam fenómenos de indução significativos adoptar-se-ão medidas complementares de segurança, tais como:
  - A ligação à terra em intervalos adequados ou nos pontos de cruzamento com outras linhas, de forma a reduzirem-se os potenciais induzidos a níveis seguros;
  - Ligações equipotenciais no local de trabalho, de forma a evitar que os trabalhadores se insiram numa malha de indução perigosa.

  Estas medidas adicionais deverão ser previstas pela entidade que programa o trabalho, verificadas pelo responsável/delegado(s) de consignação e implementadas pelo responsável de trabalhos, excepto nos locais coincidentes com ligações à terra e em curto-circuito efectuadas pela consignação.

→ Em instalações de baixa tensão as ligações à terra e em curto-circuito são exigidas se houver:
  - Risco de tensões induzidas provocadas pela proximidade com linhas aéreas AT;
  - Risco de poderem ser realimentadas, nomeadamente por um gerador de reserva;
  - Presença de condensadores ou de cabos de grande comprimento;
  - Cruzamento com outras linhas aéreas em condutores nus.

→ Nas linhas aéreas de baixa tensão em condutores nus com o neutro directamente ligado à terra em diferentes pontos, é admissível que seja feita apenas a ligação em curto-circuito de todos os condutores.

3.1.5 Proteger contra as peças em tensão adjacentes e Delimitar a zona de trabalhos

→ Se existirem peças de uma instalação eléctrica na vizinhança do local de trabalhos que não possam ser postas fora de tensão, devem ser tomadas medidas de precaução adicionais antes do início do trabalho (trabalho na vizinhança de tensão).

→ A delimitação no local de trabalho, feita pelo responsável de trabalhos, ou sob a sua responsabilidade, tem por objectivo impedir o acesso indevido às zonas de perigo e, simultaneamente, encaminhar as pessoas para a zona de trabalhos, sendo, nomeadamente, obrigatória:
  - Quando nas proximidades do local de trabalho existem peças nuas ou outros equipamentos em tensão, ou susceptíveis de ficar em tensão;
  - Quando os trabalhos se realizam na via pública ou em locais com acesso de público.

  Consiste em balizar em comprimento, largura e altura – por meio de fita ou correntes delimitadoras, redes, anteparos, barreiras, etc. – e sinalizar com os sinais de perigo e de advertência adequados.

3.2 ATRIBUIÇÕES BÁSICAS NO ÂMBITO DA CONSIGNAÇÃO ELÉCTRICA DE UMA INSTALAÇÃO

As atribuições específicas para a consignação numa rede de determinada actividade (distribuição, transporte,...) devem ser estabelecidas através do respectivo regulamento de consignações.

3.2.1 Entidade Requisitante

→ A entidade interessada na realização de trabalhos fora de tensão (entidade requisitante) elabora o pedido de indisponibilidade, identificando as instalações ou partes de instalação a intervencionar ou a consignar, com indicação da localização, data e duração prevista para a realização de trabalhos fora de tensão, e dirigi-lo à entidade responsável pela condução.

- Indica o responsável de consignação e delegados de consignação à entidade responsável pela condução, que serão nomeados por esta, salvo se outro procedimento for acordado.
- Nomeia o responsável de trabalhos, da EDP ou do prestador de serviços, bem como as medidas de segurança complementares que irá tomar.
- Substitui o responsável de trabalhos nomeado, apenas em casos de reconhecida necessidade e com conhecimento imediato à entidade responsável pela condução.

3.2.2 Entidade Responsável pela Condução

→ Recebido o pedido de indisponibilidade, compete à entidade responsável pela condução analisar a sua conformidade.

- Coordena o processo de consignação;
- Elabora a documentação necessária ao processo de consignação, incluindo a ordem de manobras;
- Nomeia o responsável e delegados de consignação;
- Passa a responsabilidade do elemento de rede ou instalação ao responsável de consignação.

3.2.3 Responsável de Consignação

→ O responsável de consignação recebe da entidade responsável pela condução o processo de consignação do elemento de rede ou instalação para consignar.

Executa ou confirma as manobras de isolamento e bloqueio dos aparelhos que delimitam a instalação a consignar, de acordo com a ordem de manobras, e estabelece as medidas de segurança consideradas necessárias.

→ A identificação no local, a verificação da ausência de tensão, a ligação à terra e em curto-circuito e a delimitação são realizadas:

- Pelo responsável de consignação, ou sob a sua responsabilidade no caso da consignação visar a criação de uma zona protegida;
- Ou pelo responsável de trabalhos no local de trabalhos.

No caso de trabalhos em cabos subterrâneos, o responsável de consignação deve identificar o cabo na presença do responsável de trabalhos.

→ No boletim de trabalhos/ensaios o responsável de consignação preenche a data e a hora da consignação e assina-o, em dois exemplares, atestando que o elemento de rede ou a instalação se encontra em condições de iniciar o trabalho, logo que seja dada a devida autorização.

Um dos exemplares fica em poder do responsável de consignação, sendo o outro entregue ao responsável de trabalhos/ensaios.

A cada responsável de trabalhos/ensaios deve ser passado obrigatoriamente um boletim de trabalhos.

→ Quando a distância geográfica e as necessidades de exploração o justificarem, o boletim de trabalhos pode tomar a forma de uma mensagem registada do responsável de consignação para o responsável de trabalhos.

→ A aplicação de medidas complementares como por exemplo colocação de anteparos e ligação à terra suplementar, pode ser realizada por iniciativa do responsável de trabalhos ou por indicação do responsável de consignação.

→ No caso de trabalhos efectuados por uma empresa exterior, os acordos estabelecidos previamente devem definir se o responsável de consignação executa/confirma:

- A totalidade das operações da consignação;
- Ou as duas primeiras operações, sendo as restantes realizadas pelo responsável de trabalhos da empresa exterior.

Os acordos prévios originam sempre uma troca de documentos ou de mensagens.

→ Para evitar erros nas operações de consignação ou de desconsignação duma instalação ou duma parte da instalação, deve ser designado um único responsável pela consignação ainda que intervenham vários responsáveis de trabalhos.

→ Sempre que se justifique poderão existir vários delegados de consignação coordenados por um responsável de consignação.

→ As atribuições do responsável de consignação e do responsável de trabalhos podem ser asseguradas por uma mesma pessoa. Neste caso não haverá estabelecimento nem transmissão do boletim de trabalhos.

Desconsignação

→ Após a recepção do(s) aviso(s) de fim de trabalhos, o responsável de consignação estabelece com o centro de condução o início das manobras de desconsignação:

- Garante a retirada dos anteparos, protectores e materiais de sinalização colocados por sua iniciativa;
- Assegura a abertura dos seccionadores ou interruptores de ligação à terra e em curto-circuito que ele próprio tenha fechado e retira ou manda retirar os

dispositivos de ligação à terra e em curto-circuito que eventualmente tenham sido colocados;

- Devolve o elemento de rede ou instalação à entidade responsável pela condução.

> Nenhuma instalação pode ser reposta em tensão enquanto o aviso de fim de trabalhos não for entregue ou transmitido pelo responsável de trabalhos ao responsável de consignação

3.2.4 Responsável de Trabalhos

→ O responsável de trabalhos deve receber uma cópia do Boletim de Trabalhos do responsável de consignação e, depois de autorizado por este, dar início às operações que lhe são confiadas.

Na preparação do trabalho, o responsável de trabalhos deve assegurar-se que:

- O trabalho foi claramente definido e que todos os riscos, eléctricos ou não, nomeadamente de vizinhança ou de indução foram devidamente analisados;
- Os executantes possuem a qualificação adequada aos trabalhos;
- Os executantes possuem os equipamentos de protecção individual e colectiva necessários.

Antes de iniciar o trabalho, o responsável de trabalhos deve:

- Confirmar a realização das manobras, bloqueios e outras medidas de segurança mandadas executar pelo responsável de consignação ou delegado de consignação, só as podendo alterar com a autorização destes;
- Receber do responsável de consignação a autorização para dar início aos trabalhos (expressa na entrega do boletim de trabalhos ou através de uma mensagem registada);
- Identificar a instalação;
- Verificar a ausência de tensão e, salvo indicações contrárias, proceder imediatamente a ligação à terra e em curto-circuito, no caso em que estas operações lhe estão atribuídas;
- Efectuar a delimitação da zona de trabalho;

  Para tal, utiliza todos os meios adequados, tais como o limite físico das instalações, anteparos e outros meios de balizagem, em todos os planos em que seja necessário;

  Os dispositivos de ligação à terra e em curto-circuito quando aplicados nas redes aéreas de condutores nus podem contribuir para definir o limite da zona de trabalhos;
- Informar os executantes da natureza dos trabalhos, das medidas de segurança tomadas, das precauções a respeitar, dos limites da zona de trabalho, do ponto de encontro em caso de interrupção do trabalho e do fim do trabalho;

> Nenhum trabalho fora de tensão pode ser iniciado sem que a referida autorização seja dada pelo responsável de consignação

Durante os trabalhos, o responsável de trabalhos deve:

- Zelar pela aplicação das medidas de segurança;
- Assegurar a vigilância dos executantes, em particular nas fases de maior risco;
- Zelar pela boa execução do trabalho;
- Zelar pela boa utilização das ferramentas e dos equipamentos de segurança.

No caso de interrupção temporária dos trabalhos, o responsável de trabalhos deve:

- Dar aos executantes a ordem de interrupção dos trabalhos e de reunião no ponto combinado;
- Tomar as medidas para garantir a segurança da zona de trabalhos relativamente a terceiros;
- Interditar aos executantes qualquer acesso à zona de trabalhos até que seja dada ordem em contrário.

No recomeço dos trabalhos, o responsável de trabalhos deve:

- Certificar-se que as medidas de segurança inicialmente tomadas continuam válidas e confirmá-las;
- Dar ordem de recomeço dos trabalhos.

No fim dos trabalhos, o responsável de trabalhos deve:

- Certificar-se da boa execução dos trabalhos e da recolha de todas as ferramentas e materiais sobrantes;
- Reagrupar o pessoal no ponto combinado e comunicar a interdição definitiva de acesso à zona de trabalhos;
- Retirar os equipamentos de ligação à terra e em curto-circuito e os dispositivos de sinalização das ligações à terra e em curto-circuito que tenham sido colocados;
- Retirar os equipamentos de delimitação da zona de trabalhos;
- Assinar e devolver ao responsável de consignação o Boletim de Trabalhos, ficando com uma cópia.

3.2.5 Atribuições do executante

O executante zela pela sua própria segurança

→ O executante deve:

- Seguir as instruções do responsável de trabalhos;
- Respeitar os limites da zona de trabalhos que lhe foram definidos e os dispositivos de segurança colocados no interior dessa zona;
- Utilizar os equipamentos de protecção individual;

- Utilizar ferramentas adequadas ao trabalho a executar;
- Respeitar as características técnicas dos equipamentos e as regras de segurança e da técnica aplicáveis a cada tarefa;
- Verificar as ferramentas e equipamentos antes e após a sua utilização.

O executante só pode iniciar o trabalho depois de receber ordem para isso

3.3 TRABALHOS COM PRESENÇA DE TENSÕES INDUZIDAS

3.3.1 Generalidades

→ Um condutor próximo de um ou mais condutores em tensão pode possuir uma determinada tensão, por influência eléctrica, em particular em caso de existência de um paralelismo bastante longo dos dois condutores ou em caso de defeito

Estes fenómenos podem produzir-se quer numa instalação colocada fora de tensão, quer numa instalação em construção e criam tensões que podem dar origem a correntes não negligenciáveis em malhas constituídas pelos próprios condutores, ligações à terra e com retorno pelo solo.

→ A protecção contra o risco de tensão ou corrente induzidas, nomeadamente quando os trabalhos implicam a abertura de arcos, deve ser feita na zona de trabalhos:

- Com a utilização de dispositivos de ligação à terra complementares àqueles já colocados no quadro da consignação,
- Ou utilizando os métodos e ferramentas adaptados aos Trabalhos em Tensão, sem prejuízo das ligações à terra colocadas a montante e jusante para a criação de uma zona protegida dentro do quadro da consignação.

→ A escolha da protecção a aplicar deve resultar de um acordo entre o responsável da instalação objecto dos trabalhos e o responsável da instalação mantida em serviço, em função:

- Do tipo de trabalho a efectuar;
- Da competência e dos meios materiais do pessoal interveniente;
- Dos níveis possíveis de tensão induzida.

3.3.2 Condições gerais de execução dos trabalhos

→ Para além das operações de consignação indicadas no § 3.1, deverão tomar-se, no caso de trabalhos submetidos a uma tensão induzida as precauções complementares abaixo definidas:

3.3.2.1 Caso das canalizações eléctricas isoladas BT e AT

→ É necessário ligar à terra e em curto-circuito os condutores e as armaduras metálicas dos cabos, quando existam, o mais próximo possível da zona de trabalho.

Os cabos isolados cuja armadura metálica está em contacto com o solo ou que são ligados à terra nas extremidades não são normalmente sede de tensão induzida.

3.3.2.2 Caso das linhas aéreas BT e AT em condutores nus

São necessárias medidas rigorosas para assegurar em permanência:

A) O escoamento das correntes induzidas ou resultantes de um defeito eventual

A zona de trabalhos deve ser delimitada pela colocação de terras o mais próximo possível do local onde se desenvolvem os trabalhos.

B) A equipotencialidade da zona de trabalhos

Os executantes nunca se devem colocar entre duas peças condutoras, incluindo o solo e a massa dos suportes metálicos, susceptíveis de ficarem submetidos a potenciais diferentes.

Assegurar previamente uma ligação equipotencial entre estas peças tomando todas as precauções necessárias para evitar aquela situação.

C) A continuidade eléctrica das malhas criadas.

Os condutores, as ligações à terra e o solo criam anéis dentro dos quais circulam correntes induzidas importantes. A abertura de um arco num destes anéis deve ser precedido pela ligação de um dispositivo *shunt* para manter a continuidade.

3.4 CONDIÇÕES ATMOSFÉRICAS

→ Em caso de trovoada (aparecimento de relâmpagos, ou percepção do trovão) nenhum trabalho deve ser começado nem acabado na rede ou nas instalações, tanto interiores como exteriores, se forem alimentadas por uma linha aérea em condutores nus.

→ Para as instalações exteriores:

- Em caso de vento violento que torne impraticável a utilização dos meios necessários à execução do trabalho, os trabalhos não devem ser começados nem acabados;
- Em caso de precipitações atmosféricas importantes, nevoeiro espesso, que impeçam a vigilância do responsável de trabalhos:
  - ↘ Nas linhas aéreas nuas ou isoladas o trabalho não deve ser começado, mas a operação em curso pode ser acabada;
  - ↘ Em canalizações subterrâneas os trabalhos só podem ser iniciados ou acabados se o local de trabalhos estiver abrigado da precipitação, da passagem de águas, e suficientemente iluminado.

→ Em instalações interiores alimentadas exclusivamente por uma rede subterrânea ou aérea em condutores isolados, nenhuma restrição é preconizada.

3.5 TRABALHOS NÃO ELÉCTRICOS

→ Dentro do quadro de procedimentos dos trabalhos fora de tensão, os trabalhos não eléctricos podem ser executados, no âmbito de uma autorização para trabalhos não eléctricos, de acordo com as prescrições seguintes:

A) Foram eliminados todos os riscos eléctricos de contacto e de vizinhança

Os trabalhos não eléctricos podem ser executados sem prescrições complementares.

B) Os riscos de contacto foram suprimidos mas ainda restam riscos eléctricos de vizinhança

Neste caso, a associação das disposições do presente capítulo e as do capítulo 5, aplicáveis a trabalhos não eléctricos, conduzem às disposições seguintes:

- O pessoal não qualificado deve trabalhar sob as ordens de um responsável de trabalhos qualificado, que deve assegurar a vigilância permanente de todos os membros da equipa que dirige;
- A vigilância permanente pode não ser necessária se a totalidade do pessoal que vai efectuar o trabalho não eléctrico está instruída sobre o risco eléctrico (o que pressupõe que o pessoal tem formação adequada que lhe permite zelar pela sua própria segurança dentro das condições particulares da instalação).
- Antes de iniciar os trabalhos o responsável de trabalhos deve receber do responsável de consignação a autorização de início de trabalhos (através da entrega do boletim de trabalhos ou duma mensagem registada) e tomar as medidas correspondentes à sua responsabilidade;

→ No fim dos trabalhos o responsável de trabalhos restitui a autorização para trabalhos não eléctricos.

4. TRABALHOS EM TENSÃO

4 — TRABALHOS EM TENSÃO

4.1 CASOS EM QUE O TRABALHO PODE SER EXECUTADO EM TENSÃO

→ Os trabalhos em tensão podem ser executados, de acordo com a regulamentação vigente nas redes de distribuição e de transporte, nas instalações de produção e seus anexos, bem como nas instalações de edifícios e de utilização:

- Por razões de exploração ou de utilização;
- Se a natureza das operações ou as condições de exploração tornam perigosa ou impossível a colocação fora de tensão;
- Se a natureza do trabalho requer a presença de tensão.

→ São aplicadas as prescrições estabelecidas:

- No presente Capítulo 4 – Trabalhos em Tensão;
- Nas Condições de Execução do Trabalho (CET);
- Nas Fichas Técnicas e Modos Operatórios (FT e MO);
- Nos Processos Operatórias (PO), quando existam.

4.2 DEFINIÇÕES (RECAPITULAÇÃO DO CAPÍTULO 2)

4.2.1 Pedido de intervenção em tensão (PIT)

→ Documento escrito pelo qual a entidade interessada na realização dos trabalhos dá a conhecer ao responsável pelos trabalhos em tensão na empresa, ou de uma empresa exterior, a sua intenção de lhe confiar a execução de trabalhos em tensão.

Depois de confirmada a exequibilidade do trabalho em tensão, o responsável de manutenção remete ao centro de condução uma cópia do PIT, com a indicação do responsável de trabalhos, para emissão da AIT respectiva.

Um pedido de intervenção em tensão pode ser geral, isto é, válido para um conjunto de trabalhos escalonados num período de tempo limitado ou estabelecido para um trabalho limitado.

Todo o trabalho em tensão deve ser precedido de um pedido de intervenção escrito

4.2.2 Licença para intervenção em tensão (LIT)

→ Documento escrito de carácter permanente, estabelecido pelo responsável de manutenção das instalações, para uso do(s) responsável(eis) de trabalhos, em que são fixadas as operações BT habituais que pelo seu carácter podem ser executadas sem uma autorização para intervenção em tensão.

Para tal, o responsável de manutenção recebe uma lista dos trabalhadores em condições de intervir no âmbito de uma LIT, da própria empresa e das empresas exteriores que podem actuar nas instalações a seu cargo.

4.2.3 Autorização para intervenção em tensão (AIT)

→ Documento escrito, com validade limitada, por meio do qual o responsável de condução autoriza um responsável de trabalhos – pertencente quer à própria empresa quer a uma empresa exterior – a executar em tensão uma tarefa definida, em condições precisas de data e de lugar, especificando, se for caso disso, as disposições particulares de exploração, nomeadamente a duração previsível.

Excepcionalmente, quando a distância geográfica e as necessidades de exploração o justificarem, a AIT pode tomar a forma de uma mensagem registada do responsável de condução para o responsável de trabalhos. Neste caso, cada correspondente deve preencher um impresso numerado e anotar nele o número de identificação do impresso preenchido pelo outro correspondente, assim como os números de ordem da mensagem.

A autorização para intervenção em tensão fica concluída com o aviso de fim de trabalho em tensão, redigido no mesmo documento. A redacção e a transmissão são efectuadas nas mesmas condições que a autorização de trabalho em tensão.

4.2.4 Regime especial de exploração (REE)

→ Situação em que é colocado um elemento de rede ou uma instalação durante a realização de trabalhos em tensão, a fim de diminuir as consequências de um eventual incidente e de evitar reposições de tensão automáticas ou voluntárias no seguimento do disparo das protecções.

As disposições a tomar em cada caso são as indicadas nas condições de execução do trabalho (CET).

4.3 PRESCRIÇÕES A RESPEITAR PARA TRABALHAR EM TENSÃO

4.3.1 Generalidades

→ Para trabalhar em tensão – isto é, para trabalhar sobre peças nuas em tensão dentro das distâncias mínimas de aproximação que são definidas no § 2.6.2 – o trabalhador deve prevenir-se contra os riscos de electrização e de curto-circuito face às peças nuas em tensão onde vai intervir e face às peças nuas a um potencial diferente do seu.

As prescrições adiante definidas visam os trabalhos efectuados em tensão (TET), sejam de construção, exploração ou conservação de instalações, e qualquer que seja o nível de tensão.

→ São excluídos do domínio da aplicação das prescrições TET:

- Os trabalhos na proximidade de peças nuas em tensão ou de linhas eléctricas em tensão previstas no Capítulo 5;

- As intervenções de reparação de avarias em equipamentos do domínio BT, as intervenções de ligação na presença de tensão 400/230 V e as manobras, medições, ensaios e verificações que devem ser efectuados conforme os Capítulos 6 – Intervenções particulares nos domínios da Alta e da Baixa Tensão e 7 – Manobras, Medidas, Ensaios e Verificações;
- A ligação e desligação de peças de órgãos amovíveis especialmente concebidos e realizados de maneira a permitir a operação sem risco de curto-circuito ou de contacto involuntário com as peças nuas em tensão;
- Os trabalhos fora de tensão na presença de tensões induzidas, previstos no § 3.4.

4.3.2 Métodos de trabalho

→ Distinguem-se três métodos de trabalho conforme a posição do executante em relação às peças em tensão e aos meios que utiliza para se prevenir contra riscos de electrização e de curto-circuito:

Trabalho ao contacto

Neste método o executante penetra na zona situada entre as peças em tensão e a distância mínima de aproximação definida no § 2.6.2 e trabalha em contacto directo com as peças em tensão, protegendo-se destas com equipamentos de protecção (luvas isolantes, protectores isolantes,...) dotados de isolamento adequado ao nível de tensão das peças em que está a intervir.

Trabalho à distância

Neste método, o executante mantém permanentemente uma distância igual ou superior à distância mínima de aproximação entre as suas mãos, ou qualquer outra parte do corpo, e as peças em tensão e trabalha com o auxílio de ferramentas fixadas na extremidade de tubos, varas ou cordas dotados de isolamento adequado ao nível de tensão das peças em que está a intervir.

Trabalho ao potencial

Neste método, o executante realiza o seu trabalho em contacto eléctrico com a peça em tensão, após se ter intencionalmente colocado ao potencial dessa peça e estar convenientemente isolado em relação às peças adjacentes a potenciais diferentes do seu.

Durante a transição do potencial das massas para o potencial das peças em tensão e vice-versa, o executante não está ligado a nenhum potencial fixo, pelo que está a potencial flutuante.

Estes métodos podem ser utilizados separadamente ou em combinação no decurso de um determinado trabalho, designando-se este procedimento por **combinação dos 3 métodos** (C3M) ou **método global**.

4.3.3 Condições de execução do trabalho, fichas técnicas e modos operatórios

→ As condições de execução do trabalho (CET) definem as regras gerais a respeitar para a realização de trabalhos em tensão, nomeadamente:

- Regras do relacionamento entre o responsável de exploração e o responsável de trabalhos;
- Metodologias segundo as quais o trabalho deve ser preparado;

- Ferramentas a utilizar;
- Verificação da boa execução do trabalho;
- Regras relativas às condições atmosféricas;
- Regras relativas aos regimes especiais de exploração (REE).

→ Os trabalhadores a quem são confiados trabalhos em tensão devem dispor, nomeadamente, de equipamentos e ferramentas especialmente concebidos e do equipamento de protecção necessário à sua segurança.

As fichas técnicas (FT) e os modos operatórios (MO), relativos a cada tipo de material, equipamento ou ferramenta, indicam as suas características e respectivas condições de utilização. As FT devem indicar com precisão as condições de conservação, de manutenção, de transporte e de controlo de equipamentos e ferramentas.

4.3.4 Formação e habilitação

→ Só podem realizar trabalhos em tensão trabalhadores devidamente habilitados e possuidores dum título de habilitação.

→ Em partes do trabalho que podem ser executados fora de tensão ou na vizinhança, e para as operações de manutenção, o trabalhador com a habilitação T pode ser auxiliado por trabalhadores qualificados para a realização de trabalhos fora de tensão ou na vizinhança, consoante o caso.

→ No entanto, esses trabalhadores não podem em nenhuma circunstância entrar na zona de trabalhos em tensão.

4.4 HABILITAÇÃO PARA TRABALHOS EM TENSÃO

4.4.1 Condições para atribuição dum título de habilitação

→ A atribuição dum título de habilitação pressupõe o prévio reconhecimento de que o trabalhador possui a competência técnica e humana relativamente às precauções a tomar para prevenir os acidentes de origem eléctrica ou outros associados à execução dos trabalhos ou tarefas que lhe são confiadas.

Competência técnica

→ A competência técnica, adquirida na formação, comporta conhecimentos relativos a:
- Métodos de trabalho que permitem efectuarem em tensão os trabalhos que lhe são confiados.
- Instalações e equipamentos eléctricos em que actuará;
- Riscos da electricidade;
- Regras de segurança para prevenir esses riscos;
- Métodos de trabalho em tensão;
- Procedimento a adoptar em caso de acidente eléctrico;
- Medidas de segurança para prevenir outros riscos ligados à sua actividade normal e ao seu habitual ambiente de trabalho.

→ Os responsáveis pela formação teórica e prática devem no final da mesma formular uma apreciação sobre a aptidão da pessoa para pôr em prática as regras e procedimentos para prevenção do risco eléctrico.

→ Os programas devem comportar exercícios realmente executados em tensão.

Aptidão médica

→ O reconhecimento sobre a não existência de impedimentos de natureza médica que impeçam o trabalhador de realizar as tarefas que lhe vão ser confiadas é obtido através da Ficha de Aptidão médica emitida pela Medicina do Trabalho.

Adequação humana

→ A adequação humana deverá reconhecer o equilíbrio comportamental compatível com a boa execução dos trabalhos que lhe podem ser confiados.

4.4.2 Atribuição do Título de Habilitação

→ Face aos antecedentes de cada trabalhador e aos requisitos enumerados nos parágrafos anteriores, o empregador, ou por delegação o responsável pela unidade organizativa a que o trabalhador pertence, está em condições de decidir sobre a atribuição do título de habilitação.

→ A atribuição dum título de habilitação implica que o trabalhador seja informado sobre as responsabilidades inerentes a essa habilitação.

4.4.3 Códigos da habilitação para trabalho em tensão

4.4.3.1 Letras e índices numéricos

→ A habilitação é codificada por letras maiúsculas e índices numéricos.

- A primeira letra indica o **nível de tensão** em que o titular da habilitação pode intervir:

  B para as instalações de BT;

  M para instalações de MT

  A para as instalações de AT (U = 60 kV)

  H para instalações de MAT

- O índice numérico a seguir à primeira letra indica o **grau de intervenção** para o qual o titular está habilitado:

  1 para os electricistas executantes;

  2 para os electricistas que poderão ser designados para chefiar trabalhos.

- A letra, **T** indica que o titular pode "trabalhar em tensão".

  A seguir à letra **T** deve ser indicada a(s) letra(s) correspondente ao método de trabalho para o qual o trabalhador está habilitado.

  ↘ **D** método à distância

- ↘ **C** método ao contacto
- ↘ **P** método ao potencial
- ↘ **G** método global (combinação dos três métodos)

- A letra **L** indica que o titular pode efectuar trabalhos de limpeza em tensão;
- a letra **E** indica que o titular pode conduzir viaturas com equipamentos especiais (grua/perfuradora, elevador com barquinha,...), operar e proceder à manutenção corrente das referidas viaturas e equipamentos.

Exemplos de códigos de habilitações:

B2T *electricista habilitado para realizar trabalhos em tensão, baixa tensão, responsável de trabalhos*

M1TG *electricista habilitado para realizar trabalhos em tensão, média tensão, método global, executante*

M1L *electricista habilitado para realizar trabalhos de limpeza em tensão, média tensão, executante*

→ Uma habilitação de índice numérico determinado acarreta a atribuição das habilitações de índice inferior, mas exclusivamente para as operações sobre as instalações do mesmo domínio de tensão e para uma mesma natureza de operações.

→ Um trabalhador pode acumular habilitações de códigos diferentes.

4.4.4 Conteúdo do título de habilitação

→ O título de habilitação deve precisar, nomeadamente:

- As indicações relativas ao empregador e ao titular;
- A codificação do domínio de tensão, grau e natureza das operações que o trabalhador está habilitado a realizar, quando solicitado;
- A definição do domínio de aplicação da habilitação;
- A sua validade.

4.4.5 Validade de renovação do título de habilitação

→ O título de habilitação tem a validade máxima de três anos e deve ser revisto em função da evolução das aptidões do trabalhador ou sempre que ocorra alguma das seguintes situações:

- Interrupção de prática de trabalhos em tensão durante um período superior a seis meses;
- Violação grosseira das prescrições para TET.

→ Devem ser assegurados os procedimentos administrativos para a devolução imediata do título de habilitação dos trabalhadores que por algum destes motivos lhe seja retirada a habilitação.

→ A renovação do título de habilitação depende do cumprimento dos requisitos referidos no § 4.4.1.

4.4.6 Condições atmosféricas

O Quadro I-5, para trabalhos em tensão em BT, e o Quadro II-5, para trabalhos em tensão em AT, indicam as limitações a que os mesmos estão sujeitos em função das condições atmosféricas(*).

Quadro I-5 - Limitações aos Trabalhos em Tensão em Baixa Tensão em função das condições atmosféricas

Em caso de	Linhas aéreas em condutores nus no exterior	Linhas aéreas em condutores isolados no exterior	Canalizações eléctricas subterrâneas ou instalações no interior de edifícios
Precipitação atmosférica pouco importante	O trabalho pode ser começado e acabado.	O trabalho pode ser começado e acabado.	O trabalho pode ser começado e acabado se o estaleiro: – Está abrigado da precipitação – Não há perigo de inundação – Tem condições de visibilidade.
Precipitações atmosféricas importantes	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho pode ser começado e acabado se o estaleiro: – Está abrigado da precipitação – Não há perigo de inundação – Tem condições de visibilidade.
Nevoeiro espesso	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	– O trabalho pode ser começado e acabado se o estaleiro tem condições de visibilidade.
Vento violento	Segundo as prescrições eventuais das CET.	Segundo as prescrições eventuais das CET.	Segundo as prescrições eventuais das CET.
Trovoada	O trabalho não deve ser começado nem acabado.	O trabalho não deve ser começado nem acabado, a menos que as linhas aéreas ou canalizações em que se vão realizar os trabalhos não estejam ligadas senão a redes BT inteiramente em cabos isolados ou situadas no interior de edifícios, e se forem alimentadas exclusivamente por redes AT inteiramente realizadas em cabos isolados ou situadas no interior de edifícios.	

Quadro II-5 - Limitações aos Trabalhos em Tensão em Alta Tensão em função das condições atmosféricas

Em caso de	Tensão nominal (em kV)	Trabalho ao contacto	Trabalho à distância	Trabalho ao potencial

Precipitação atmosférica pouco importante	$U_n \leq 30$	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho pode ser começado e acabado.	O trabalho pode ser começado e acabado.
	$U_n > 30$	Método de trabalho interdito.		
Precipitações atmosféricas importantes	$U_n \leq 30$	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho não deve ser começado mas a operação em curso pode ser acabada.
	$U_n > 30$	Método de trabalho interdito.	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser começado, nem acabado.
Nevoeiro espesso	$U_n \leq 30$	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho não deve ser começado mas a operação em curso pode ser acabada.	O trabalho não deve ser começado mas a operação em curso pode ser acabada.
	$U_n > 30$	Método de trabalho interdito.	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser começado, nem acabado.
Vento violento	$U_n \leq 30$	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser começado, nem acabado.
	$U_n > 30$	Método de trabalho interdito.		
Trovoada	$U_n \leq 30$	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser começado, nem acabado.	O trabalho não deve ser nem começado, nem acabado.
	$U_n > 30$	Método de trabalho interdito.		

(*) As condições atmosféricas consideradas para as presentes prescrições estão definidas no § 2.8.

→ Se as condições atmosféricas obrigarem à interrupção de trabalho, o pessoal deve abandonar o seu posto de trabalho e garantir a segurança da zona de trabalhos em relação a terceiros, podendo deixar no local os dispositivos isolantes não acessíveis a partir do solo.

O responsável de trabalhos deve informar o centro de condução da interrupção do trabalho.

Logo que as condições atmosféricas se tornem favoráveis e antes de retomar o trabalho, o responsável de trabalhos deve verificar o estado da zona de trabalhos e informar o centro de condução do início dos trabalhos ou das anomalias eventualmente encontradas.

4.5 TRABALHOS EM TENSÃO EM BT

→ O Pedido de Intervenção em Tensão pode ser comum a diversos trabalhos (grupo de trabalhos).

→ Os trabalhos em BT em instalações situadas no exterior e no interior de edifícios podem ser executados em tensão na condição de se respeitarem as prescrições seguintes:

- Aplicação de um dos métodos de trabalho, ao contacto ou à distância;
- Condições de execução do trabalho (CET) definidas para a BT;
- Utilização de acordo com as fichas técnicas (FT) e modos operatórios (MO) das ferramentas, equipamentos e materiais adaptados ao nível de tensão e aprovados;
- Limitações relativas às condições atmosféricas;
- Regras definidas para a preparação, condução, interrupção e de fim de trabalhos.

4.6 TRABALHOS EM TENSÃO NO DOMÍNIO AT (MT, AT E MAT)

→ Qualquer trabalho em instalações do domínio AT (que inclui os níveis MT, AT e MAT) deve ser objecto de uma AIT.

→ Os trabalhos em instalações do domínio AT situadas no exterior e no interior de edifícios podem ser executados em tensão dentro dos limites das possibilidades técnicas (isolamento dos executantes, material, isolamento da ferramenta, distância entre peças a potencial fixo diferente, etc.), na condição de se respeitarem as prescrições seguintes:

- Aplicação de um dos três métodos de trabalho ou da sua combinação;
- Condições de Execução do Trabalho (CET) para o nível de tensão;
- Utilização, de acordo com as fichas técnicas (FT) e modos operatórios (MO), das ferramentas e materiais adaptados ao nível de tensão e homologados;
- Respeito das limitações relativas às condições atmosféricas;
- Regras definidas para a preparação, colocação em regime especial de exploração, condução dos trabalhos, interrupção eventual e fim dos trabalhos.

4.7 PREPARAÇÃO E CONDUÇÃO DOS TRABALHOS

4.7.1 Pedido de intervenção em tensão

→ O pedido de intervenção em tensão (PIT), efectuado pela entidade requisitante, é entregue ao responsável TET da EDP ou à empresa exterior adjudicatária, se for o caso.

O responsável de trabalhos da equipa que irá intervir examina no local se o trabalho pode ser realizado em tensão e, caso afirmativo, elabora o respectivo plano de trabalhos, indicando os modos operatórios e as ferramentas melhor adaptadas ao trabalho a executar, no cumprimento das CET; caso contrário, informa a sua hierarquia sobre as dificuldades encontradas.

O responsável de trabalhos, indicado pelo responsável pelos TET da equipa interveniente ou pela empresa exterior, é designado por escrito na AIT emitida pelo responsável de condução.

Se o responsável de trabalhos não está sob a dependência hierárquica da entidade requisitante, ou trabalha por conta de uma empresa exterior, e os trabalhos são executados com base numa licença de intervenção em tensão (LIT), o responsável de trabalhos deve prevenir o responsável de manutenção do início de trabalhos.

4.7.2 Colocação do regime especial de exploração (REE) para trabalhos em redes do domínio AT

→ O centro de condução toma as medidas necessárias para colocar em regime especial de exploração a instalação AT onde o trabalho se vai realizar. Este regime comporta as seguintes medidas:

- Interdição de qualquer reposição voluntária da instalação em serviço, sem acordo prévio do responsável de trabalhos, após a ocorrência de um disparo;
- Disposições particulares, fixadas nas CET, adaptadas à natureza, ao nível de tensão e ao trabalho a efectuar.

Estas medidas, definidas nas CET, podem incluir a supressão dos reengates automáticos e a modificação da regulação das protecções.

Nota: A colocação em regime especial de exploração não abrange os trabalhos em BT.

4.7.3 Relações entre o centro de condução e o responsável de trabalhos no quadro do REE

→ O responsável de condução, após ter garantido a colocação da instalação em REE de acordo com o pedido do responsável de trabalhos, entrega ou transmite a validação da AIT ao responsável de trabalhos.

O trabalho é confiado ao responsável de trabalhos com a entrega ou transmissão da AIT, mas só pode ser iniciado depois da respectiva validação

Na eventualidade de alguma ocorrência que ponha em causa o REE em curso, o centro de condução informa do facto o responsável de trabalhos, para que sejam executados os procedimentos para a suspensão provisória dos TET.

4.7.4 Informação aos executantes

→ Antes de iniciar o trabalho, ou reiniciá-lo após uma interrupção, o responsável de trabalhos informa os executantes das condições de execução de trabalho e os modos operatórios que irão ser utilizados, assegurando-se que cada membro da sua equipa entendeu perfeitamente a sua tarefa e o modo como se integra no trabalho conjunto.

4.7.5 Direcção e vigilância da zona de trabalhos

→ O responsável de trabalhos deve assegurar a direcção efectiva e a vigilância global da zona de trabalhos e tomar as medidas de segurança necessárias ao trabalho em curso. Esta vigilância deve ser permanente durante todas as fases de trabalho.

Se a extensão da frente dos trabalhos não lhe permite assegurar pessoalmente uma vigilância total, deve designar para o secundar:

- Um executante obrigatoriamente habilitado com índice 2T, se a vigilância se exercer sobre o pessoal;
- Um executante habilitado com índice 1T se a vigilância se exercer sobre os materiais;
- Ou um executante não habilitado TET se a vigilância se exercer sobre as zonas circundantes.

→ Se os trabalhos necessitam ser interrompidos, o responsável de trabalhos certifica-se da segurança da zona de trabalhos relativamente a terceiros. Se a interrupção de trabalho, pela sua duração provável, compromete o tempo previsto para o fim dos trabalhos, o responsável de trabalhos informa o centro de condução e a entidade responsável pelas instalações.

4.7.6 Fim de trabalhos

→ Depois de terminados os trabalhos o responsável de trabalhos reúne os executantes e verifica a boa execução do trabalho.

Se os trabalhos forem executados na sequência da entrega de uma autorização de intervenção em tensão (AIT), o responsável de trabalhos envia ou transmite, por nota ou mensagem, para o centro de condução, o aviso de fim de trabalho.

Se os trabalhos forem executados na sequência de uma licença de intervenção em tensão (LIT), o responsável de trabalhos avisa a entidade requisitante do fim dos trabalhos de acordo com os procedimentos fixados anteriormente.

4.8 LIMPEZA EM TENSÃO

→ Os trabalhos de limpeza em tensão, por aspiração ou sopro, com escovas, lavagem com água pulverizada ou produto de limpeza aprovado, devem ser executados em conformidade com as respectivas CET.

4.9 REGRAS PARTICULARES PARA OS TRABALHOS EM INSTALAÇÕES DE CONTROLO, DE TELETRANSMISSÃO E DE TELECOMUNICAÇÕES QUE POSSAM SER SEDE DE TENSÕES INDUZIDAS E SOBRE INSTALAÇÕES DE ENSAIO

→ Nos trabalhos sobre certos circuitos de instalações de controlo, teletransmissão e de telecomunicações, podem surgir outros perigos para além dos contactos eléctricos directos ou indirectos, nomeadamente:

- A presença de tensões superiores às tensões nominais;

- O risco de curto-circuito ou de queimaduras;
- A vizinhança de peças nuas em tensão com valores de tensão superiores ao domínio de tensão daquelas onde se vai trabalhar.

→ Durante os ensaios eléctricos em instalações de produção ou de distribuição, pode haver necessidade de executar trabalhos em tensão. O nível de tensão que possa surgir na instalação de ensaio definirá as regras a aplicar, BT ou AT, sendo então os trabalhos executados de acordo com os princípios de segurança definidos respectivamente, nos § 4.5 e 4.6.

→ Em alta tensão, tratando-se de ensaio, a colocação em REE pode ser dispensada. As disposições de segurança para os operadores e a protecção eléctrica para as respectivas instalações devem, nestes casos, ser tomadas em acordo com a entidade requisitante.

4.10 COORDENAÇÃO ENTRE TRABALHOS EM TENSÃO E TRABALHOS FORA DE TENSÃO

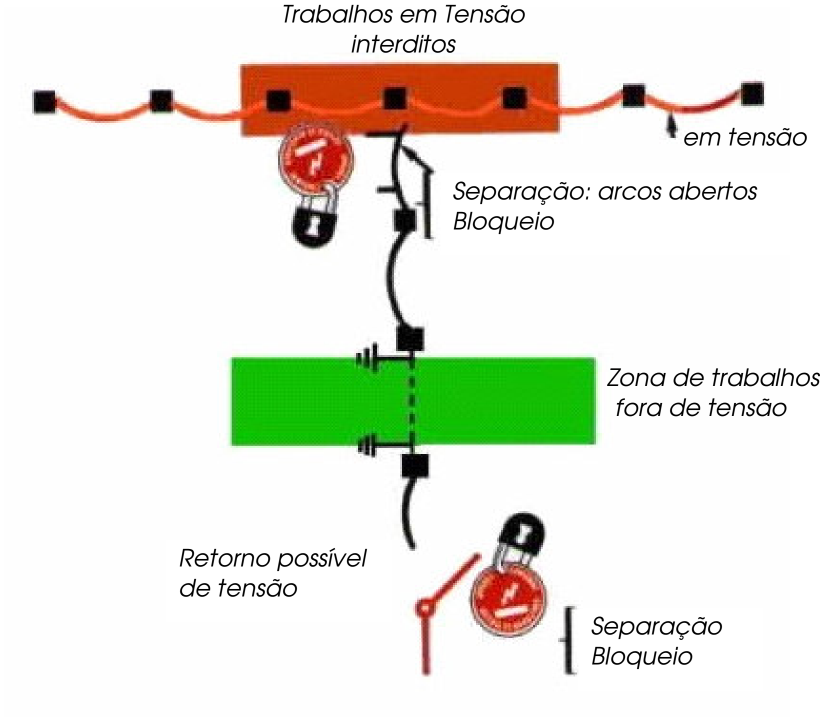
→ Uma zona de trabalhos pode comportar fases sucessivas de trabalhos em tensão, fora de tensão ou na vizinhança.

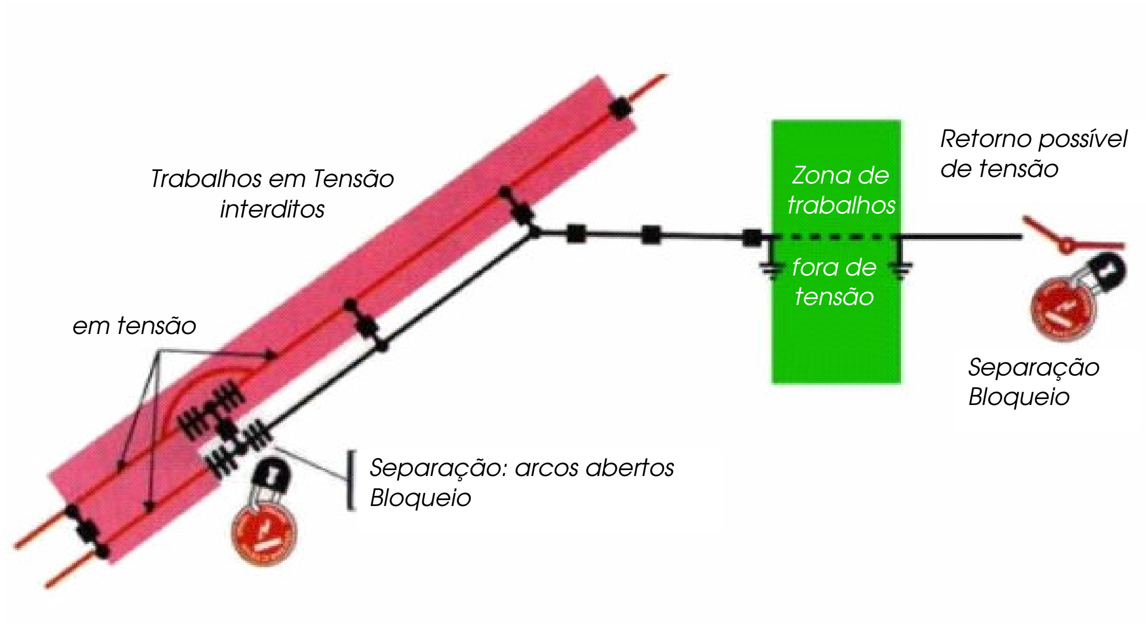
Estas fases de trabalhos devem obrigatoriamente ser distintas, aplicando-se consoante cada caso as prescrições dos capítulos correspondentes.

→ No caso da existência simultânea de duas zonas de trabalho, das quais pelo menos uma respeita a trabalhos em tensão, em caso de risco de interferência de uma zona de trabalhos sobre a outra, e se não for possível eliminar o(s) risco(s) dessa interferência, é interdita a realização simultânea dos trabalhos. (ver ilustração dos dois exemplos na página seguinte).

Execução simultânea de trabalhos em tensão e fora de tensão

exemplos de situações em que a realização de trabalhos em simultâneo daria origem a riscos de interferência entre as zonas de trabalho, o que conduz à interdição de trabalhos em tensão (na zona assinalada a vermelho) quando decorram trabalhos fora de tensão (na zona assinalada a verde) e vice-versa.





Os trabalhos em tensão a realizar sobre o terno esquerdo comportariam o risco de estabelecer uma ligação eléctrica com o terno direito

5. TRABALHOS NA PROXIMIDADE DE INSTALAÇÕES ELÉCTRICAS EM TENSÃO

5 — TRABALHOS NA PROXIMIDADE DE INSTALAÇÕES ELÉCTRICAS EM TENSÃO

5.1 PROXIMIDADE ELÉCTRICA

→ No decorrer de trabalhos em instalações eléctricas o trabalhador poderá ter de se aproximar de peças nuas em tensão.

Esta aproximação pode acontecer, nomeadamente:

- Em locais de acesso reservado a electricistas, qualquer que seja a natureza do trabalho ou intervenção;
- Quando da subida a apoios ou pórticos e na aproximação a condutores nus de linhas aéreas para a realização de trabalhos de construção ou de conservação da instalação eléctrica.

Segundo as instalações e a distância do trabalhador face às peças nuas em tensão, são definidas regras particulares.

5.2 ZONAS DE PROXIMIDADE

5.2.1 Trabalhos no interior de espaços reservados a electricistas

→ A proximidade a uma instalação eléctrica contendo peças nuas em tensão perto das quais os trabalhos são susceptíveis de serem realizados, está dividida em 4 Zonas (ver desenho da página seguinte), determinadas em função:

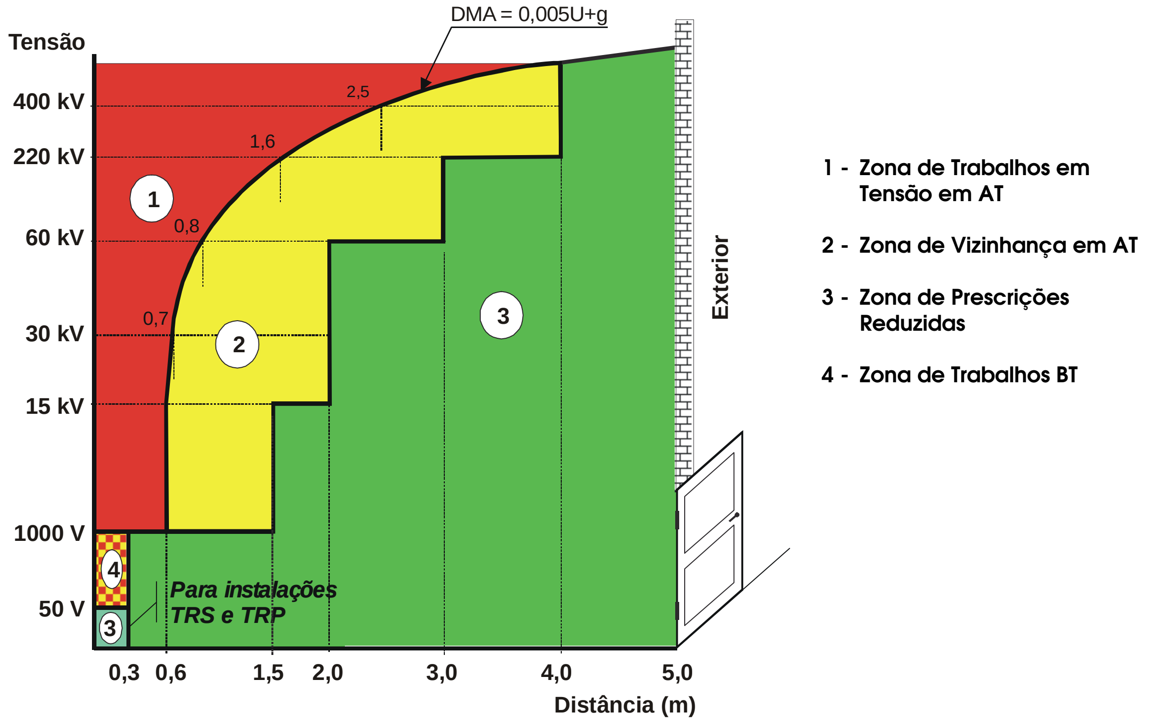
- Do limite exterior da zona de trabalhos em tensão (DL);
- Da distância de vizinhança (D_V) (§ 2.6.5).

O limite exterior da zona de trabalhos em tensão (D_L) coincide com a distância mínima de aproximação (§ 2.6.2) definida para cada nível de tensão.

→ As distâncias de vizinhança (D_v) prescritas pela EDP são:

Domínio e nível de tensão		**D_v**
Domínio BT	$U_n \leq 1000$ V	0,30 m
Domínio AT	1000 V $< U_n \leq 20$ kV	1,5 m
	20 kV $< U_n \leq 60$ kV	2 m
	60 kV $< U_n < 220$ kV	3 m
	$U_n = 220$ kV	4 m
	$U_n = 400$ kV	5 m

Trabalhos no interior de espaços reservados a electricistas



5.2.2 Zona de Trabalhos em Tensão em AT (Zona 1)

→ Espaço em volta das peças em tensão, até à distância mínima de aproximação, no qual o nível de isolamento destinado a evitar o perigo eléctrico não é garantido se nele se entrar sem serem tomadas medidas de protecção.

Nesta zona os trabalhos só podem ser realizados com o respeito pelas regras dos trabalhos em tensão (TET) (capítulo 4).

5.2.3 Zona de Vizinhança AT (Zona 2)

→ Esta zona, definida apenas para o domínio AT, fica compreendida entre o limite exterior da zona de trabalhos em tensão (D_L) e a distância de vizinhança (D_V).

Só podem trabalhar nesta zona pessoas instruídas e autorizadas pelo empregador para trabalhar na vizinhança de peças nuas em tensão do domínio considerado.

Só é permitido trabalhar nesta zona com a delimitação material da zona de trabalho – por meio de anteparos, protectores isolantes,... – para assegurar que não é possível tocar nas peças em tensão ou entrar na zona de trabalhos em tensão.

Excepcionalmente, caso não possa ser adoptada nenhuma forma de delimitação material da zona de trabalhos, o responsável pela instalação poderá autorizar o trabalho desde, que possa ser garantida uma distância de segurança não inferior a D_L e assegurando uma vigilância adequada por pessoa instruída designada para o efeito.

5.2.4 Zona de Prescrições Reduzidas (Zona 3)

→ Zona de trabalhos, definida para os domínios BT e AT, situada no interior de um local de acesso reservado a electricistas, mas para além da distância de vizinhança (D_V).

Só é permitido o acesso a pessoas autorizadas pelo respectivo empregador. Estas pessoas devem:

- Ser instruídas para as operações a efectuar em instalações do domínio de tensão considerada no local;
- Ou possuir uma autorização escrita ou verbal do empregador e serem vigiadas por uma pessoa instruída designada para esse efeito. Esta vigilância não é necessária se estiver materializado no local o limite entre as zonas 2 e 3 em AT, e entre 3 e 4 em BT.

Nas condições anteriores, fora do limite exterior da zona de vizinhança não é necessário tomar precauções especiais relativamente às peças nuas em tensão, salvo a de não entrar na zona de vizinhança.

Na preparação dos trabalhos, os riscos de tensão induzida devem ser tidos em conta

5.2.5 Zona de Trabalhos BT (Zona 4)

→ Zona localizada entre as peças nuas em tensão e a distância mínima de aproximação (0,30 m).

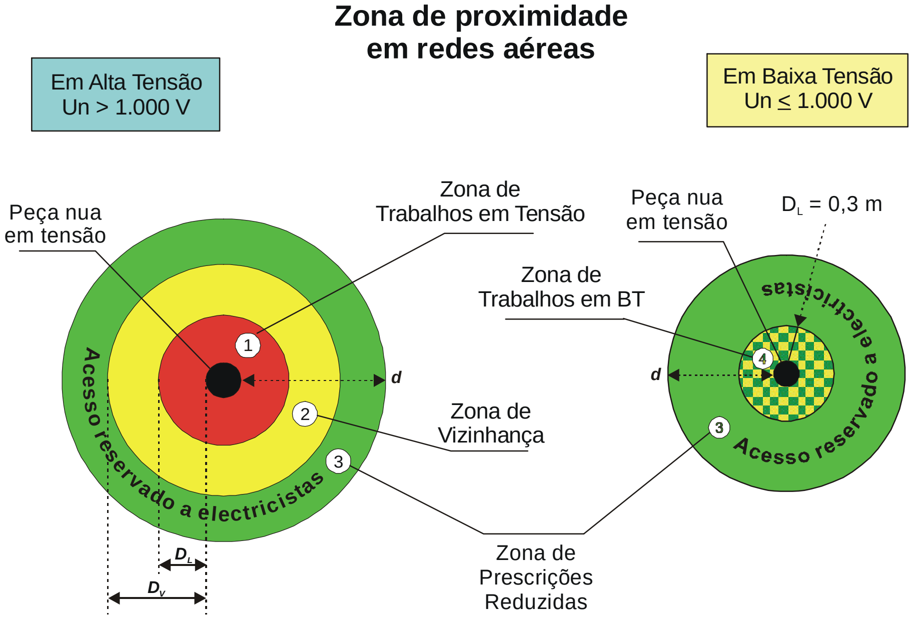
Esta zona é considerada:

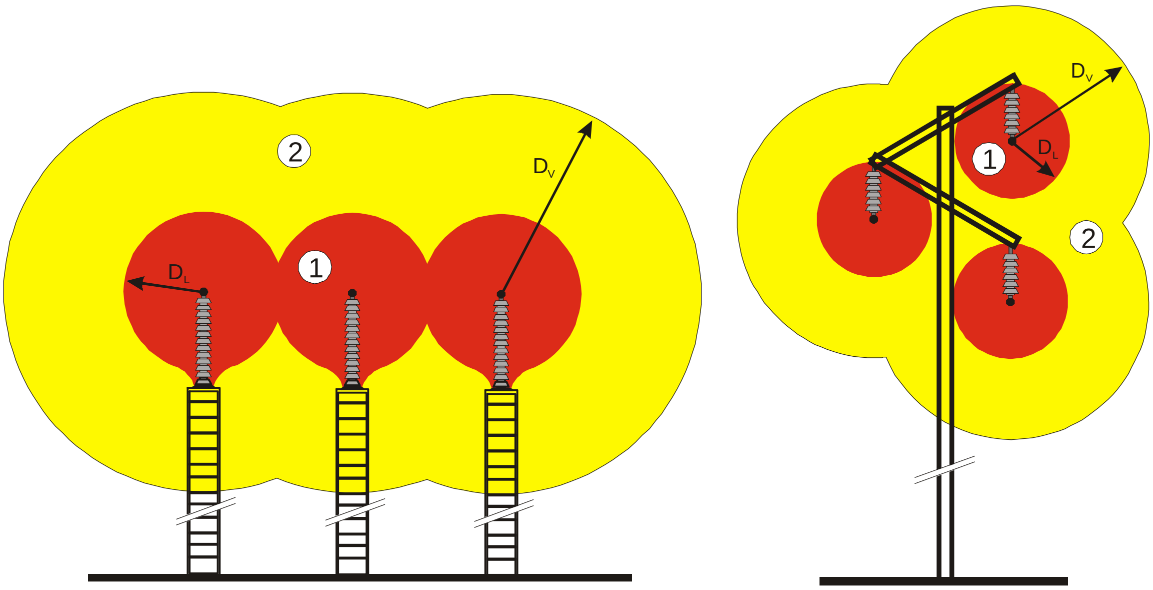
- De trabalhos em tensão, se não tiverem sido tomadas medidas para afastar ou impedir o contacto com as peças em tensão;
- De vizinhança BT se forem tomadas medidas adequadas para impedir qualquer contacto com as peças em tensão.

→ No caso das Tensões Reduzidas:

- As zonas de trabalhos do domínio da tensão reduzida funcional (TRF) são equiparadas às dos trabalhos em BT.
- A zona de prescrições reduzidas tem como limite o contacto com a peça em tensão.

Para os trabalhos executados na proximidade de instalações dentro do domínio das tensões reduzidas o executante deve ter em conta sempre o risco de curto-circuito e de queimaduras e, quando for o caso, o risco de explosão.


Zona de proximidade
em redes aéreas
Em Alta Tensão
Un > 1.000 V
Em Baixa Tensão
Un ≤ 1.000 V
Peça nua
em tensão
Zona de
Trabalhos em Tensão
Peça nua
em tensão
D_L = 0,3 m
Zona de
Trabalhos em BT
Acesso reservado a electricistas
1
2
3
4
d
Zona de
Vizinhança
D_L
D_V
Zona de
Prescrições
Reduzidas


2
1
D_V
D_L

5.2.6 Trabalhos fora de locais reservados a electricistas

→ Fora dos locais de acesso reservado a electricistas, não havendo nenhum limite exterior materializado por obstáculos ou protecções adequadas, para trabalhadores não instruídos toma-se como limite exterior a distância *d* relativamente às peças em tensão:

- ↘ 3 metros para Un ≤ 60 kV;
- ↘ 5 metros para 60 kV < Un ≤ 220 kV;
- ↘ 6 metros para Un > 220 kV.

5.2.7 Caso da subida de postes de linhas aéreas em condutores nus

→ A partir do momento em que os executantes iniciam a subida dos postes, as regras a aplicar são as referidas na zona 3, desde que não ultrapassem o limite interior de vizinhança (D_L) em relação aos condutores nus.

Se tiverem de ultrapassar este limite:

- Em BT, entram na zona 4 e, em consequência, devem aplicar as regras para trabalhos em tensão, ou tomam previamente as medidas para colocar fora de alcance as peças em tensão;
- Em AT, entram na zona 2, pelo que devem aplicar as correspondentes regras para trabalho na vizinhança.

5.3 ELIMINAÇÃO DOS RISCOS DEVIDOS À VIZINHANÇA

→ Sempre que for possível, quando razões de segurança ou necessidades de exploração não o impeçam, antes de iniciar o trabalho devem ser eliminados os riscos devidos à vizinhança de peças nuas em tensão, suprimindo essa mesma vizinhança.

→ A supressão dos riscos devidos à vizinhança pode ser feita por:

Consignação

Na preparação dos trabalhos, o responsável pela realização dos trabalhos deve determinar com o responsável de exploração (condução) da instalação vizinha, se ela pode ou não ser consignada. Se tal for possível e se assim for decidido, essa consignação deve ser feita respeitando as disposições do § 3.1.

Colocação das peças nuas em tensão fora do alcance dos executantes

Esta decisão não deve ser tomada se o trabalho para realizar esta operação comportar tantos ou mais riscos que o trabalho principal.

A colocação das peças nuas em tensão fora do alcance pode ser realizada por afastamento das peças em tensão, por interposição de obstáculos, ou por isolamento (colocação de anteparos, ecrãs, invólucros ou protectores isolantes,...).

5 — TRABALHOS NA PROXIMIDADE DE INSTALAÇÕES ELÉCTRICAS EM TENSÃO

Estas operações devem ser realizadas respeitando as regras relativas ao tipo de intervenção, ou seja, as regras do capítulo 3 se efectuadas fora de tensão, as do capítulo 4 se efectuadas em tensão e, as do presente capítulo (§ 5.4) se efectuadas na vizinhança de outras peças em tensão.

A partir do momento em que a instalação está consignada ou é concluída a colocação fora do alcance de todas as peças nuas em tensão que se encontram na vizinhança, as prescrições relativas à zona de vizinhança já não são aplicáveis.

5.4 TRABALHOS NA VIZINHANÇA

5.4.1 Regras gerais

→ Quando os trabalhos tiverem de ser efectivamente realizados na vizinhança de peças nuas em tensão, sem supressão dessa vizinhança, há necessidade de criar condições para eliminar os riscos que daí resultem. Para isso:

- Os executantes devem dispor de um apoio sólido que lhes assegure uma posição de trabalho estável e que permita ter as mãos livres;
- Quando houver necessidade de vigilância, a pessoa encarregada de a fazer deve dedicar-se exclusivamente a esta tarefa em todas as fases do trabalho, em particular naquelas em que os executantes corram o risco de se aproximarem das peças nuas em tensão;
- No caso em que exista vizinhança com instalações de características e de tensões diferentes, as regras de prevenção a tomar devem ser as da zona mais restritiva tendo em conta distâncias e tensões no local;
- Antes do início dos trabalhos o responsável de trabalhos deve instruir o pessoal sobre:
  - ↘ a manutenção das distâncias de segurança;
  - ↘ as medidas de segurança que foram adoptadas;
  - ↘ a necessidade de adopção de comportamentos que estejam de acordo com os princípios da segurança.

→ Para a avaliação das distâncias e delimitação da zona de trabalho é necessário ter em conta todos os movimentos normais e reflexos das pessoas e dos materiais ou ferramentas que manipulam, bem como os possíveis deslocamentos das peças nuas em tensão (por exemplo, o movimento dos condutores de uma linha aérea por acção do vento).

O próprio executante deve garantir que quaisquer que sejam os seus movimentos nenhuma parte do seu corpo, nem nenhuma ferramenta ou objecto que manipula, entra dentro do limite da zona de trabalhos em tensão.

5.4.2 Disposições a respeitar antes do início e no fim da execução de trabalhos na vizinhança de peças nuas em tensão

A) Antes do início dos trabalhos, devem ser efectuadas as operações seguintes:

- Fazer a consignação das instalações ou equipamentos que estão previstos consignar;
- Colocar fora do alcance as peças nuas mantidas em tensão que estão previstas isolar ou afastar;
- Tomar as disposições que permitam eliminar as consequências perigosas de todos os contactos fortuitos com peças nuas em tensão ou susceptíveis de estarem ou ficarem em tensão.

B) Para além disso, antes do início dos trabalhos, o responsável de trabalhos deve:

- Identificar os materiais e equipamentos onde vai intervir;
- Reconhecer as partes que se mantêm em tensão ou susceptíveis de virem a ficar em tensão;
- Verificar que os executantes dispõem do material de execução e de segurança apropriados à natureza do trabalho a executar e aos riscos devidos à vizinhança.

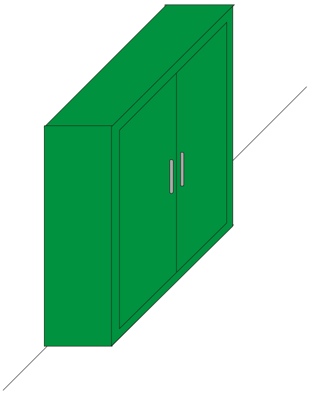
Depois das precauções enunciadas em A) e B) terem sido tomadas, o responsável de trabalhos pode dar início ou fazer iniciar os trabalhos.

C) No fim dos trabalhos, o responsável de trabalhos deve:

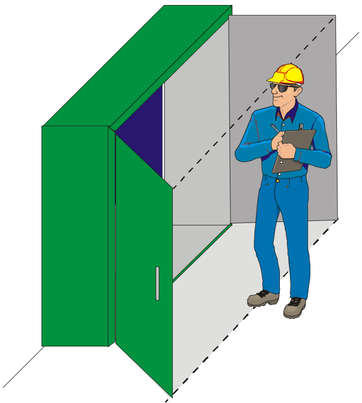
- Verificar visualmente o trabalho efectuado;
- Fazer retirar os anteparos isolantes e protectores;
- Juntar o pessoal;
- Enviar o aviso de fim de trabalhos para permitir a colocação em exploração das partes consignadas;
- Providenciar a recolha e encaminhamento dos materiais sobrantes.

As fitas métricas e réguas a utilizar em trabalhos na vizinhança de peças nuas em tensão ou insuficientemente protegidas devem ser de material não condutor

ABERTURA DE LOCAIS RESERVADOS AOS ELECTRICISTAS
(PT, armários, quadros BT, portinholas, etc. do domínio BT)

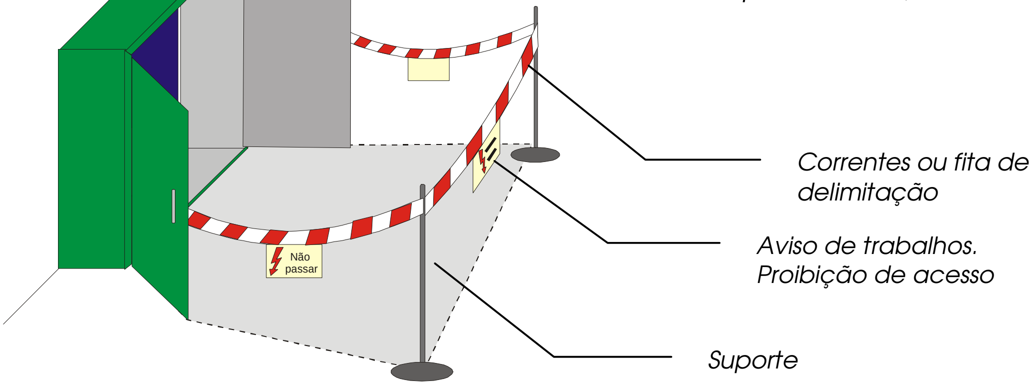


1 - Exemplo de local fechado



2 - Exemplo de local aberto
(com o trabalho em curso, o próprio trabalhador constitui a delimitação)

3 - Exemplo de balizagem
(no decurso do trabalho, em que o trabalhador, ao deslocar-se, não constitui uma delimitação permanente)



5.5 PRESCRIÇÕES PARA TRABALHOS NA VIZINHANÇA DE PEÇAS NUAS EM TENSÃO DO DOMÍNIO BT

→ Diz-se que o trabalho é efectuado na vizinhança sempre que o executante ou os objectos que ele manipula entrem dentro da zona 4, ou seja a uma distância inferior a 0,30 metros a partir das peças nuas em tensão, mas sem que estabeleça contacto intencional com essas peças nuas.

São exemplos de intervenções que podem colocar pessoas na vizinhança de peças nuas em tensão do domínio BT, situadas na zona 4:

- Colocação ou retirada de materiais não eléctricos diversos (calhas, invólucros,...);
- Limpeza e pintura de material eléctrico;
- Colocação ou retirada de anteparos ou de protectores isolantes;
- Montagem ou desmontagem de aparelhagem eléctrica fora de tensão.

5.5.1 Trabalhos de natureza eléctrica

→ Neste caso:

a) O trabalhador deve ser instruído e estar autorizado a trabalhar na vizinhança de peças nuas do domínio BT. A autorização pode ser permanente;

b) A delimitação material da zona de trabalhos feita pelo responsável de trabalhos, deve ser colocada em todos os locais onde é necessária para protecção dos executantes e de terceiros;

c) Quando no decorrer do trabalho uma pessoa é conduzida a suprimir uma protecção contra os contactos directos (por exemplo abrindo um armário que contém equipamento eléctrico) tornando acessíveis as peças nuas de BT, tem de ser feita uma delimitação da zona para impedir o acesso àquelas quando o trabalhador se retira temporariamente da zona de trabalho.

5.5.2 Trabalhos de natureza não eléctrica

→ Se os trabalhos de natureza não eléctrica são efectuados por pessoal executante não instruído, são aplicadas as disposições seguintes:

a) Necessidade de uma autorização expressa perante um Plano de Segurança com as medidas a tomar, nomeadamente as medidas para o controlo do risco e para a delimitação material da zona de trabalhos;

b) Antes do início dos trabalhos deve ser dado conhecimento aos executantes das medidas de protecção definidas no Plano;

c) Vigilância permanente por uma pessoa instruída designada para esse efeito, encarregada de zelar para que todas as precauções de segurança necessárias sejam observadas;

d) Mantêm-se as disposições b) e c) do § 5.5.1.

→ Se os trabalhadores são instruídos, aplicam-se as disposições das alíneas b) e c) do § 5.5.1.

5.6 PRESCRIÇÕES PARA TRABALHOS NA VIZINHANÇA DE PEÇAS NUAS EM TENSÃO NO DOMÍNIO AT

→ Diz-se que o trabalho se efectua na vizinhança sempre que os executantes tenham que se aproximar da peça nua em tensão de uma distância inferior à distância de vizinhança.

5.6.1 Trabalhos de natureza eléctrica

→ Neste caso:

a) O pessoal deve ser instruído e estar autorizado a trabalhar na vizinhança de peças nuas do domínio de alta tensão. Esta autorização pode ser permanente;

b) A delimitação material da zona de trabalhos pelo responsável de trabalhos deve ser feita em todos os planos onde seja necessária para a protecção dos executantes;

c) Durante as fases em que os executantes correm risco de se aproximar de Zona de Trabalhos em Tensão, deve ser assegurada uma vigilância permanente. Esta vigilância é normalmente efectuada pelo responsável de trabalhos ou por pessoa instruída e designada para o efeito.

5.6.2 Trabalhos de natureza não eléctrica

→ Se os trabalhos de natureza não eléctrica são efectuados por pessoal executante não instruído, são aplicadas as disposições seguintes:

a) Necessidade de uma autorização expressa perante um Plano de Segurança com as medidas de protecção a tomar, nomeadamente as medidas para a delimitação material da zona de trabalhos;

b) Antes do início dos trabalhos deve ser dado conhecimento aos executantes das medidas de protecção definidas no Plano.

c) Vigilância permanente por uma pessoa instruída designada para esse efeito, encarregada de zelar para que todas as precauções de segurança necessárias sejam observadas.

d) Mantêm-se as disposições b) e c) do § 5.6.1.

→ Se os executantes são instruídos, aplicam-se as prescrições das alíneas b) e c) do § 5.6.1.

5.7 TRABALHOS NA VIZINHANÇA DE CANALIZAÇÕES ELÉCTRICAS SUBTERRÂNEAS OU ISOLADAS

5.7.1 Trabalhos na vizinhança de canalizações eléctricas subterrâneas ou embebidas

→ Se os trabalhos forem executados a menos de 1,50 m de uma canalização eléctrica isolada, devem ser aplicadas as regras seguintes:

- A identificação e balizagem do traçado devem ser realizadas de forma bem visível pelo responsável pela execução dos trabalhos, em ligação com o responsável de manutenção;
- O desenrolar dos trabalhos deve ser acompanhado por uma pessoa instruída;

→ A aproximação à canalização é permitida nas condições seguintes:

- Se forem utilizadas ferramentas manuais (pá ou enxada), a aproximação pode ser feita até à canalização, com o cuidado de não a ferir;
-

É interdita a utilização da picareta na aproximação à canalização

- Se forem utilizadas equipamentos ou ferramentas mecânicas:
  - ↘ Se a canalização estiver visível, um vigilante assegurará que a máquina não se aproxime a menos de 0,30 m da canalização;
  - ↘ Se a canalização não estiver visível, a distância mínima estimada será de 0,50 m e a vigilância deverá permanecer reforçada.

Se houver dúvidas quanto às distâncias ou quanto à sinalização de presença da canalização, a aproximação será sempre feita manualmente, com os cuidados necessários para não ferir o isolamento

→ O procedimento para a realização dos trabalhos será o seguinte:

- Preparação do trabalho precisando as medidas de segurança a respeitar, informação e comunicação das mesmas aos executantes;
- Delimitação material da zona de trabalhos;
- Vigilância a definir de acordo com as distâncias a manter.

Se não for possível a aplicação de algumas destas regras a canalização deve ser consignada

→ Quando uma mesma vala está ocupada por vários cabos e se vai trabalhar num deles, é conveniente isolar esse cabo dos outros, utilizando anteparos isolantes apropriados.

5.7.2 Trabalhos na vizinhança de canalizações isoladas aéreas ou em elevação

→ Se a canalização está visível, uma pessoa instruída deve ser designada para a vigilância do pessoal, logo que a ferramenta que este manipula se aproxime a uma distância:

- Nula, mas sem bater ou forçar a canalização, se os trabalhos forem executados sem meios mecânicos; neste caso particular se o pessoal é instruído, a vigilância não é exigida;
- A uma distância de 0,30 m se os trabalhos forem realizados com o recurso a meios mecânicos (elevadores com barquinha, gruas,...).

5.8 CONDIÇÕES ATMOSFÉRICAS

→ Em caso de trovoada (percepção de relâmpagos, ou de trovões) nenhum trabalho em redes ou instalações eléctricas, tanto interiores como exteriores, deve ser começado nem acabado se forem alimentadas por uma linha aérea em condutores nus.

→ Em caso de precipitações atmosféricas importantes ou nevoeiro espesso que impeçam a vigilância do responsável de trabalhos ou da pessoa designada, ou de vento violento que torne impraticável a utilização dos meios necessários à execução do trabalho e comprometem por esse facto a segurança, nenhum trabalho no exterior deve ser começado nem acabado.

→ Em instalações interiores alimentadas exclusivamente por uma rede subterrânea ou aérea em condutores isolados, nenhuma restrição é preconizada.

5.9 CIRCULAÇÃO DE PESSOAS NA PROXIMIDADE DAS INSTALAÇÕES EM TENSÃO

→ A simples circulação na zona de vizinhança não é considerada como trabalho para efeitos deste Manual.

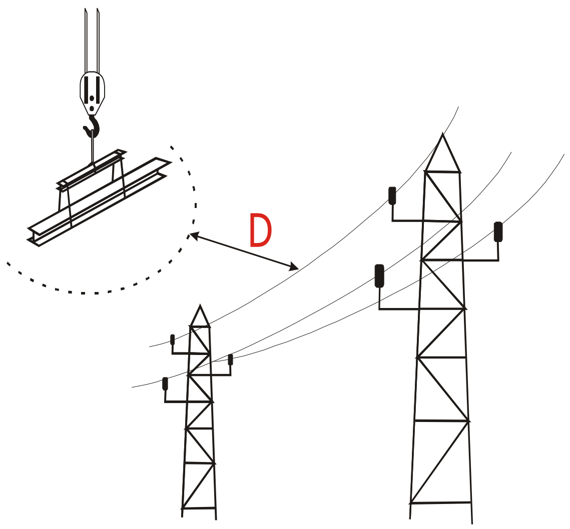
→ A locais de acesso reservado a electricistas só podem aceder, por regra, pessoas instruídas e autorizadas, ou pessoas informadas sobre as prescrições a respeitar face aos riscos eléctricos e sob a vigilância de uma pessoa instruída.

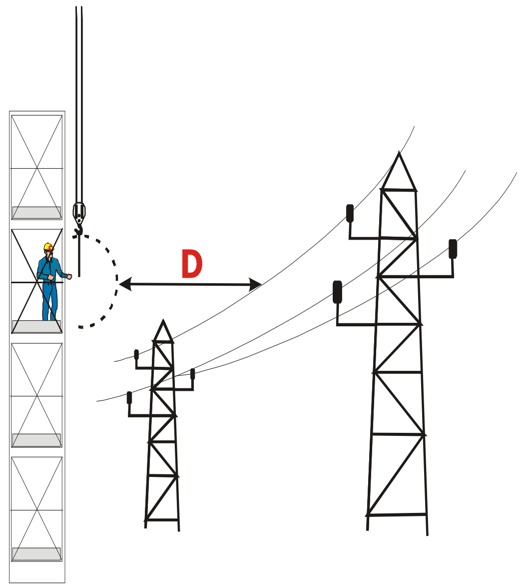
Dentro de locais de acesso reservado a electricistas podem ser criados corredores de circulação desde que devidamente delimitados e sinalizados.

5.10 TRABALHOS NÃO ELÉCTRICOS DE CONSTRUÇÃO NA PROXIMIDADE DE INSTALAÇÕES ELÉCTRICAS EM TENSÃO

→ Para a realização de trabalhos de construção na proximidade de linhas aéreas em tensão, o responsável de exploração (manutenção) indicará a distância (D) a guardar para os equipamentos de elevação, escavação ou transporte, tendo como mínimo:

- 3 metros para as linhas aéreas em condutores nus de tensão até 60 kV;
- 5 metros para as linhas aéreas AT em condutores nus de tensão superior a 60kV;
- 6 metros para as linhas aéreas MAT de tensão igual ou superior a 220 kV.





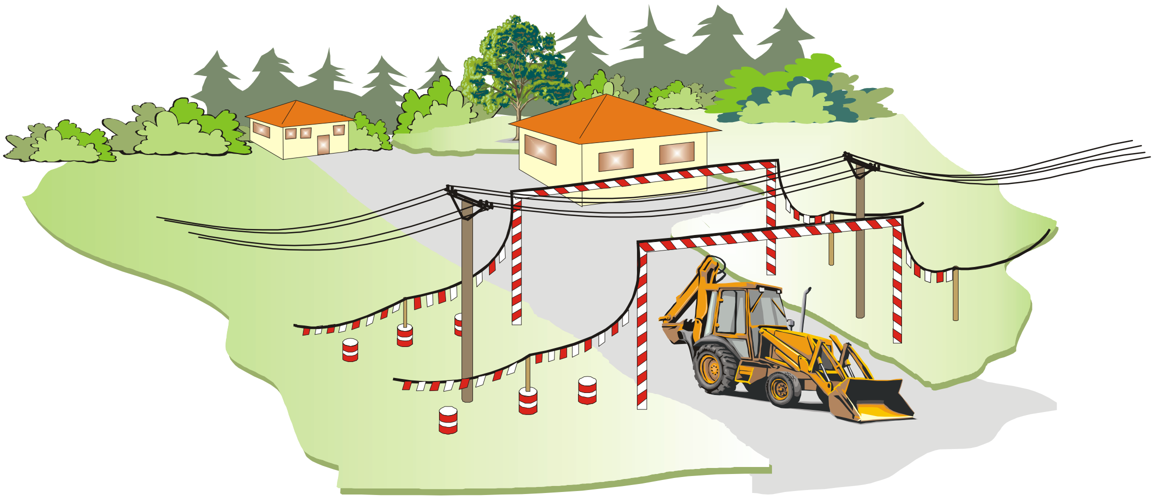
As distâncias indicadas têm em consideração a possibilidade do trabalho ser realizado por pessoas não instruídas para trabalhar em instalações eléctricas.

→ As distâncias são consideradas a partir do condutor mais próximo, tendo em conta:

- Todos os possíveis movimentos das peças nuas condutoras em tensão (nomeadamente por acção do vento);
- Os possíveis movimentos normais e reflexos das pessoas com as ferramentas ou materiais que manuseiem;
- Todos os movimentos previsíveis para as máquinas, nomeadamente, deslocações, balanços, chicotes ou queda (nomeadamente em caso de ruptura eventual de um órgão), etc..

→ Na utilização de máquinas (de terraplanagem de elevação, de transporte, de manutenção...) os percursos a seguir e os locais de implantação devem ser escolhidos de modo a não penetrarem dentro da zona limitada exteriormente pelas distâncias acima indicadas, tendo em conta que:

- Se o percurso de circulação das máquinas passar por debaixo de linhas em tensão, devem colocar-se, de um e de outro lado da linha, pórticos delimitadores da altura da máquina e carga;
- Se o trajecto apenas se aproxima da linha, devem colocar-se barreiras de sinalização ao longo de todo o percurso, com placas de aviso de perigo de electrocussão colocadas de 20 em 20 metros;
- No caso de utilização de gruas devem ser colocados interruptores fim de curso em todas as peças móveis cujo movimento possa levar a máquina ou a carga a entrar na zona interdita delimitada pelas distâncias anteriormente referidas.



→ No caso das canalizações subterrâneas deve ser guardada uma distância não inferior a 1,50 m, qualquer que seja a tensão. Se não for possível satisfazer este requisito deve ser respeitado o estabelecido no § 5.7.1.

6. INTERVENÇÕES PARTICULARES NOS DOMÍNIOS DA ALTA E DA BAIXA TENSÃO

6 — INTERVENÇÕES PARTICULARES NOS DOMÍNIOS DA ALTA E DA BAIXA TENSÃO

6.1 DOMÍNIO DE APLICAÇÃO

→ Integram-se neste capítulo algumas intervenções consideradas de rotina, nos domínios da alta e da baixa tensão, que podem ser de três tipos:

- Conservação ou reparação;
- Ligação na presença de tensão (nos domínios BT e TR);
- Substituição de aparelhagem (fusíveis, lâmpadas,...).

6.2 DISPOSIÇÕES RELATIVAS AO PESSOAL E AOS EQUIPAMENTOS E FERRAMENTAS

6.2.1 Disposições relativas ao pessoal

→ As pessoas designadas para este tipo de trabalhos devem:

- Possuir qualificação adequada;
- Ter o acordo do responsável pela instalação e ter recebido ordem de trabalho para proceder à sua execução;
- Ter adquirido o conhecimento do funcionamento do equipamento. Para uma pessoa qualificada, esse conhecimento pode resultar da leitura dos esquemas e instruções de utilização postos à sua disposição;
- Tomar todas as medidas necessárias para a segurança no decurso do trabalho, sem esquecer a de terceiros;
- Precaver-se contra os riscos devidos a peças em tensão na vizinhança daquelas em que vai intervir.

6.2.2 Disposições relativas aos equipamentos e ferramentas

→ Os responsáveis de trabalhos devem aplicar, nomeadamente, as seguintes prescrições:

A) Protecção individual dos executantes:

- Utilizar o equipamento de protecção individual (luvas isolantes, óculos ou viseiras de protecção, capacete, calçado de protecção, ...) adaptado aos trabalhos a efectuar;
- Não usar objectos pessoais metálicos (fios, pulseiras,...);

B) Meios de intervenção:

- Usar ferramentas isoladas ou isolantes de acordo com a norma em vigor;
- Usar aparelhos portáteis de medição que não apresentem perigo em caso de erro de ligação ou de má escolha da gama de medição.

Antes da utilização, os equipamentos e ferramentas destinados a garantir a segurança do pessoal devem ser verificados e substituídos em caso de defeito

6.3 INTERVENÇÕES EM LOCAIS DE ACESSO RESERVADO A ELECTRICISTAS

6.3.1 Prescrições gerais

6.3.1.1 Montagem/desmontagem de divisórias, painéis, ou redes de protecção

→ As divisórias, painéis, ou redes de protecção colocadas à volta de peças nuas em tensão acima de 500 V e destinadas a pô-las fora do alcance das pessoas, só devem ser desmontadas depois dessas peças terem sido colocadas fora de tensão, salvo quando aplicadas as prescrições para trabalhos em tensão ou trabalhos na vizinhança.

A colocação fora de tensão, só por si, não autoriza a realização de trabalhos na instalação

→ A reposição em tensão das mesmas peças nuas só pode ser feita depois de previamente terem sido repostas as protecções desmontadas ou colocada uma protecção equivalente.

→ Se as divisórias, painéis ou redes de protecção só puderem ser desmontadas com o auxílio de ferramentas, os espaços que encerram devem ser considerados como inacessíveis em exploração normal.

→ Caso estas divisórias, painéis ou redes de protecção possam ser deslocadas ou desmontadas sem o auxílio de ferramentas, a sua deslocação ou desmontagem deve provocar automaticamente a colocação fora de tensão dos condutores e peças condutoras que protegem.

→ No domínio da AT, a colocação fora de tensão dos equipamentos protegidos deve preceder sempre a supressão das protecções.

6.3.1.2 Armazenagem de materiais

→ Nos locais de acesso reservado a electricistas é proibido armazenar materiais que não sejam peças de substituição, salvo com autorização do responsável pelas instalações.

Os acessos e passagens de circulação devem ser conservados desimpedidos.

6.3.1.3 Fecho dos locais de acesso reservado a electricistas

→ Os locais de acesso reservado a electricistas devem ser mantidos fechados à chave.

Esta norma aplica-se também aos armários que contenham equipamento eléctrico em serviço situados em locais de acesso não reservado a electricistas.

→ Os locais que contêm peças nuas em tensão devem ser fechados à chave.

6.3.2 Postos AT em invólucro metálico

→ Estes Postos comportam dois tipos de compartimentos:

A) Compartimentos cujo acesso é autorizado em exploração normal

→ Estes compartimentos devem:

- Estar fechados à chave;
- Assegurar por construção, de forma permanente e completa, a segurança das pessoas chamadas a intervir;
- Comportar indicações claras, fixadas permanentemente, indicando sem ambiguidade:
- A posição que devem ocupar os órgãos de manobra para assegurar o corte dos circuitos de AT e, eventualmente, as ligações à terra e em curto-circuito;
- As localizações dos dispositivos de encravamento desses órgãos.

→ Para estes compartimentos, podem não ser aplicadas certas disposições dos trabalhos fora de tensão (por exemplo, a verificação directa da ausência de tensão antes da ligação à terra e em curto-circuito), sob reserva de serem verificados previamente os dispositivos que indicam a presença de tensão ou dispositivos equivalentes.

→ No local devem ser afixadas instruções contendo o esquema da instalação, as características de construção e as ligações dos compartimentos. Estas instruções devem precisar as regras particulares de intervenção e indicar os aparelhos exteriores ao Posto que sejam eventualmente necessários bloquear em posição de abertura quando as intervenções requeiram a supressão da ligação à terra dos cabos.

→ No caso de Postos antigos onde peças nuas em tensão fiquem acessíveis após abertura das portas, um painel afixado na porta deve chamar à atenção para a presença dessas peças perigosas.

B) Compartimentos cujo acesso é proibido em exploração normal

→ Estes compartimentos devem:

- Ser fechados por painéis fixos, que só possam ser desmontados com ferramentas apropriadas. Estes painéis não devem possuir dobradiças;
- Ser perfeitamente diferenciados daqueles cujo acesso é permitido, por aposição em cada painel desmontável do sinal de aviso de perigo de electrocussão.

As operações de manutenção desses compartimentos devem ser efectuadas segundo as regras de segurança definidas pelo fabricante.

6.3.3 Equipamentos que utilizam substâncias (sólidos, líquidos ou gases) como isolantes

→ Certas intervenções nestes equipamentos, devido ao isolante utilizado, podem apresentar um risco acrescido para os executantes.

Antes de iniciar qualquer intervenção, é necessário saber qual a substância isolante e conhecer as prescrições e as instruções do fabricante sobre a matéria.

6.3.4 Postos AT com fases separadas

A) Procedimento específico de consignação

→ Normalmente, nestes equipamentos não é possível fazer a verificação da ausência de tensão após a separação das fontes, nem o bloqueio dos aparelhos de corte e seccionamento.

Os interruptores de ligação à terra apresentam por isso características tais que a ligação à terra pode ser feita sem riscos para os operadores, mesmo se as partes activas por qualquer razão se mantiveram em tensão.

Nos casos em que as distâncias de separação dos aparelhos de seccionamento são reduzidas, devido à utilização de dieléctrico líquido ou gasoso, a separação só se considera efectiva após o fecho das ligações à terra e em curto-circuito.

B) Trabalhos numa única fase

→ Devido à inacessibilidade das partes activas e à separação das fases, os trabalhos fora de tensão podem ser feitos numa fase após consignação da mesma, sem que seja necessário proceder à consignação das outras fases.

6.3.5 Canalizações eléctricas

A) Deslocamento de canalizações eléctricas isoladas em tensão

O deslocamento de uma canalização eléctrica isolada em tensão deve ser excepção

→ Antes de decidir sobre a realização da operação o responsável de manutenção, depois de ter identificado a canalização, deve examinar o estado da mesma e em particular a natureza dos acessórios eventualmente existentes.

Caso se decida pela realização da operação deve:

- Sinalizar a canalização na presença do responsável de trabalhos;
- Determinar as condições do deslocamento e, se necessário, estabelecer o procedimento de trabalho a seguir pela equipa encarregada da operação.

→ Caso haja proximidade de peças nuas ou não isoladas em tensão devem ser aplicados, consoante a situação, os procedimentos para trabalhos em tensão ou trabalhos na vizinhança de tensão.

B) Intervenções em linhas aéreas com condutores nus de domínios de tensão diferentes, num mesmo poste

→ Num poste comum os trabalhos só podem ser realizados se os isoladores da linha em tensão que não vai ser intervencionada estiverem em bom estado.

No caso de trabalhos fora de tensão na linha BT, a ligação em curto-circuito dos condutores (neutro incluído) deve ser sempre precedida da ligação à terra de um primeiro condutor acessível que não seja o neutro.

Se o apoio for condutor (metálico) ou dispuser de ligação à terra, deve ser realizada a equipotencialidade do apoio com a ligação à terra e em curto-circuito.

B) Caso particular de intervenção numa linha de BT saída de um poste comum a uma linha de tensão superior

→ Nesta situação a linha BT é considerada como normal após o último poste comum.

C) Intervenções sobre linhas de telecomunicações ou teledistribuição no mesmo poste com linhas de BT em condutores nus

→ Os trabalhos numa linha de telecomunicações ou teledistribuição são considerados trabalhos na vizinhança sempre que a linha de BT em condutores nus seja mantida em tensão.

Quando a linha de BT estiver consignada os trabalhos são realizados no quadro dos trabalhos fora de tensão.

Estes trabalhos devem desenrolar-se no quadro de um acordo escrito entre as entidades responsáveis pela exploração das duas linhas.

6.3.6 Transformadores de potência e de tensão

→ Um transformador colocado fora de tensão do lado da AT continua a ser perigoso se os enrolamentos da sua parte de BT ficarem em tensão ou forem postos em tensão.

Todos os órgãos de separação de possíveis fontes de alta e baixa tensão devem ser bloqueados.

→ Para desligar os transformadores de potência ou de tensão devem-se interromper primeiro os circuitos do lado da tensão mais baixa e depois os da tensão mais alta.

→ Para ligar os transformadores de potência ou de tensão deve primeiro restabelecer-se a continuidade dos circuitos de mais alta tensão e depois dos de mais baixa tensão. Quando esta regra não se puder aplicar, o responsável de trabalhos fixará o modo operatório particular a ser utilizado.

→ Na manobra do comutador de tomadas de tensão em transformadores de potência fora de serviço, quando for necessária uma intervenção na proximidade de pontos de tensão, a ligação à terra e em curto-circuito será indispensável, nas mesmas condições que para a substituição de fusíveis (§ 6.3.8).

→ As intervenções num transformador de potência ou de tensão obrigam ao corte visível (ou efectivo) e à comprovação de ausência de tensão de ambos os lados do transformador.

→ Não deve ser esquecida a possibilidade de existência de tensão na parte AT de um transformador de potência, através dos equipamentos de medida, e na parte de BT, pela existência de outra fonte de alimentação (grupo gerador, ...).

→ O acesso aos terminais de baixa tensão, tal como aos cabos e peças que lhes estão ligadas, continua a ser perigoso, se o corte na tensão mais baixa levar à supressão da ligação à terra do terminal de neutro do transformador.

→ Não é permitido verificar o nível de óleo de um transformador com auxílio de uma chama nua, pois pode ocasionar a inflamação dos vapores do óleo. Esta observação não se aplica à verificação dos gases nos relés "Buchholz".

O curto-circuito dos terminais do secundário de um transformador de tensão cujo primário se mantém em tensão, é rigorosamente interdito

6.3.7 Transformadores de intensidade

→ As intervenções num transformador de intensidade devem ser precedidas da colocação fora de tensão do circuito primário desse transformador.

A abertura dos circuitos alimentados pelo secundário de um transformador de intensidade cujo primário permanece em tensão é rigorosamente interdita

→ As intervenções nos circuitos alimentados pelos secundários de transformadores de intensidade cujos primários permanecem em tensão devem ser precedidos da colocação em curto-circuito do secundário, por meio de dispositivos apropriados (curto-circuitadores, caixas de terminais para ensaios, …) previstos na instalação.

Se não existirem esses dispositivos, é obrigatória a colocação fora de tensão do circuito primário dos transformadores de intensidade antes de qualquer intervenção ou trabalho.

A ligação à terra do terminal do secundário não deve ser interrompida.

6.3.8 Substituição de fusíveis de AT e BT

Antes de proceder à substituição de um fusível, devem ser procuradas e reparadas as causas que levaram à sua fusão (defeito, sobrecarga...)

A) Substituição de fusíveis AT

→ A substituição de fusíveis AT deve ser precedida da colocação fora de tensão de todos os condutores de que o operador se possa aproximar no decurso da substituição.

A colocação fora de tensão deve ser efectuada primeiro nos circuitos de utilização e depois nos circuitos de alimentação. Deve ser seguida da verificação da ausência de tensão de ambos os lados de todos os fusíveis que protegem o circuito.

A ligação à terra e em curto-circuito pode ser dispensada se a ausência de tensão for verificada e os órgãos de manobra dos aparelhos de corte que separam os fusíveis de todas as fontes possíveis de corrente (incluindo o retorno pelos circuitos BT de um transformador) estão situados na proximidade e à vista do operador, assegurando assim a impossibilidade de uma reposição em tensão intempestiva.

- → Se após a abertura dos dispositivos de corte e seccionamento existirem riscos de contacto ou de estabelecimento de arcos eléctricos com peças vizinhas que tenham ficado em tensão, a substituição de fusíveis deve ser efectuada segundo as disposições prescritas para trabalhos na vizinhança de tensão.
- → Se a substituição de fusíveis não puder ser efectuada senão em tensão, a operação deve efectuar-se de acordo com as disposições prescritas para trabalhos em tensão.

B) Substituição de fusíveis BT na rede de distribuição

- → A substituição de um fusível em tensão e em carga só é autorizada com fusíveis concebidos para o efeito, que garantam a segurança do operador.

C) Substituição de fusíveis BT nas instalações e equipamentos

- → Antes de proceder à substituição de um fusível deve ser pesquisada e eliminada a avaria ou a sobreintensidade que provocou a sua fusão.
- → O elemento de substituição deve ter as mesmas características geométricas e eléctricas e estar adaptado à instalação em causa.
- → A substituição dum fusível deve, em princípio, ser efectuada fora de tensão e depois de ter sido verificada a ausência de tensão de ambos os lados do fusível.

  Se o elemento de fusão é do tipo encerrado e está montado num aparelho que assegura a protecção do operador contra riscos de contacto directo e a protecção em caso de fecho sobre curto-circuito, não é necessário verificar a ausência de tensão.
- → Nos casos em que a substituição em tensão de um fusível com elemento de fusão do tipo não encerrado apresentar risco de contacto directo, devem ser aplicadas as regras para trabalhos em tensão.

A substituição de um fusível em tensão e em carga só é autorizada com fusíveis concebidos para o efeito e que assegurem a protecção do operador.

SUBSTITUIÇÃO DE FUSÍVEIS BT
nas instalações e equipamentos

	COM RISCO DE CONTACTO DIRECTO	SEM RISCO DE CONTACTO DIRECTO
Exemplos de corta circuitos fusíveis		
Pessoa designada para a substituição	Qualificada	Qualificada
Substituição sem tensão	Substituição **autorizada**	Substituição **autorizada**
Substituição com tensão, o circuito a jusante aberto ou o defeito a jusante eliminado	Substituição **permitida** com a utilização de: • Punho saca- fusíveis adequado • Luvas isolantes e viseira	Substituição **autorizada**

6.3.9 Instalações de iluminação

→ As intervenções em instalações de iluminação pública devem ser efectuadas por pessoal qualificado.

Situações particulares:

- **Caso do condutor neutro comum** - Quando numa instalação de iluminação pública o condutor neutro é comum a uma linha de distribuição pública que não pode ser consignada, os trabalhos devem ser realizados de acordo com as prescrições para trabalhos em tensão.
- **Caso de postes comuns** - Quando uma instalação de iluminação tem postes comuns com a rede de distribuição pública e existam peças nuas acessíveis ou na vizinhança, os trabalhos devem ser realizados, consoante a situação, de acordo com as prescrições para trabalhos em tensão ou na vizinhança de tensão.

A) Substituição das lâmpadas e acessórios dos aparelhos de iluminação

→ A substituição de lâmpadas e de acessórios com contactos de encaixe (arrancadores) pode ser feita na presença de tensão por pessoas autorizadas, quando o material apresentar protecção contra contactos directos fortuitos durante a sua introdução e remoção.

No caso de substituição de um acessório sem contactos de encaixe (transformador, condensador, suporte, etc.), a operação deve ser executada:

- Fora de tensão;
- Ou utilizando os procedimentos para trabalhos em tensão.

→ Sempre que exista risco de contacto directo acidental, e também no caso de certos tipos de lâmpadas que apresentam especial risco de explosão em caso de quebra (lâmpadas de vapor de sódio de baixa pressão, por exemplo) a substituição deve ser efectuada por uma pessoa qualificada, seguindo:

- Os procedimentos de conservação indicados no § 6.3.10;
- As prescrições que garantam a protecção do operador contra os riscos de:
  - ↘ Contactos eléctricos;
  - ↘ Curto-circuito;
  - ↘ Quebra de lâmpadas, se necessário.

A protecção contra estes riscos deve ser assegurada pela escolha criteriosa dos meios apropriados (luvas isolantes, viseira, etc.) e pelo respeito das condições de utilização das ferramentas e de execução do trabalho.

→ As lâmpadas usadas não devem ser destruídas. Devem ser recolhidas em conformidade com o plano de recolha de resíduos estabelecido pela empresa.

6.3.10 Reparação de avarias em BT

→ A intervenção para reparação duma avaria compreende 3 etapas:

1. **Pesquisa e localização dos defeitos**
2. **Eliminação do(s) defeito(s), reparação ou substituição do(s) elemento(s) defeituoso(s)**
3. **Regulação e verificação do funcionamento do equipamento ou aparelho após reparação**

→ As etapas 1 e 3 podem exigir a presença de tensão e, eventualmente, de outras fontes de energia quando existam (fluido sob pressão, vapor,...). A etapa 2 pode, por razões de segurança ou de ordem técnica, ter de ser realizada com os equipamentos fora de tensão e consignados.

→ Se as operações exigem a ausência de tensão, o responsável de trabalhos só deve proceder à consignação no local depois de devidamente autorizado, através de mensagem registada, pelo responsável de condução.

→ A ligação à terra e em curto-circuito não é obrigatória em BT , a menos que haja risco de tensões induzidas, risco de realimentação ou na presença de condensadores ou de cabos de comprimento elevado.

Prescrições para a pesquisa e localização dos defeitos (etapa 1)

→ Para proceder a estas operações é necessário previamente:

- Tomar conhecimento dos esquemas dos circuitos em causa a fim de evitar funcionamentos intempestivos e os riscos devidos à corrente de curto-circuito;
- Ter identificado e eliminado, se necessário, os riscos devidos à vizinhança;
- Ter em atenção que podem surgir correntes de curto-circuito importantes devido à proximidade de transformadores ou de canalizações de grande secção.

→ As operações que podem ser realizadas na presença de tensão são as seguintes:

a) Medição de grandezas eléctricas por meio de aparelhos de medição ou de verificação que não exijam a abertura de circuitos;

A abertura de circuitos alimentados pelo secundário de um transformador de intensidade cujo primário esteja em tensão, ou susceptível de estar em tensão (corrente induzida), **é completamente interdita** antes de terem sido curto-circuitados os terminais do secundário

b) Colocação ou retirada de uma ligação entre dois terminais da mesma polaridade de um circuito no qual não passem mais de 50 A.

Esta operação só deve ser feita utilizando condutores flexíveis especiais comportando em série um fusível do tipo **gI** com um poder de corte mínimo de 50 kA. A intensidade nominal do fusível deve ser adaptada à corrente do circuito;

c) Desligação e religação de condutores.
Para limitar as consequências em caso de curto-circuito esta operação só é permitida em circuitos protegidos contra sobreintensidades e para secções de, no máximo:

- 6 mm^2 em circuitos de potência;
- 10 mm^2 em circuitos de comando e medição.

Quando é necessário desligar vários condutores, um após outro, as extremidades dos condutores desligados devem ser isoladas com dispositivos apropriados (capuzes isolantes, terminais de ligação, elementos de barras de ligação, etc.).

d) Certas operações particulares tais como:

- Eliminação temporária de um encravamento eléctrico (por exemplo, um detector de posição de um elemento mecânico);
- Manobras manuais de relés e contactores electromagnéticos.

Estas operações só devem ser efectuadas após um exame das situações concretas que podem originar e após terem sido tomadas as disposições necessárias para evitar qualquer acidente.

Prescrições para a eliminação dos defeitos (etapa 2)

→ As operações para eliminação do ou dos defeitos, bem como para a reparação ou substituição dos elementos defeituosos devem ser realizados, consoante a situação, de acordo com as prescrições dos capítulos 3 (trabalhos fora de tensão), 4 (trabalhos em tensão) ou 5 (trabalhos na proximidade de instalações eléctricas em tensão).

Prescrições para a regulação e verificação do funcionamento do equipamento ou aparelho após reparação (etapa 3)

→ A fase das regulações é particularmente perigosa, não só do ponto de vista eléctrico, como do mecânico, térmico, etc..

Até indicação em contrário por parte do responsável de trabalhos, durante os ensaios as instalações ou equipamentos devem ser considerados em tensão.

Fim da intervenção de reparação de avarias

→ A intervenção considera-se terminada se o equipamento funcionar normalmente:
- Através dos órgãos afectos ao comando (botões, interruptores, ...);
- Com as regulações normais (de curso, de temperatura, de nível, ...);
- Se todos os dispositivos de protecção mecânica e de encravamento eléctrico são capazes de assegurar o que deles é esperado (fim de curso, verificação da execução de certas operações antes de ordenar outras, …).

→ Se após as verificações continuarem a existir anomalias, devem ser previstas novas etapas 1 e 2.

→ No fim da intervenção o responsável de trabalhos deve proceder ou fazer proceder à reposição de tampas e coberturas e ao fecho das portas de acesso à aparelhagem eléctrica e às partes mecânicas: não devem ficar acessíveis qualquer peça normalmente em tensão fora dos locais reservados a electricistas, nem nenhuma zona de risco mecânico.

→ O responsável de trabalhos repõe em seguida o equipamento à disposição da exploração ou do utilizador, a quem informa de ter efectuado:
- Uma reparação definitiva;
- Ou uma reparação provisória, com ou sem limitações de utilização.

Neste último caso deve ser elaborada informação escrita do carácter provisório da reparação e enviada para o responsável pela exploração do equipamento.

6.3.11 Reparação de avarias em equipamentos dos domínios TR e BT comportando circuitos AT

→ Trata-se de equipamentos em que certos órgãos necessitam para o seu funcionamento de tensões superiores às do domínio BT, tais como: queimadores de fuelóleo, aparelhos com tubos de raios catódicos, aparelhos de raios X, filtros electrostáticos, detectores de defeitos em cabos, pontes de medição AT, etc..

A concepção destes equipamentos deve permitir a sua colocação fora de tensão total por seccionamento da alimentação (interruptores omnipolares, tomadas de corrente, …).

Um aviso, assinalando a presença de circuitos de alta tensão, deve ser aposto nas partes acessíveis que delimitam os compartimentos que contenham os circuitos de AT.

→ A execução dos trabalhos de conservação e reparação de avarias deverá ser feita de acordo com as prescrições do § 6.3.10.

Contudo, quando da execução da primeira etapa "*pesquisa e localização das avarias na presença de tensão"* deverão ser tomadas as seguintes precauções suplementares:

- Fazer um exame completo do equipamento fora de tensão, visando:
- Localizar os circuitos de AT e as suas protecções;
- Detectar por observação visual um eventual defeito ou avaria do isolamento desses circuitos.

→ Qualquer intervenção nos circuitos de AT só deve ser efectuada após a colocação fora de tensão e a descarga dos elementos capacitivos.

- As medições nos circuitos devem ser feitas com aparelhos cujo isolamento seja apropriado; estes só devem ser ligados e desligados quando o equipamento estiver fora de tensão.
- Os invólucros que protejam as partes de AT não devem ser retirados nem repostos senão com o equipamento fora de tensão.

→ Se a parte em causa for a do domínio BT, a pesquisa e localização da avaria poderá exigir a reposição em tensão do equipamento. Essa reposição em tensão só poderá ter lugar após ter sido assegurado que os elementos AT estão correctamente protegidos e não representam risco de contacto directo.

→ Quando as prescrições do parágrafo precedente não puderem ser aplicadas e a intervenção apresentar risco para o operador, é recomendado inserir, na origem do cabo flexível de alimentação do aparelho, um dispositivo de corrente diferencial de alta sensibilidade ou um transformador de isolamento, antes de qualquer intervenção nas partes activas dos equipamentos.

6.4 LIGAÇÕES NA PRESENÇA DE TENSÃO EM INSTALAÇÕES DO DOMÍNIO BT

→ Incluem-se nestas ligações as intervenções que têm por fim:

- Pôr em serviço um novo equipamento;
- Alterar uma ligação sem perturbar o funcionamento da instalação.

→ Só podem efectuar-se ligações ou desligações nos terminais de um aparelho ou numa placa de terminais, nas seguintes condições:

- Os circuitos estão protegidos contra sobreintensidades**;**
- A secção dos condutores, quer sejam condutores existentes quer sejam os que se pretende colocar em tensão, seja limitada a:
  - ↘ 6 mm^2 para circuitos de potência;
  - ↘ 10 mm^2 para circuitos de comando e de medição.

Estas operações podem ser executadas sem interrupção da alimentação a pedido do responsável pela exploração da instalação e na condição de serem respeitadas as disposições definidas no § 6.3.10.

→ No fim da operação, o responsável pela ligação deve avisar o responsável pela exploração da instalação do fim dos trabalhos e das alterações introduzidas na configuração da rede ou nos equipamentos colocados eventualmente em tensão e em serviço.

6.5 TRABALHOS EM BATERIAS DE CONDENSADORES

→ Atendendo ao perigo que representa o facto de armazenarem energia eléctrica durante bastante tempo após terem sido desligados, os condensadores devem sempre ser tratados como peças em tensão, salvo comprovação efectiva e segura do contrário.

→ Para trabalhar em baterias de condensadores, devem efectuar-se as seguintes operações:

1. Abrir todos os interruptores, seccionadores ou disjuntores.
2. Esperar cerca de cinco minutos e fazer uma ligação à terra de todos os elementos da bateria através dos correspondentes seccionadores, caso existam.
3. Com uma vara dotada de um condutor ligado à terra, tocar nos terminais de cada elemento da bateria. Ter em atenção que pode haver elementos com os fusíveis fundidos.
4. Comprovar, com um verificador de tensão, a ausência de tensão em todos os elementos da bateria.
5. Manter todos os elementos da bateria de condensadores ligados à terra, durante o trabalho.

→ Para repor em serviço baterias de condensadores, retiram-se as ligações à terra e entrega-se a instalação ao centro de condução.

6.6 TRABALHOS EM BATERIAS DE ACUMULADORES COM ELECTRÓLITO

→ Devem ser respeitadas as seguintes regras:

- É proibido fumar ou utilizar «chamas nuas» dentro das salas de baterias de acumuladores;
- Antes de entrar numa sala de baterias de acumuladores, é conveniente verificar se está devidamente ventilada;
- Para efectuar trabalhos com electrólitos, utilizar sempre o equipamento de segurança adequado (luvas, avental, máscara, óculos, etc.);
- Quando for necessário retirar um elemento de uma bateria, é conveniente vazar o electrólito para um recipiente adequado, para evitar o derrame do mesmo;

- Ao preparar o electrólito para as baterias ácidas nunca deitar a água sobre o ácido sulfúrico (devido a possíveis projecções) mas sempre o ácido sobre a água, muito lentamente;
- Não empregar ferramentas ou elementos metálicos que, no caso de caírem sobre os terminais da bateria, possam produzir chispas;
- Não andar ou trabalhar numa sala de baterias com calçado que tenha peças metálicas nas solas (para evitar a produção de chispas). Igualmente deve ser evitado o uso de peças de roupa que originem electricidade estática;
- Nas proximidades do local onde se trabalha com electrólitos, deve haver abundante provisão de água limpa, para os trabalhadores se lavarem no caso de projecções do líquido;
- Nas salas de baterias de acumuladores não se devem armazenar materiais combustíveis. Os interruptores, seccionadores, fusíveis, etc., devem estar instalados fora da sala de baterias, ou então devem ser do tipo antideflagrante;
- Para além do cumprimento das regras anteriores, devem ser respeitadas as instruções de serviço das baterias nas quais se executam os trabalhos.

→ Nas salas de baterias de acumuladores deve existir o seguinte material de socorro:

A) No caso de baterias de chumbo:

↘ Um frasco contendo soro (solução a 1% de cloreto de sódio em água destilada – 10g de sal de cozinha em 1 l de água destilada) para, no caso de acidente com electrólito que tenha atingido os olhos, se lavar imediatamente a vista com este soro.

↘ Uma caixa contendo sal de cozinha para, no caso de haver derrame de electrólito sobre a pele ou vestuário, de deitar uma porção de sal na zona atingida, depois de lavada abundantemente com água corrente.

B) No caso de baterias alcalinas:

↘ Um frasco contendo uma solução de ácido bórico a 5%.

↘ Uma caixa contendo areia para deitar sobre o electrólito, em caso de derrame sobre o pavimento.

6.7 TRABALHOS EM ZONAS APRESENTANDO RISCO DE EXPLOSÃO

→ Um trabalho de natureza eléctrica em zona com risco de explosão impõe o respeito das seguintes regras específicas:

- Proibir qualquer trabalho dessa natureza enquanto não forem tomadas medidas para fazer eliminar o perigo de explosão: por exemplo, supressão da libertação de gases explosivos seguida de ventilação, …;
- Se não for possível, aplicar medidas apropriadas ao risco de explosão, tais como:

↘ Controlo permanente da atmosfera, proibindo qualquer fonte de energia capaz de inflamar a mistura explosiva logo que o limiar de 10% do LII (limite inferior de inflamabilidade) do gás e/ou vapor susceptível de criar a atmosfera explosiva, for atingido, fazendo funcionar um alarme;

↘ Ventilação permanente com controlo da atmosfera;

- Intervenção limitada unicamente aos circuitos constituintes de um sistema de segurança intrínseca;
- Qualquer outra medida equivalente que apresente um grau de segurança suficiente.

→ No entanto, qualquer trabalho nas partes eléctricas de aparelhagem que exija a sua abertura, só poderá ser feito após verificação da ausência de perigo de explosão.

No caso do perigo não poder ser eliminado, a intervenção só poderá ser realizada suprimindo qualquer perigo de faísca ou curto-circuito entre componentes ou circuitos internos (interposição de ecrã, ...).

Independentemente do risco de explosão ligado à electricidade será necessário ter em conta outras fontes de ignição em presença de atmosferas explosivas: chamas, faíscas de origem mecânica, fontes de calor, fontes de radiação, ...

6.8 TRABALHOS NO INTERIOR DE MÁQUINAS ROTATIVAS

→ Para realizar trabalhos no interior de uma máquina, antes de os iniciar o operador deve assegurar-se de que:
- A máquina está parada;
- Os terminais estão em curto-circuito e ligados à terra;
- A protecção de incêndios, caso exista, está bloqueada;
- Está interrompida a alimentação da protecção de terra do rotor, quando esta protecção é de funcionamento permanente.

→ Tratando-se de uma inspecção à máquina na sequência do accionamento de um sistema de alarme (contra incêndio, refrigeração, etc.), antes de aceder ao interior da máquina devem abrir-se as portas de ventilação e esperar algum tempo.

O trabalhador que entra em primeiro lugar deve comprovar com um detector de gases apropriado, que a concentração de gases (H_2, CO_2) é inferior aos níveis perigosos. Durante esta operação, e enquanto durar a intervenção, haverá sempre um segundo trabalhador vigiando no exterior a vigiar.

7. MANOBRAS, MEDIDAS, ENSAIOS E VERIFICAÇÕES

7 — MANOBRAS, MEDIDAS, ENSAIOS E VERIFICAÇÕES

7.1 MANOBRAS

São operações que conduzem a uma mudança da configuração eléctrica de uma rede, de uma instalação ou da alimentação eléctrica de um equipamento.

Estas operações são realizadas com o auxílio de aparelhos ou de dispositivos especialmente concebidos para o efeito, tais como interruptores, disjuntores, seccionadores, ou pela abertura ou fecho dos arcos,….;

→ A ordem de sucessão das manobras não é, em regra, indiferente.

Um seccionador não deve ser manobrado em carga.

Na ausência de encravamento que impeça a sua manobra intempestiva, devem ser tomadas todas as medidas para alertar o pessoal para esta inibição

O código de manobras para uma rede poderá definir condições específicas de actuação sobre os seccionadores para determinadas operações, por exemplo no caso de intervenções nas redes em anel.

→ Dentro das manobras distinguem-se:
- Manobras de consignação;
- Manobras de exploração;
- Manobras de urgência/emergência.

7.1.1 Manobras de exploração

→ As manobras de exploração podem ter por finalidade:
- A modificação do estado eléctrico de uma rede ou de uma instalação no âmbito do seu funcionamento normal;
- A colocação em funcionamento, regulação ou paragem de um equipamento;
- A ligação, desligação, colocação em funcionamento ou paragem de equipamentos amovíveis especialmente concebidos para efectuar as ligações ou desligações sem risco (tomadas de corrente e ligadores BT,…).

→ O pessoal encarregado das manobras de exploração deve ser qualificado ou ter recebido instruções para o efeito.

→ Os aparelhos situados nos locais de acesso reservado a electricistas ou os aparelhos que não tenham um grau de protecção pelo menos iguais a IP 2X em BT ou a IP 3X em AT (§2.6.6) só podem ser manobrados por pessoal qualificado.

7.1.2 Manobras de consignação e de desconsignação

→ São operações coordenadas para realizar a consignação (ou a desconsignação) duma rede, duma instalação ou dum equipamento.

Estas manobras podem ser classificadas em dois grupos de acordo com a sua finalidade.

A) Manobras que têm como finalidade a consignação (ou a desconsignação) duma instalação eléctrica

→ Devem ser executadas sob o comando de um responsável de consignação e de acordo com os procedimentos descritos no capítulo 3. Trabalhos fora de tensão.

B) Manobras que têm como finalidade a consignação (ou a desconsignação) duma máquina ou de um aparelho para permitir trabalhos de natureza não eléctrica

→ Para a execução de trabalhos de natureza não eléctrica nas partes não eléctricas de máquinas ou aparelhos, as manobras devem inspirar-se nos procedimentos de consignação eléctrica de uma instalação e devem ser definidas, em cada caso particular, por meio de procedimentos escritos.

→ Certas consignações podem exigir operações múltiplas ou impor uma escolha rigorosa dos órgãos de manobra ou da ordem de sucessão das diversas operações a realizar. Estas manobras devem ser executadas por pessoal qualificado que deverá seguir instruções contidas em fichas de manobras pré-estabelecidas.

7.1.3 Manobras de urgência

→ As manobras de urgência nas redes de transporte e distribuição estão reservadas a pessoal qualificado actuando com conhecimento de causa, ou sob as ordens do responsável de condução ou do responsável de manutenção.

→ As manobras dos aparelhos que asseguram a função de corte de urgência por razões evidentes de segurança duma instalação de utilização (incêndio, electrização, etc.) podem ser efectuadas por qualquer pessoa presente na instalação.

7.2 MEDIÇÃO DE GRANDEZAS FÍSICAS

São operações que permitem medir grandezas eléctricas, mecânicas ou térmicas.

Neste capítulo apenas são tratadas as medições efectuadas através de aparelhos portáteis.

7.2.1 Precauções fundamentais

→ A medição de grandezas eléctricas acarreta frequentemente para o operador o risco de entrar em contacto com peças nuas em tensão (por vezes com uma tensão de valor desconhecido).

O pessoal que procede a medições deve:

- Utilizar equipamentos de protecção individual adequado;
- Utilizar aparelhos adaptados ao tipo de medição a efectuar e às tensões que podem ser encontradas (por exemplo pontas de prova isoladas);
- Seleccionar rigorosamente o calibre a utilizar, no caso de aparelhos de calibres múltiplos;
- Verificar antes de cada operação o bom estado dos aparelhos de medição e dos equipamentos de protecção;
- Tomar precauções, em particular, contra os riscos de curto-circuito.

7.2.2 Medição de grandezas eléctricas em BT e TR

A) Medições que não exigem a abertura de circuitos eléctricos

→ Medições realizadas com:

- Pinças amperimétricas;
- Voltímetros;
- Osciloscópios ou outros aparelhos operando por captação de tensão.

→ No caso de medições efectuadas com um osciloscópio, as operações para a utilização deste aparelho são semelhantes às realizadas em operações de ligação (§ 6.4).

→ As medições realizadas em caixas de terminais de ensaio, especialmente concebidas para o efeito, não são consideradas como implicando a abertura de circuitos eléctricos.

B) Medições que exigem a abertura de circuitos eléctricos

→ As medições que exigem a abertura de circuitos eléctricos para inserção de aparelhos mais ou menos complexos, tais como *shunts*, transformadores de intensidade, wattímetros, etc., efectuam-se segundo os procedimentos usados para trabalhos ou intervenções BT.

Consoante a situação podem ser efectuadas segundo os procedimentos para trabalhos na vizinhança de tensão, para trabalhos em tensão ou para trabalhos fora de tensão.

7.2.3 Medição de grandezas eléctricas em AT

→ Para além das disposições previstas no § 7.2.1, a colocação ou retirada de aparelhos para medição de grandezas eléctricas em circuitos AT devem ser efectuadas no respeito pelas regras dos trabalhos fora de tensão, dos trabalhos em tensão e, se necessário, as de trabalhos na vizinhança.

7.2.4 Medição de grandezas não eléctricas

→ A medição de grandezas não eléctricas que apresentem o risco de contacto com peças nuas em tensão ou realizadas na vizinhança destas, devem ser executadas em conformidade com as prescrições respectivas.

7.3 ENSAIOS

São operações destinadas a verificar o funcionamento ou o estado eléctrico, mecânico ou outro de uma instalação que se mantém alimentada pela rede.

→ Devem ser tomadas as precauções necessárias para proteger as pessoas presentes contra os riscos mecânicos que podem resultar dos ensaios.

O equipamento de protecção individual deve ser adaptado aos ensaios a efectuar.

→ Quando se trata de ensaios executados segundo os procedimentos de trabalhos em tensão, devem ser respeitadas as prescrições respectivas.

→ O responsável de ensaios antes do início dos trabalhos deve dar conhecimento da sua realização ao responsável pela condução da instalação.

7.3.1 Ensaios comportando exclusivamente medições e experimentações fora de tensão

→ O procedimento adoptado é o dos trabalhos fora de tensão (capítulo 3).

Os ensaios só podem ser iniciados depois do boletim de ensaios ter sido validado pelo responsável de consignação.

→ Se os ensaios assim o exigiram, compete ao responsável de ensaios decidir não efectuar as ligações à terra e em curto-circuito na sua zona de trabalho.

Contudo, a verificação de ausência de tensão deve ser sempre feita.

7.3.2 Ensaios com a instalação em exploração

→ Neste caso os procedimentos adoptados são, consoante o caso, os de:

- Trabalhos em tensão (capítulo 4);
- Intervenções particulares em BT e AT (capítulo 6);
- Manobras (§ 7.1).

Quando necessário, devem ser tidos em conta os problemas ligados à vizinhança de peças em tensão.

O regime de ensaios não pode ser em caso algum utilizado para a realização de trabalhos na instalação.

- → Quando no decurso dos ensaios sob alimentação normal, tanto nos circuitos de potência como nos circuitos de controlo e comando for preciso executar ensaios dieléctricos ou de continuidade requerendo por tempo limitado uma alimentação exterior, a mudança de alimentação exige a colocação fora de tensão com encravamento dos aparelhos de isolamento.

  Neste caso, o responsável de condução ou o responsável de consignação entrega ao responsável de ensaios um boletim de ensaios.

- → O responsável de ensaios só poderá dar início aos trabalhos depois de obtida autorização do responsável de consignação.

7.3.3 Ensaios em tensão com alimentação exterior autónoma

- → Regime que permite, após o isolamento da instalação das suas fontes normais de alimentação (operação chamada, em certos casos, saída de exploração), realimentá-la por meio de fontes auxiliares, para efectuar as medições, ensaios ou verificações.

  Este regime implica a transferência da instalação, ou parte da instalação, do responsável de condução para um responsável de ensaios no âmbito duma consignação para ensaios.

  Os ensaios só podem ser iniciados depois de emitido e validado pelo responsável de consignação o respectivo boletim de ensaios.

7.3.4 Ensaios em laboratório ou em plataforma de ensaios

- → Os ensaios na presença de peças nuas em tensão realizados em laboratório e em plataforma de ensaios podem caracterizar-se por condições excepcionais para o material:
  - Diminuição das protecções contra contactos directos;
  - Regimes anormais (sobrecargas, sobrevelocidades, sobretensões, etc.);
  - Cablagens e instalações mecânicas provisórias;
  - Diminuição das protecções eléctricas e mecânicas, etc..

- → Estas condições exigem:
  - Pessoal individualmente designado para efectuar esses ensaios e qualificado;
  - Acesso aos laboratórios e plataformas de ensaios estritamente regulamentado por uma autorização para outras pessoas;
  - Que a zona de ensaios seja demarcada e sinalizada.

→ Consoante as situações, são aplicadas as prescrições para trabalhos fora de tensão (capítulo 3) e de manobras (§ 7.1), ou para trabalhos em tensão (capítulo 4) e, se necessário, tomada atenção aos problemas ligados à vizinhança.

O equipamento a ensaiar é colocado sob a autoridade do responsável de ensaios.

7.3.5 Fim dos ensaios

→ No fim dos ensaios o responsável de ensaios restitui o boletim de ensaios, indicando que ficaram concluídas as operações para as quais o pedido de indisponibilidade tinha sido emitido, e que foram tomadas as medidas necessárias para restituir a instalação em condições de serviço.

O aviso de fim de ensaios deve precisar ainda se a instalação ficou em estado de exploração normal ou se há restrições.

7.4 VERIFICAÇÕES

→ São operações destinadas a confirmar que uma instalação está conforme com as disposições previstas.

Certas verificações são de natureza técnica e prévias à colocação em tensão (por exemplo o controlo de fases), outras são impostas com a finalidade de pesquisar se as instalações estão em conformidade com os textos regulamentares.

O pessoal deve ser qualificado.

→ Para efectuar verificações iniciais ou periódicas, aplicam-se as prescrições de medição de grandezas físicas (§ 7.2) ou de ensaios (§ 7.3).

→ Certas verificações técnicas em instalações do domínio AT, tais como por exemplo a concordância de fases, a medição da intensidade em condutores isolados,…, podem ser realizadas com a instalação em tensão, na condição de ser utilizado equipamento apropriado e de serem mantidas distâncias suficientes das peças em tensão, tal como definido no capítulo 5.

7.5 OPERAÇÕES NOS CIRCUITOS DE TERRA

→ Nas proximidades de um circuito de terra, durante a passagem de correntes de defeito nesse circuito, podem surgir diferenças de potencial perigosas para as pessoas, devido à tensão de passo ou à tensão de contacto com uma peça adjacente não ligada à terra.

Por outro lado os eléctrodos de terra podem sofrer a influência de outros eléctrodos de terra na proximidade de outra instalação (por exemplo da proximidade de uma linha de caminhos de ferro electrificada, aquando da passagem de um comboio).

→ As operações nos circuitos de terras requerem precauções especiais:

- Durante as operações devem ser utilizados equipamentos de protecção individual apropriados.

- Em caso de trovoada é proibido intervir em circuitos de terra, a menos que a instalação seja interior e exclusivamente ligada a cabos subterrâneos.

Mesmo com as instalações fora de serviço podem ocorrer tensões de contacto ou de passo perigosas durante as medições, especialmente quando se utiliza o método de injecção de corrente

7.5.1 Interrupção de um circuito de terra

→ No caso de ser necessário interromper um circuito de terra assegurar-se previamente a continuidade da ligação à terra de cada elemento do circuito a interromper; esta continuidade pode ser assegurada por meio de um *shunt* aplicado enquanto durar a intervenção, ou por meio de uma ligação da parte que vai ficar separada do circuito de terra a outro condutor ligado à terra.

Um circuito de terra nunca deve ser aberto sem ser precedido pela colocação de um *shunt*.

7.5.2 Ligação a um circuito de terra

→ Quando for necessário fazer a ligação de uma parte metálica a um circuito de terra, por meio de um condutor, deve em primeiro lugar fazer-se a ligação do condutor ao circuito de terra e só depois a ligação do condutor à parte metálica em causa.

7.6 SEPARAÇÃO DE UMA INSTALAÇÃO PARTICULAR DA REDE DE DISTRIBUIÇÃO PÚBLICA EM MÉDIA E ALTA TENSÃO

→ Se o responsável por uma instalação particular pretender isolar-se da rede, deve fazer um pedido nesse sentido à entidade responsável pela condução da rede que o alimenta, o qual depois de concretizada a separação entregará ao interessado o respectivo boletim de corte e seccionamento.

Esse documento permite-lhe efectuar trabalhos fora de tensão nas suas instalações.

O corte e seccionamento não dispensam o responsável pela instalação isolada de realizar a consignação para a execução dos trabalhos

7.6.1 Pedido de fim de separação da rede de distribuição pública

→ O pedido de fim de separação da rede de distribuição pública é feito pelo responsável da instalação isolada sobre o boletim de corte ou seccionamento que lhe foi entregue.

Neste pedido, assinado e com a indicação da data e hora, o responsável pela instalação isolada certifica que a instalação pode de novo receber tensão.

7.6.2 Caso particular

→ O boletim de corte ou seccionamento não é necessário se o responsável de condução da rede de distribuição autorizou, por escrito, o responsável pela instalação particular a proceder ele próprio às operações que lhe permitem isolar-se da rede.

Antes do isolamento o responsável pela instalação particular informa o responsável de condução de que vai proceder ao corte ou seccionamento.

Antes de voltar à condição normal de exploração o responsável pela instalação particular informa o responsável de condução do final do corte ou seccionamento.

8. EQUIPAMENTOS DE PROTECÇÃO E FERRAMENTAS ELÉCTRICAS

8 — EQUIPAMENTOS DE PROTECÇÃO E FERRAMENTAS ELÉCTRICAS

8.1 UTILIZAÇÃO E MANUTENÇÃO DO EQUIPAMENTO DE PROTECÇÃO INDIVIDUAL E COLECTIVO

→ O equipamento de protecção é utilizado para proteger individual ou colectivamente o pessoal, e deve respeitar as características indicadas na respectiva Ficha Técnica.

Deve ser mantido de acordo com instruções precisas e as suas características iniciais não devem ser alteradas.

→ Independentemente da verificação feita pelo trabalhador antes da utilização, é necessário que o equipamento seja objecto de controlo periódico feito por pessoal qualificado.

Os controlos periódicos dos equipamentos de protecção da Categoria 3ª (que se destinam a impedir uma ocorrência com consequências previsivelmente muito graves ou mortais) devem ficar registados.

> As Fichas Técnicas do Catálogo de Equipamentos de Protecção indicam as características técnicas dos equipamentos de protecção, bem como as regras para a sua correcta utilização, verificação e controlo, manutenção e transporte.

8.1.1 Equipamento de protecção individual (EPI)

8.1.1.1 Capacete de protecção

→ A utilização de capacete de protecção é obrigatória para todas as pessoas que se encontrem numa zona em que haja o risco de queda ou projecção de objectos, choque com objectos, ou riscos de queda de um nível diferente (por exemplo, trabalhos em instalações eléctricas aéreas, em terraços ou locais exíguos, trabalhos em estaleiros de construção civil ou mecânica).

→ Existem diferentes tipos de capacetes de protecção para responder a diferentes necessidades, por exemplo:

- Capacetes para electricista que não devem possuir abas nem peças metálicas;
- Capacetes para permitir a colocação de acessórios, para utilizações específicas (por exemplo, para utilizar com protectores auriculares).

→ O dispositivo de suspensão do casco (arnês) é de grande importância para a absorção de impactos e deve ser ajustado de forma a mantê-lo afastado cerca de 4 cm da cabeça do utilizador.

→ Nos trabalhos em altura é obrigatório o uso do francalete, sendo contudo sempre recomendada a sua utilização.

8.1.1.2 Luvas de protecção mecânica

→ Devem ser utilizadas para protecção das mãos em trabalhos, tais como:

- Movimentação manual de materiais e equipamentos que possam ferir as mãos (cargas, ferragens, madeiras, escadas, aparelhos...),

- Subida a postes,
- Montagem de ferragens,
- Aplicação de materiais termo-retrácteis,
- Manobras e trabalhos em instalações mecânicas e térmicas,

Estas luvas **não devem** ser utilizadas para a execução de manobras ou Trabalhos em Tensão ao contacto.

8.1.1.3 Luvas isolantes

→ As luvas isolantes devem ser adaptadas à tensão das instalações onde se vão realizar as intervenções.

→ Quando nas operações a efectuar haja o risco de serem rasgadas ou perfuradas, as luvas isolantes devem ser usadas sob luvas de protecção mecânica *(no caso dos trabalhos em tensão devem ser utilizadas luvas de protecção mecânica siliconizadas).*

→ As luvas isolantes devem ser verificadas imediatamente antes de usar, aplicando um verificador pneumático de luvas, ou enchendo a luva de ar e enrolando o canhão várias vezes sobre si mesmo. Se houver perfuração (fuga de ar) ou apresentarem qualquer tipo de vincos, arranhões ou fissuras, não devem ser utilizadas e o par deve ser destruído.

→ Depois de utilizadas, as luvas isolantes devem ser limpas, polvilhadas com pó de talco e guardadas na respectiva embalagem, sem as dobrar nem vincar.

→ As luvas isolantes para trabalhos em tensão devem ser objecto de ensaios de isolamento periódicos, de acordo com as Condições de Execução dos Trabalhos e Fichas Técnicas respectivas.

8.1.1.4 Óculos e viseiras

→ A utilização de óculos ou de viseira é obrigatória para todos os trabalhos que envolvam risco para os olhos, tais como as radiações luminosas e a projecção de vapor ou de partículas de matérias sólidas ou líquidas.

→ Os óculos de protecção contra radiações luminosas não constituem protecção contra os efeitos do arco eléctrico, sendo nestes casos necessário utilizar uma viseira para protecção integral dos olhos e da face contra a projecção de partículas e possíveis queimaduras.

8.1.1.5 Calçado de protecção

→ O calçado de protecção destina-se a utilizar nos locais de trabalho onde exista o risco de ferimentos nos pés, nomeadamente choque ou queda de objectos ou perfuração.

Em função do risco a que o trabalhador possa estar exposto, assim o calçado deverá apresentar características diferentes e marcados com o símbolo respectivo:

- risco de perfuração: símbolo P (com palmilha de aço);
- risco eléctrico: símbolo A (sola anti-estática);
- atmosferas explosivas: símbolo C (sola electricamente condutora).

→ Para os trabalhos em tensão em AT o calçado de segurança tem exigências específicas ao nível do isolamento especificadas na respectiva Ficha Técnica .

→ Sempre que os trabalhos se desenvolvam em locais com solos húmidos, terrenos lodosos ou pantanosos, em estaleiros e obras hidráulicas ou na manipulação de líquidos corrosivos deve ser utilizado calçado de protecção impermeável.

8.1.1.6 Arnês e acessórios para protecção contra quedas em altura

→ O arnês é utilizado sempre que exista risco de queda em altura, nomeadamente nos trabalhos em postes, torres metálicas, fachadas, desrame de árvores, tomadas de água, acesso a silos etc..

→ Para trabalhos em apoios deve ser utilizado um arnês com cinto de trabalho incorporado. O arnês simples é utilizado exclusivamente em intervenções em elevação, quando o utilizador não necessita de se apoiar para executar o trabalho.

Este equipamento é utilizado em conjunto com um dispositivo de interrupção da queda, que poderá ser um qualquer dos sistemas pára-quedas:

- Pára-quedas deslizante (para suporte de ancoragem flexível ou rígida);
- Amortecedor de quedas;
- Pára-quedas retráctil.

O cinto de trabalho por si só não constitui protecção contra quedas em altura.

8.1.2 Equipamento de protecção colectiva (EPC)

8.1.2.1 Estribos para subida de apoios

→ Para cada tipo de apoio, tais como postes metálicos, betão ou de madeira, devem ser utilizados estribos adaptados a cada uma das situações.

É interdita a utilização dos estribos para outro efeito diferente do escalamento de tipo de apoio para que está desenhado.

→ Todos os defeitos nas partes metálicas, fivelas incluídas, devem ser reparadas pelo construtor.

Os outros elementos, tais como as partes em têxtil ou em couro, devem ser mantidas em bom estado, e não devem apresentar golpes nem fissuras.

8.1.2.2 Escadas portáteis e andaimes isolantes

→ As escadas portáteis são utilizadas para:

- Passar de um plano de trabalho para outro.
- Efectuar trabalhos em altura de curta duração; para trabalhos mais prolongados devem ser utilizados andaimes ou plataformas;

- → Em locais de acesso reservado a electricistas onde existam peças nuas em tensão acessíveis (trabalhos na vizinhança de tensão), nomeadamente no interior postos de transformação, parques exteriores de subestações, etc., só é permitida a utilização de escadas e andaimes isolantes ou plataformas com braços isolantes.

- → Nos trabalhos realizados em apoios ou em fachadas é permitida a utilização de escadas portáteis extensíveis mistas, com o troço superior em material isolante, desde que o último troço em alumínio fique a, pelo menos, 2 m da peça nua em tensão mais próxima.

- → Sempre que o utilizador tenha que desenvolver trabalhos apoiado numa escada deve estar equipado com arnês de protecção contra quedas e fixo a um ponto de ancoragem que não a própria escada.

- → Antes de cada utilização o estado de conservação da escada deve ser verificado pelo utilizador, nomeadamente:
  - a boa fixação dos montantes e dos degraus;
  - o bom estado dos apoios anti-derrapantes da escada;
  - que estão isentas de sujidade e de gordura.

- → A colocação da escada deve ser feita de tal forma que a distância dos pés da escada ao plano vertical de apoio do topo da escada e altura da escada corresponda a uma proporção de 1:4 a 1:3.

É interdita a subida simultânea de mais que um utilizador na mesma escada.

8.1.2.3 Linha de vida

- → As linhas de vida são utilizadas como suporte de ancoragem de pára-quedas deslizante, sempre que haja o risco de queda em altura.

  Podem ser realizadas em corda, em cabo metálico ou em barra metálica e devem ser especificadas para utilizar com o dispositivo pára-quedas.

- → Na subida a apoios metálicos para a realização de trabalhos deve ser utilizada uma corda linha de vida vertical.

- → Na deslocação nos braços de uma torre ou estrutura metálica deve ser utilizada uma linha de vida horizontal.

8.1.2.4 Tapetes e estrados isolantes

- → Os tapetes e estrados isolantes permitem isolar o operador do solo e devem ser adaptados à tensão nominal das instalações onde vão ser utilizados.

- → Antes da utilização de um estrado isolante, é necessário assegurar que os seus pés estão apoiados numa superfície regular, que os isoladores são adequados e em bom estado e que a plataforma do estrado está suficientemente afastada de qualquer estrutura condutora ligada à terra.

→ O operador deve posicionar-se no centro do estrado ou do tapete e deve evitar qualquer contacto com as massas metálicas.

Contudo, em alguns postos de transformação em que existe uma ligação equipotencial à terra entre as massas, a utilização do tapete e do estrado isolante não é necessária se o operador se colocar numa superfície equipotencial relativamente às massas metálicas e ao órgão de comando manual dos seccionadores.

8.1.2.5 Verificador de ausência de tensão

O verificador de ausência de tensão não deve ser utilizado como aparelho de medição, a menos que o aparelho seja previsto também para esta finalidade

→ Os verificadores de ausência de tensão são utilizados nomeadamente no decurso das operações de consignação, previamente à ligação à terra e em curto-circuito, para confirmar a ausência de tensão.

Estes aparelhos podem ser do tipo sonoro e/ou do tipo luminoso e sempre adaptados ao nível de tensão das instalações onde vão ser utilizados.

→ Imediatamente antes de qualquer operação efectuada com este equipamento e imediatamente após esta, é indispensável verificar o bom funcionamento do aparelho, com o recurso a partes activas em tensão na proximidade, ou com a ajuda de um dispositivo com fonte de alimentação autónoma prevista pelo fabricante.

→ Durante a utilização do equipamento:

- Em BT, é obrigatória a utilização de luvas isolantes sempre que na proximidade existam peças nuas em tensão que representem um risco importante de contacto directo devido a um movimento inesperado;
- Em AT, é obrigatória a utilização de luvas isolantes.

É proibida a utilização de uma lâmpada num suporte com duas "pontas de prova", bem como a utilização de busca-polos de contacto

8.1.2.6 Espingarda lança-cabos

→ A espingarda lança cabos é utilizada, em alternativa ao verificador de ausência de tensão, para a verificação da ausência de tensão em linhas aéreas nuas MT, antes da ligação à terra em curto-circuito.

A utilização da espingarda lança-cabos não dispensa, em caso algum, a ligação à terra e em curto-circuito com o equipamento apropriado.

→ É proibido utilizar a espingarda lança-cabos em situações:

- Em que não fiquem abraçados os três condutores (por exemplo, com os condutores dispostos em esteira)

- Em que haja o risco da vareta ao ser projectada entrar em contacto com outras instalações com ou sem tensão.

8.1.2.7 Dispositivo Pica-cabos

→ O dispositivo pica-cabos é utilizado para verificar a ausência de tensão em cabos subterrâneos em MT e BT, por picagem do cabo.

Antes de ser cortado, um cabo deverá ser obrigatoriamente picado com o pica-cabos, ainda que tenha sido previamente identificado por meios não destrutivos.

8.1.2.8 Varas Isolantes

→ As varas isolantes destinam-se a permitir executar à distância determinadas manobras, medições ou intervenções sobre um elemento da rede.

Deve ter um isolamento e um comprimento adequado à tensão de serviço da instalação onde vai ser utilizada.

Antes da utilização de uma vara isolante deve ser verificada a existência de qualquer defeito pelo seu aspecto exterior, deve ser limpa e estar isenta de humidade ou depósitos de sal.

Se a vara isolante dispõe de saias isolantes, o utilizador deve verificar o seu estado aparente, que não deve apresentar sinais de fissuras nem falhas, e que a sua fixação é sólida.

8.1.2.9 Equipamentos móveis de ligação à terra e em curto-circuito

→ A ligação à terra e em curto-circuito ou a ligação em curto-circuito de todos os condutores ou aparelhos onde se vai efectuar o trabalho só pode ser feita com um equipamento especial que permita ao operador manter-se isolado das partes activas.

O referido dispositivo deve ser adaptado à tensão nominal da instalação e às correntes de curto-circuito esperadas no ponto de colocação.

→ As operações devem ser realizadas de acordo com as prescrições do (§ 3.1.4 – Estabelecimento das ligações à terra e em curto-circuito), com a seguinte ordem:

1. Assegurar-se que todas as peças de contacto, bem como os condutores do equipamento, estão em bom estado;

2. Ligar o cabo de terra do equipamento:
   - De preferência à terra das massas existentes nos postos de transformação ou sobre os apoios, pórticos, … ;
   - Ou a um eléctrodo metálico convenientemente enterrado no solo suficientemente afastado dos trabalhadores.

3. Desenrolar completamente o condutor do equipamento, se estiver montado num enrolador, para evitar os efeitos electromagnéticos no caso de um eventual curto-circuito;

4. Fixar as pinças sobre cada um dos condutores, começando pelo mais próximo e utilizando ferramentas isolantes adaptadas à tensão nominal da instalação, normalmente varas isolantes.

→ Nas instalações de BT, as pinças podem ser colocadas à mão desde que sejam utilizadas luvas isolantes. Durante esta operação, o operador deve-se manter afastado dos condutores activos.

→ Para retirar os equipamentos de ligação à terra e em curto-circuito, executar as operações pela ordem inversa.

8.1.2.10 Anteparo

→ Dispositivo considerado como um obstáculo destinado a evitar a aproximação ou o contacto com peças nuas em tensão.

Podem igualmente delimitar uma zona de trabalhos.

→ O anteparo pode ser realizado em:

- Material condutor ligado à terra;
- Material não condutor sem garantir um nível de isolamento determinado;
- Material isolante ou isolado.

→ Antes da utilização destes anteparos, deverão ser estabelecidas as regras de utilização em função das características mecânicas e dieléctricas dos materiais utilizados e das tensões em presença.

Estas regras definirão as distâncias mínimas a respeitar tendo em conta as peças nuas em tensão e as condições ambientais (humidade, ...).

8.1.2.11 Anteparos para TET - AT

→ Os anteparos para TET-AT em material isolante, são usados para colocar fora do alcance as peças nuas AT em tensão, mas não são nem obstáculos intransponíveis, nem protecções isolantes, nem superfície sobre a qual o operador se possa apoiar.

São colocados e posicionados, por pessoal habilitado, sobre um apoio, uma estrutura ou um chassis de um aparelho, permitindo trabalhar na proximidade de uma instalação de alta tensão respeitando as distâncias às peças nuas em tensão de acordo com as CET e as FT.

8.1.2.12 Protectores

→ Dispositivos constituídos por invólucro isolante com determinadas características dieléctricas.

São fixados sobre as peças nuas em tensão.

As precauções de utilização (humidade) e as características (mecânicas e dieléctricas) devem ser especificadas para definir as condições de utilização (ver CET e FT respectivas).

8.2 UTILIZAÇÃO DE EQUIPAMENTOS E FERRAMENTAS ELÉCTRICAS

→ Os equipamentos e ferramentas devem estar em bom estado, em particular os cabos de alimentação quando o isolamento for em borracha ou material equivalente.

Devem ser adaptados às condições em que vão ser utilizados e a protecção contra os contactos indirectos deve ser assegurada para as condições mais desfavoráveis de utilização, qualquer que seja a classe de isolamento – por exemplo, no caso de utilização exterior de equipamentos portáteis, devem oferecer protecção contra a eventual penetração de água da chuva (IP x4).

Como lâmpadas portáteis só é permitida a utilização de gambiarras especialmente concebidas para esse efeito.

→ Antes de serem utilizados os equipamentos e ferramentas eléctricas devem ser objecto de uma verificação visual pelo utilizador sobre o seu estado aparente e do seu funcionamento normal.

Qualquer defeito ou suspeita de defeito no isolamento ou no funcionamento deve ser assinalado e o equipamento deve ser imediatamente retirado para reparação.

→ Independentemente da verificação feita pelos operadores antes da utilização, devem também ser objecto de controlo periódico por pessoal qualificado.

8.2.1 Aparelhos de medida portáteis em BT

→ Os aparelhos de medida portáteis devem ter invólucro isolante e não devem constituir risco para o utilizador mesmo em caso de erro de ligação ou de selecção incorrecta da gama de medição.

É obrigatório o uso de luvas isolantes sempre que o utilizador opere na proximidade de peças nuas em tensão que representem risco de contacto directo.

→ A introdução de aparelhos de medida portáteis no secundário de transformadores de intensidade deve ser efectuada nas condições definidas no § 6.3.7. Se a instalação dispõe de dispositivos especiais que facilitam a ligação de aparelhos, esta deve ser feita com a ajuda destes dispositivos.

→ Sempre que a medição de uma corrente alternada seja efectuada com uma pinça transformadora de corrente separada do aparelho de leitura, devem ser efectuadas as operações a seguir indicadas, e pela seguinte ordem:

1. Ligação do aparelho à pinça transformadora;
2. Colocação da pinça em redor do condutor mantendo a pinça aberta;
3. Fechar progressivamente a pinça;

4. Após a medição, não interromper a continuidade do circuito secundário sem ter aberto e retirado a pinça.

→ Se, no decurso da manobra de fecho progressivo da pinça, o aparelho não acusar nenhuma indicação, retirar imediatamente a pinça e verificar a continuidade do circuito de medida. Qualquer alteração da escala de medida do aparelho deve ser precedida da abertura e retirada da pinça, a menos que as instruções do construtor dispensem, sem ambiguidades, esta precaução.

Ter em conta a adequação da escala do aparelho ao nível esperado do parâmetro a medir.

8.2.2 Utilização de ferramentas eléctricas portáteis

→ Durante a utilização de uma ferramenta eléctrica deverá ser tomada pelo menos uma das quatro medidas de protecção a seguir indicadas, tendo em conta as condições de utilização:

- Para as ferramentas da classe III utilizar tensão reduzida de segurança (TR);
- Utilizar equipamento da classe II;
- No caso de ferramentas da classe I:
  - ↘ Separação de circuitos;
  - ↘ Ou ligação à terra das massas e um dispositivo de corte automático associado.

8.2.3 Utilização em locais expostos a condições particulares

8.2.3.1 Condições ambientais

→ Os equipamentos e ferramentas eléctricas a utilizar deverão ter que assegurar a protecção contra riscos particulares resultantes de condições de utilização especiais (projecção de água, imersão, etc.).

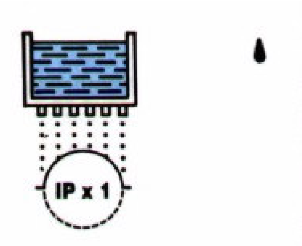
Assim, nos locais onde a humidade, a impregnação por líquidos condutores, a libertação de vapores corrosivos estão habitualmente presentes (por exemplo locais exteriores, húmidos, …), devem ser utilizados equipamentos que assegurem o nível de isolamento de acordo com as condições de utilização e, em particular, resistir à acção da humidade.

→ Os equipamentos utilizados devem ter apostos símbolos que correspondam às condições de utilização (*Norma CEI 529*):

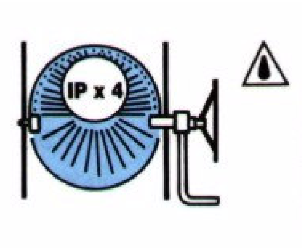
- Protecção contra a projecção vertical de água - IP X1;
- Protecção contra a projecção de água - IP X4;
- Protecção contra a imersão temporária - IP X7.

Quando não for possível utilizar estes equipamentos, deve ser utilizada a TR de segurança.

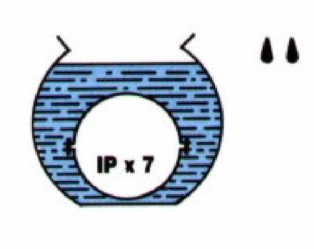
Protecção contra a queda vertical de gotas de água (condensação)



Protecção contra a projecção de água de todas as direcções



Protecção contra os efeitos da imersão temporária



8.2.3.2 Utilização em espaços confinados com paredes condutoras

→ Espaço ou local de trabalho em que as paredes são essencialmente constituídas por partes metálicas ou condutoras e no interior do qual seja difícil limitar as possibilidades de contacto de uma pessoa com as partes condutoras envolventes.

- As gambiarras utilizadas em tais espaços devem ser alimentadas em TR.
- Os aparelhos ou motores portáteis dentro destes espaços deverão ser alimentados seja em TR de segurança, seja em BT por um transformador de isolamento da classe II. Caso as soluções anteriores não existam no mercado, excepcionalmente poderão ser utilizados aparelhos da classe I.
- Os transformadores de segurança ou de isolamento não devem estar localizados no interior destes espaços, a menos que façam parte integrante da instalação (numa caleira técnica, por exemplo).

8.2.3.3 Atmosferas explosivas

→ Quando os equipamentos ou ferramentas portáteis se destinem a ser utilizados em locais onde existam riscos de incêndio ou explosão devem respeitar as prescrições particulares a essa utilização, nomeadamente o regulamento de segurança de instalações de utilização de energia eléctrica.

9. INCIDENTES E ACIDENTES EM INSTALAÇÕES ELÉCTRICAS

9 — INCIDENTES E ACIDENTES EM INSTALAÇÕES ELÉCTRICAS

9.1 INCÊNDIO NAS INSTALAÇÕES ELÉCTRICAS

9.1.1 Prescrições gerais

→ Em caso de incêndio numa instalação eléctrica ou na sua vizinhança, o pessoal de serviço, após ter dado o alarme, deve tentar combater o fogo, observando as prescrições específicas das instruções para incêndios afixadas no local, e as seguintes prescrições gerais:

- Colocar fora de tensão, sempre que possível, o aparelho incendiado e preferencialmente as instalações vizinhas;
- Munir-se de máscaras de protecção contra gases tóxicos, se necessário;
- Abrir os exaustores de fumos, caso existam;
- Fechar todas as portas, janelas ou alçapões, que não sejam especialmente previstas para exaustão de fumos.

9.1.2 Prescrições complementares quanto à utilização de extintores em instalações em tensão ou susceptíveis de o estar

→ Utilizar o agente extintor adequado à classe de fogo e tendo em atenção se existe ou pode existir a presença de tensão.

TIPO DE EXTINTOR	CLASSE DE FOGOS			NA PRESENÇA DE ELECTRICIDADE
	A SÓLIDOS	B LÍQUIDOS	C GASOSOS	
ÁGUA EM JACTO	✓✓	⊘	⊘	⚠ NÃO USAR
ÁGUA PULVERIZADA	✓✓✓	✓	⊘	⚠ NÃO USAR acima de 500 V
ESPUMA FÍSICA	✓✓	✓✓✓	⊘	⚠ NÃO USAR
PÓ QUÍMICO BC	✓	✓✓✓	✓✓	⚠ NÃO USAR acima de 6.000 V
PÓ QUÍMICO ABC	✓✓✓	✓✓✓	✓✓	⚠ NÃO USAR acima de 6.000 V
DIÓXIDO DE CARBONO (CO_2)	✓	✓✓	✓✓	✓✓✓

Legenda:

⊘ Não utilizar	✓ Controla apenas pequenas superfícies	✓✓ Adequado	✓✓✓ Muito adequado	⚠ Perigo de electrocução

→ Em instalações em tensão ou susceptíveis de o estar, só é permitido utilizar extintores portáteis mantendo entre o difusor do extintor e as partes activas da instalação um afastamento mínimo de (salvo indicações em contrário no próprio extintor) (*) :

- Instalações **BT:** **0,5 m**
- Instalações **AT U ≤ 20 kV**: **1 m**
- Instalações AT 20 kV < U ≤ 50 kV: 2 m

Em instalações com mais de 50 kV, a utilização de extintores só é autorizada quando houver a certeza que a parte afectada está fora de tensão.

→ A utilização de extintores com a indicação "Não usar em presença de tensão eléctrica" é rigorosamente interdita, a menos que a instalação tenha sido previamente colocada fora de tensão.

→ Extintores com a indicação "Não utilizar sobre tensões superiores a **X** volts" só podem ser utilizados dentro desta limitação, a menos que a instalação tenha sido previamente colocada fora de tensão.

A extinção de fogos por jacto de água é proibida em instalações eléctricas

COMO UTILIZAR O EXTINTOR

1. Retirar a cavilha de segurança

2. Agarrar firmemente o extintor pela pega e pelo difusor

3. Premir o manípulo do difusor, orientando o jacto para a base das chamas

Depois de usado, o extintor deve ser posto deitado no chão para evitar que possa incorrectamente ser arrumado como bom.

→ Após a extinção do incêndio, assegurar a evacuação de todos os gases tóxicos por ventilação do local.

(*) Valores de referência de acordo com a norma UTE - C 18 510, de 17 de Janeiro de 1989. A ser objecto de confirmação com o Serviço Nacional de Bombeiros.

9.2 ACTUAÇÃO NO CASO DE INCIDENTE NAS REDES AÉREAS OU NA SUA VIZINHANÇA

9.2.1 Condutor caído por terra

→ Perante um condutor caído por terra:
- Se for necessário libertar uma vítima, utilizar ferramentas isolantes ou isoladas para a tensão em causa;
- Evitar aproximar-se do condutor e impedir que outros o façam;
- Prevenir o responsável de exploração pelos meios mais rápidos disponíveis;
- Para se aproximar da vítima ou para se afastar da mesma, saltar com os pés juntos (com cuidado para não se desequilibrar) ou dar pequenos passos, para evitar o risco de choque eléctrico por tensão de passo.

9.2.2 Incêndios na vizinhança de uma linha

→ Perante um incêndio na vizinhança de uma linha eléctrica:
- Prevenir imediatamente o responsável de condução para que a linha seja colocada fora de tensão;
- No caso de um incêndio debaixo de uma linha ou perto de um apoio, não se aproximar enquanto a linha não for colocada fora de tensão (risco de queda dos condutores);
- Não utilizar água em jacto sobre um foco de incêndio situado sob os condutores ou perto dos apoios de uma linha de alta tensão, salvo se houver a garantia de que esta se encontra fora de tensão.

9.2.3 Incidente em zona apresentando riscos de explosão

→ Em caso de disparo do aparelho de protecção duma parte da instalação situada em atmosfera com perigo de explosão, a reposição em tensão só deve ser feita após a verificação da manutenção das disposições regulamentares relativas à protecção contra esse risco.

9.3 DISPOSIÇÕES A TOMAR EM CASO DE INCIDENTE EM EQUIPAMENTOS BT

9.3.1 Incidente com actuação das protecções

Antes de intervir considerar que a instalação continua em tensão

→ Se a causa é conhecida e passageira a pessoa encarregada da condução do equipamento (ou da sua vigilância) poderá rearmar a protecção e religar uma primeira vez.

Contudo, se o órgão de protecção não estiver protegido com, pelo menos, um grau IP 2X (§2.6.6), ou se o seu acesso exige a abertura de um armário ou de uma portinhola, essa operação só pode ser feita por uma pessoa qualificada.

→ Em caso de novo disparo ou se as causas são desconhecidas, deve solicitar a intervenção a uma pessoa qualificada e devidamente autorizada.

→ No caso de incidente provocado por avaria, a religação só é autorizada após detecção e eliminação da mesma.

9.3.2 Incidente sem actuação das protecções

→ O equipamento afectado deve ser colocado fora de tensão o mais depressa possível.

Só deve ser reposto em tensão após eliminação da avaria e verificação do bom estado da instalação.

A reparação deve ser efectuada por pessoas qualificadas.

9.4 DISPOSIÇÕES A TOMAR EM CASO DE ACIDENTE DE ORIGEM ELÉCTRICA

Em caso de acidente eléctrico, é necessário:

- **PROTEGER**: resgatar o acidentado, isto é, libertá-lo do contacto com o condutor ou peça em tensão,
- **SOCORRER**: proceder ao socorro, de acordo com a lesão do acidentado
- **ALERTAR**: chamar os primeiros socorros especializados

A) LIBERTAR O ACIDENTADO (PROTEGER)

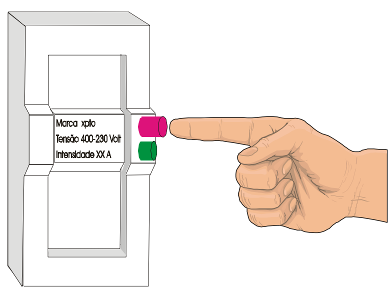
→ Se o acidentado ficou em contacto com o condutor ou a peça em tensão:

Para resgatar a vítima dos efeitos da corrente, o primeiro passo é separá-lo da fonte de tensão, tendo em atenção que uma intervenção imprudente pode pôr em risco a vida da pessoa que pretende salvar acidentado.

Em baixa tensão

Colocar a instalação fora de tensão:

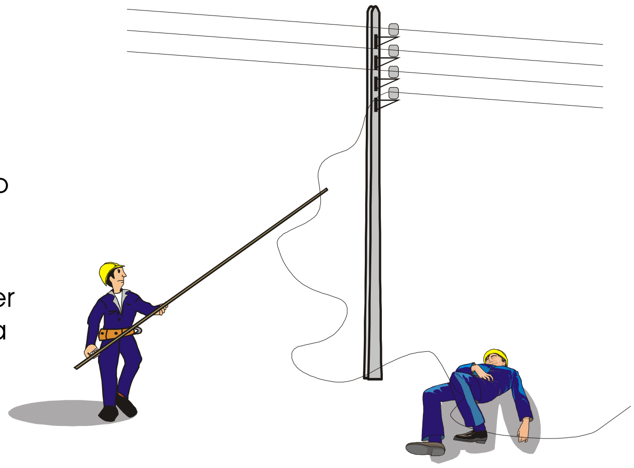
Manobrando o aparelho de corte



Desligando a ficha da tomada de corrente

Se não for possível colocar rapidamente a instalação fora de tensão, a pessoa que pretende libertar a vítima do condutor em tensão deve isolar-se com o auxílio de uma vara isolante, de uma ferramenta isolada, de luvas isolantes...

Na inexistência destes utilizar um qualquer material não condutor, por exemplo uma vara ou uma tábua, tendo o cuidado de verificar que estão secos.



Em alta tensão

É necessário colocar a instalação fora de tensão, operação que deve ser realizada por uma pessoa qualificada conhecedora da instalação.

O socorrista só deverá afastar o condutor ou a peça em tensão do acidentado, no caso de dispor de equipamento para trabalho em tensão à distância adequado ao nível de tensão em causa.

Caso particular dos acidentes eléctricos no cimo de um apoio

Se o acidentado ficou suspenso pelo seu sistema anti-queda (arnês e amortecedor de quedas ou pára-quedas), o socorrista deve começar por verificar se o acidentado respira;

Caso o acidentado não respire, as hipóteses de reanimação serão maiores se o socorrista puder (sem risco de contacto dele próprio com o condutor ou peça em tensão) ministrar três insuflações longas e profundas (boca-boca ou boca-nariz) antes de descer rapidamente o acidentado.

Se sentir uma oposição anormal à entrada de ar, confirmar que as vias não estão obstruídas, por exemplo a língua caída, situação frequente em electrizações;

Se o socorrista não tiver condições para fazer a reanimação ainda no cimo do apoio, o acidentado deve ser descido o mais rapidamente possível.

B) PRIMEIROS SOCORROS

→ Proceder a um exame primário do acidentado, de acordo com a ordem seguinte:

1º - Avaliar o estado de consciência do acidentado

2º - Avaliar se respira

3º - Avaliar se tem pulsação

4º - Detectar hemorragias externas graves

5º - Detectar sinais evidentes de choque

1º - Estado de consciência do acidentado

→ Iniciar a abordagem do acidentado, começando por avaliar o seu estado de consciência, incitando-o a responder a diversos estímulos (chamando pelo nome, tocando-lhe suavemente, etc.).

Se o acidentado se encontra inconsciente, colocar-lhe a cabeça em extensão, elevando o maxilar inferior e verificar se está a respirar (durante 5 segundos):

2º - Respiração

→ Se o acidentado respira:

Vigiar as funções vitais e verificar se o acidentado tem hemorragias externas graves ou se apresenta sinais evidentes de choque;

→ Se não respira:

Começar imediatamente o processo de respiração artificial utilizando preferencialmente o método boca-a-boca ou boca-nariz.

3º - Pulsação

Após ter efectuado as primeiras insuflações, verificar se o acidentado possui pulsação cardíaca (durante 10 segundos), através da pesquisa no pulso carotídeo, no pescoço.

→ Tem pulsação, mas não respira:

Fazer uma insuflação em cada 5 segundos. Esta manobra mantém-se até que o acidentado recupere a respiração normal ou até que chegue alguém mais qualificado ou que venha prestar socorro.

→ Não tem pulsação:

Iniciar de imediato a manobra de Reanimação Cardio-Pulmonar (RCP) (§ 9.2)

4º - Hemorragias externas graves

Verificar se o acidentado tem hemorragias externas graves (no caso de queda); no caso de existirem usar uma das seguintes técnicas:

→ Compressão manual directa

É a técnica mais simples e que resolve a maioria das situações. Consiste em aplicar uma compressa esterilizada sobre a zona da hemorragia e depois com o punho fechado fazer compressão, até que a hemorragia fique estancada. Esta técnica não pode ser usada quando o acidentado tem objectos cravados ou facturas expostas.

→ Compressão manual indirecta

Quando não se consegue estancar a hemorragia pelo método anterior, procurar a montante o vaso sanguíneo que está a alimentar a hemorragia, sendo feita nesse local a compressão de modo a estrangular a passagem de sangue. Esta compressão deve ser efectuada sobre a zona onde se situa a veia ou a artéria, para minimizar eventuais lesões dos tecidos.

→ Garrote

Deve ser evitado. Só pode ser aplicado por pessoa habilitada e depois de esgotadas as outras técnicas.

5º - Sinais de choque

Um acidentado pode apresentar um ou vários sinais de choque, manifestados de forma mais ou menos evidente:

- Alterações do estado de consciência;
- Dificuldade em respirar;
- Pulsação rápida e fraca;
- Lábios pálidos e cianosados;
- Pele pálida e cianosada, com a temperatura baixa e suores frios;
- Náuseas, vómitos e secura da boca;
- Olhos baços e sem brilho.

→ Existem, vários cuidados que se podem prestar a um acidentado em estado de choque:

- Actuar sobre a causa do choque, por exemplo, controlar uma hemorragia;
- Posicionar o acidentado em decúbito dorsal (deitado de costas para baixo), mantendo a cabeça ao nível inferior das costas e os membros inferiores elevados a 30º;
- Se possível arejar o local onde se encontra o acidentado;
- Conservar a temperatura do corpo, agasalhando o acidentado;
- Quando o acidentado manifestar uma sede insuportável, humedecer-lhe os lábios. Nunca lhe dar de beber.
- Avaliar e registar os sinais vitais.

C) PEDIDO DE SOCORROS EXTERIORES (ALERTAR)

→ O pedido de socorros especializados deve ser feito o mais rapidamente possível pelo meio mais expedito (telemóvel, telefone, rádio-telefone...), preferencialmente através do número nacional de emergência 112.

Com o pedido de socorros deve ser dada a informação mais relevante quanto a:

- Localização exacta do acidente;
- Número de vítimas;
- Estado do(s) acidentado(s), nomeadamente os sinais vitais, feridas visíveis, se está consciente, etc.;

- Medidas tomadas;
- Tempo que decorreu desde o acidente até à chamada de socorros exteriores.

→ Quando exista mais que uma pessoa no local do acidente a chamada de socorros exteriores deve ser feita imediatamente por um dos presentes, ficando o socorrista a ministrar os primeiros socorros à vítima.

Se o socorrista está sozinho com a vítima, a comunicação deverá ser feita logo que o acidentado esteja estabilizado.

Recorde que nestas situações o tempo é um factor determinante para o sucesso da recuperação do acidentado.

9.5 PRÁTICA DE REANIMAÇÃO CÁRDIO-PULMONAR (RCP)

A) RCP POR 1 SOCORRISTA

→ Iniciar a manobra com 15 compressões torácicas, seguidas de 2 insuflações. Repetir esta sequência 4 vezes e reavaliar a situação palpando o pulso carotídeo durante 5 segundos:

- Se ainda não há pulsação, reiniciar a RCP;
- Se há pulsação, verificar se a respiração espontânea se restabeleceu;
- Se há pulsação e respira espontaneamente, manter vigilância constante;
- Se há pulsação e não respira, reiniciar a ventilação artificial a um ritmo de uma insuflação em cada 5 segundos.

B) RCP POR 2 SOCORRISTAS

→ Um dos socorristas inicia com 5 compressões torácicas e de seguida o outro socorrista efectua uma insuflação. Repetir esta sequência durante 12 ciclos, altura em que deve ser reavaliada a situação do acidentado;

- Se o acidentado continua sem pulsação e sem respiração, mantêm-se as manobras de reanimação até que recupere as funções vitais;
- Se há pulsação mas o acidentado não respira reiniciar a ventilação artificial a um ritmo de uma insuflação em cada 5 segundos.

Estas manobras devem manter-se até que o acidentado recupere as funções vitais ou até à chegada de socorros especializados.

Não dar de beber a uma pessoa em estado de inconsciência ou em recuperação de um estado de inconsciência, ainda que a pessoa o solicite. Quando muito humedecer-lhe os lábios com água.

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Manutenção, segurança e saúde no trabalho: uma imagem estatística

Nos termos da Norma Europeia 13306 ([1]), a manutenção diz respeito à «combinação de todas as acções técnicas, administrativas e de gestão executadas durante o ciclo de vida de um artigo *[local de trabalho (edifício), equipamento de trabalho ou meio de transporte]* tendo em vista mantê-lo ou repô-lo em estado de aptidão para o desempenho das suas funções». A manutenção influencia a segurança e a saúde dos trabalhadores de duas maneiras. Em primeiro lugar, uma manutenção regular, correctamente planeada e executada, é essencial para manter as máquinas e o ambiente de trabalho seguros e fiáveis. Em segundo lugar, a própria manutenção deve ser executada de forma segura, com uma protecção adequada dos trabalhadores que a efectuam e das restantes pessoas presentes no local de trabalho.

Existem diversos tipos de manutenção:

- **manutenção correctiva**, quando as acções se destinam a repor um sistema avariado em estado de funcionamento (por exemplo, reparação ou substituição de componentes inutilizadas). Este tipo de manutenção também é denominado «manutenção reactiva» porque a acção é desencadeada pela ocorrência não programada da avaria de um equipamento;
- **manutenção preventiva**, quando as acções são executadas com uma periodicidade predeterminada ou em conformidade com os critérios prescritos para reduzir a probabilidade de avaria ou degradação do funcionamento de um artigo. Neste caso, as acções são programadas, dinâmicas e destinadas a controlar o processo de deterioração que leva à avaria de um sistema (por exemplo, substituição, lubrificação, limpeza ou inspecção).

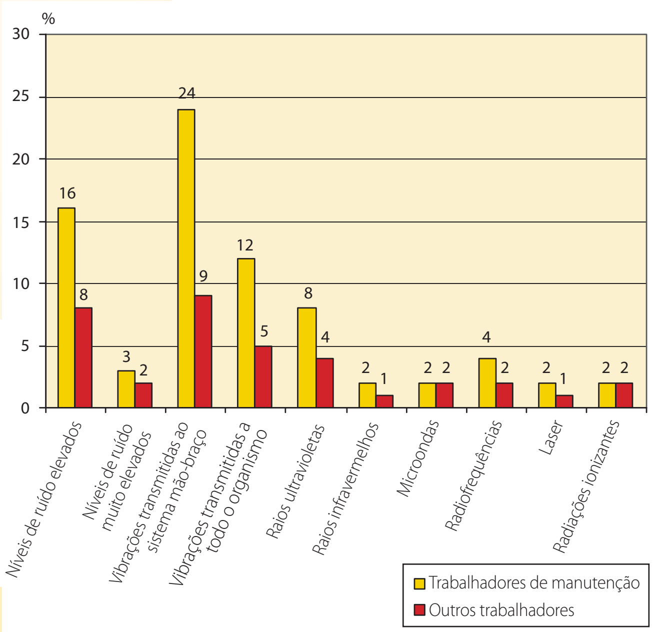
A manutenção abrange várias profissões e interessa a todos os sectores de actividade. Por estas razões, é difícil identificar o número exacto de trabalhadores implicados nas actividades de manutenção. Os dados de França e Espanha indicam que **cerca de 6% da população activa** está envolvida em trabalhos de manutenção. Os trabalhadores de manutenção são, na sua maioria, homens (cerca de 90% em França e 65% em Espanha) e situam-se, principalmente, na faixa etária dos 30 aos 49 anos.

Segundo um inquérito realizado em 2005 em França, a manutenção é a **função mais subcontratada da indústria**. Em Espanha, os trabalhadores de manutenção pertencem maioritariamente ao sector dos serviços (70% em 2004), seguidos pela indústria (19%) e pela construção (10%).

Por executarem uma gama de actividades ampla e diversificada, os trabalhadores de manutenção estão expostos a muitos e variados perigos no local de trabalho. Há riscos físicos (ruído, vibrações, calor e frio excessivos, radiação, trabalhos fisicamente muito exigentes), riscos químicos (trabalho com amianto, soldadura, exposição a substâncias perigosas em espaços confinados), riscos biológicos (legionelose, leptospirose) e riscos psicossociais (má organização do trabalho). Estes trabalhadores também estão sujeitos a sofrer todo o tipo de acidentes.

Os dados do inquérito espanhol sobre as condições de trabalho indicam que os trabalhadores de manutenção estão mais expostos ao ruído, às vibrações e a diferentes tipos de radiação do que o resto da população activa (ver figura 1). Também estão mais expostos ao calor no Verão (44% para apenas 19% noutras profissões), ao frio no Inverno (44% para 17%) e à humidade atmosférica (25% para 13%). A sua exposição a substâncias, vapores e fumos perigosos é igualmente maior.

Figura 1 — Exposição a riscos entre os trabalhadores de manutenção (Espanha, 2007)



As análises dos dados do Eurostat baseados na metodologia ESAW [European statistics on accidents at work (estatísticas europeias sobre acidentes de trabalho)] podem ajudar a identificar os acidentes relacionados com as actividades de manutenção em vários países europeus. Na variável «processo de trabalho», utilizada na classificação das causas e circunstâncias dos acidentes, há quatro subcategorias relativas às **operações de manutenção**:

- colocação, preparação, instalação, montagem, desmontagem, desmantelamento;
- manutenção, reparação, afinação, ajustamento;
- limpeza mecânica ou manual de espaços de trabalho e máquinas;

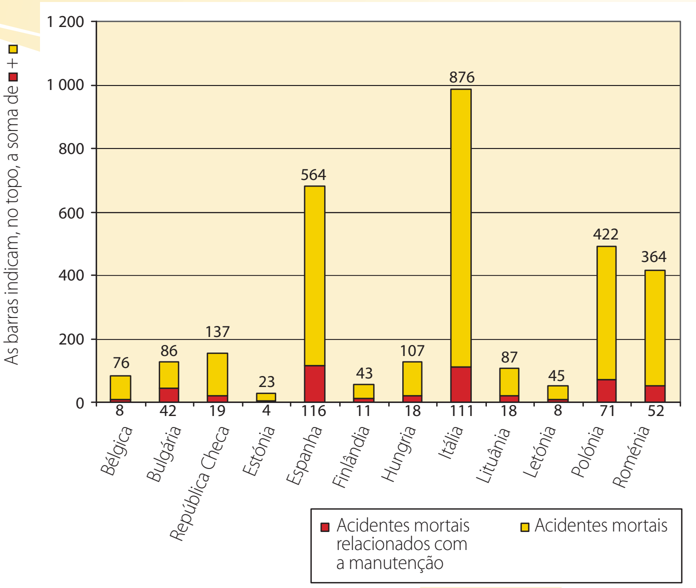
([1]) CEN EN 13306 Terminologia da manutenção, http://www.cen.eu/.

- controlo, inspecção dos processos de produção, espaços de trabalho, meios de transporte, equipamentos (com ou sem equipamentos de controlo).

O número de acidentes relacionados com estas subcategorias foi comparado com o número total de acidentes relacionados com qualquer outra subcategoria incluída na variável «processo de trabalho».

Os dados revelam que cerca de **20%** dos acidentes ocorridos na Bélgica (em 2005-2006) estavam relacionados com operações de manutenção, o mesmo acontecendo com cerca de **18% a 19%** dos acidentes na Finlândia, **14% a 17%** em Espanha e **10% a 14%** em Itália (em 2003-2006). Além disso, os valores relativos a vários países europeus indicam que, em 2006, aproximadamente **10% a 15% dos acidentes mortais estavam relacionados com operações de manutenção** (ver figura 2). Os estudos científicos indicam que as doenças profissionais e os problemas de saúde relacionados com o trabalho (como a asbestose, o cancro, problemas auditivos e lesões músculo-esqueléticas) também são mais prevalecentes entre os trabalhadores envolvidos em actividades de manutenção.

Figura 2 — Número de acidentes mortais relacionados com operações de manutenção (Eurostat, 2006)



Os dados do Eurostat relativos a cinco Estados-Membros da União Europeia indicam que a maioria dos acidentes relacionados com a manutenção tem lugar na indústria transformadora, na construção, nas actividades imobiliárias, alugueres e serviços prestados às empresas (²) e, na Áustria, também nos hotéis e restaurantes. Além disso, em 2006, no sector do **abastecimento de electricidade, gás e água**, **50%** dos acidentes ocorridos na Finlândia e na Bélgica, **34%** em Espanha e **23%** em Itália estavam relacionados com operações de manutenção. No sector das **actividades imobiliárias, alugueres e serviços prestados às empresas, 40%** dos acidentes registados na Finlândia, **34%** em Espanha, e **26%** na Bélgica estavam igualmente relacionados com a manutenção. O mesmo acontecia, também na Bélgica, com **41%** dos acidentes registados no sector

da **educação**. Noutros sectores, consoante o país, **15% a 20%** dos acidentes estavam relacionados com esse tipo de operações.

A bibliografia científica indica que a maioria dos acidentes se verificou no decurso de actividades de **manutenção correctiva**. Além disso, a análise de uma base de dados francesa sobre acidentes de trabalho mostra que, em 2002, os trabalhadores de manutenção estavam em segundo lugar entre as vítimas mais frequentes de acidentes relacionados com a subcontratação, logo a seguir aos trabalhadores da construção (³).

A falta de manutenção ou uma manutenção inadequada também podem causar situações de perigo, acidentes e problemas de saúde. Estes podem advir da ausência de manutenção ou da manutenção deficiente de veículos, máquinas industriais ou agrícolas, instalações eléctricas, extintores de incêndio, edifícios ou instalações hidráulicas.
As falhas de manutenção podem contribuir para a ocorrência de grandes desastres com consequências extremamente prejudiciais para os seres humanos e o ambiente.

O processo de manutenção deve começar na fase de concepção e planeamento, antes de os trabalhadores de manutenção entrarem sequer no local de trabalho. É essencial aplicar procedimentos apropriados de **avaliação de riscos** nas operações de manutenção e introduzir **medidas de prevenção adequadas** para garantir a segurança e a saúde dos trabalhadores envolvidos nessas actividades. Após a conclusão das operações de manutenção, devem ser efectuadas verificações especiais (inspecções e ensaios) para comprovar que a manutenção foi convenientemente efectuada e que não foram criados novos riscos. Ao longo de todo o processo, uma **boa gestão da manutenção** deve assegurar que a manutenção é correctamente coordenada, programada e executada conforme o planeado, e que o equipamento ou local de trabalho ficou em boas condições de segurança para ser utilizado.

Informações complementares

A versão integral do relatório *Maintenance and OSH — A statistical picture* está disponível em:

http://osha.europa.eu/en/publications/literature_reviews

A presente publicação é um contributo para a Campanha Europeia sobre trabalhos de reparação e manutenção seguros (2010/2011). Para aceder a outras fichas técnicas desta série e a mais informações sobre a avaliação de riscos, consulte http://osha.europa.eu/en/topics/maintenance. Este *site* está em permanente desenvolvimento e actualização.

(²) O sector das actividades imobiliárias, alugueres e serviços prestados às empresas é constituído por subcategorias como «manutenção e reparação de máquinas de escritório, de contabilidade e de material informático», ou «actividades de limpeza industrial».

(³) Grusenmeyer C. «Sous-traitance et accidents». Exploitation de la base de données EPICEA Les Notes Scientifiques et Techniques de l'INRS, p. 266, 2007.

Agência Europeia para a Segurança e Saúde no Trabalho
Gran Vía, 33, 48009 Bilbau, ESPANHA
Tel.: +34 944794360 • Fax: +34 944794383
Correio electrónico: information@osha.europa.eu

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Occupational electrical injuries in the United States, 1992–1998, and recommendations for safety research

James C. Cawley*, Gerald T. Homce

National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, P.O. Box 18070, Pittsburgh, PA 15236, USA

Abstract

Problem: CFOI and SOII data show that 2,287 U.S. workers died and 32,807 workers sustained days away from work due to electrical shock or electrical burn injuries between 1992 and 1998. *Method*: The narrative, work activity, job title, source of injury, location, and industry for each fatal electrical accident were examined. A primary causal factor was identified for each fatality. *Results*: Electrical fatalities were categorized into five major groups. Overall, 44% of electrical fatalities occurred in the construction industry. Contact with overhead power lines caused 41% of all electrical fatalities. *Discussion*: Electrical shock caused 99% of fatal and 62% of nonfatal electrical accidents. Comprising about 7% of the U.S. workforce, construction workers sustain 44% of electrical fatalities. Power line contact by mobile equipment occurs in many industries and should be the subject of focused research. Other problem areas are identified and opportunities for research are proposed. *Impact on Industry*: Improvements in electrical safety in one industry often have application in other industries.

Keywords: Electrical; Injury; Fatality; Electrocution; Shock; Electrical burn

1. Introduction

On-the-job accidents in the United States are a serious occupational problem. No one expects to be injured, much less killed on the job. Yet each calendar day on average in the United States, more than 15,000 workers sustain on-the-job injuries or illnesses and 17 are killed. Electrical incidents cause an average of 13 days away from work injuries[1] and nearly one fatality every day.

1.1. Data sources

The U.S. Labor Department's Bureau of Labor Statistics (BLS) compiles the Census of Fatal Occupational Injuries (CFOI) from death certificates and other information for U.S. workers killed on the job.[2] The 1992–1998 CFOI database contains information on 43,921 occupational fatalities from all injury-related causes.[3] Such information includes incident narratives, the source of injury, victim's occupation, location of the incident, work activity at the time of death, and other details. By analyzing such objective information, a reasonable understanding of most incidents can be achieved. Analogous to CFOI, BLS's Survey of Occupational Illnesses and Injuries (SOII) provides an estimate of the more than five million nonfatal occupational injuries and illnesses that occur in the United States each year. A statistical estimate based on a stratified sample,[4] the SOII does not contain narrative or work activity information on individual nonfatal incidents. Recent upgrades to the BLS's online search capability for both CFOI and SOII allow improved limited public access to selected U.S. occupational injury and illness information.[5] The SOII information presented in this paper

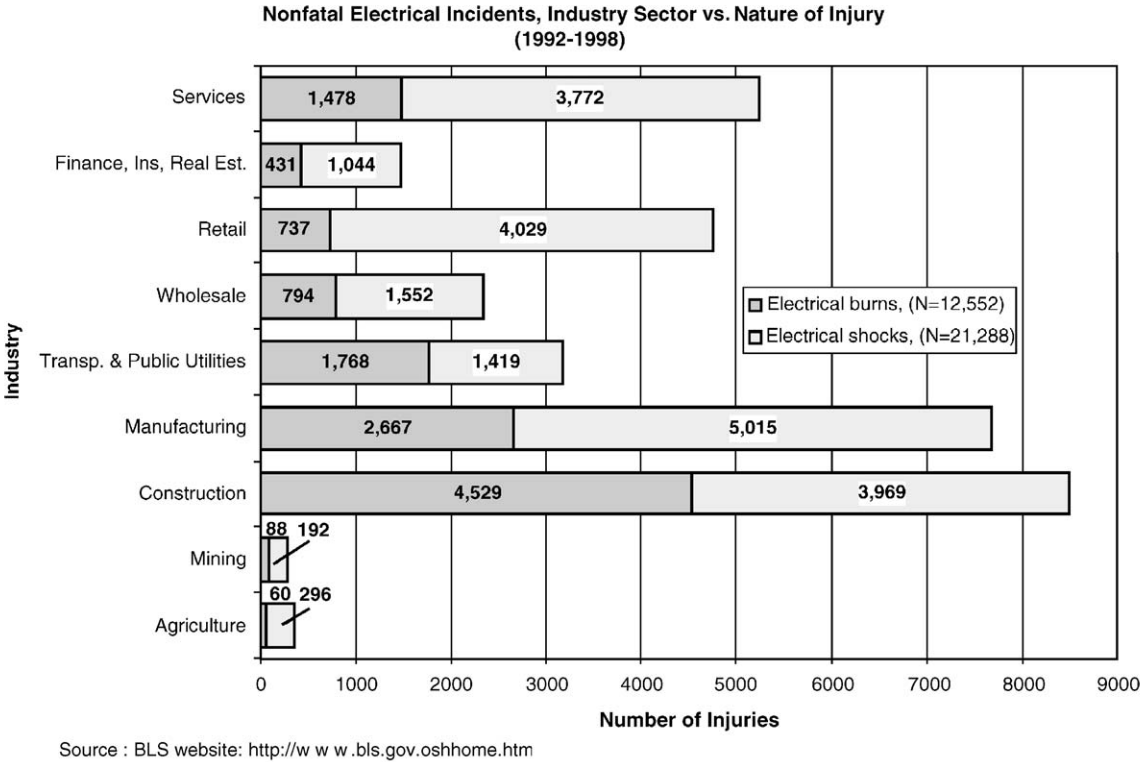

Fig. 1. Number of nonfatal electrical injuries in each major industrial sector that resulted in days away from work between 1992 and 1998 (some of the data were not available for some years).

was obtained from this publicly available source. The CFOI information was obtained from direct access to the CFOI database through special arrangement between the National Institute for Occupational Safety and Health (NIOSH) and BLS. The combination of CFOI and SOII data can provide a useful glimpse into the details of occupational electrical injury in the United States.

1.2. Selecting data for analysis

Occupational incidents often involve several events that cascade into a fatality. Consider the case where a worker is nonfatally shocked, causing a fall with a resulting fatal head injury. As a result, BLS established rules for selecting how occupational injuries and illness are classified, which are detailed in the Occupational Injury and Illness Classification System (OIICS) Manual.[6] In general, a case is coded according to the most serious nature of injury. As an example, a case in which electric shock causes a worker to fall and suffer a fatal head injury is coded as: nature = intracranial injury; part = brain; source = floor; event = fall; secondary source = electric wire or apparatus that caused the electric shock. In addition, the following events take precedence over other events or exposures: assaults and violent acts, transportation incidents, and fires and explosions. Event code counts have been used in this paper except where noted.

When event codes are used to select CFOI narratives, 2,267 electrical injuries can be isolated for the period from 1992 to 1998. When sorted by nature of injury codes *0930 (electrocution, electrical shock)* and *0520 (electrical burns)*, 2,287 cases can be found. These additional electrical fatalities stem mainly from burns resulting from electrical explosions and electrocutions from an overhead power line after a vehicular incident. The SOII shows that private industry recorded 32,309 nonfatal electrical injuries by event code and 32,807 by nature of injury codes 0930 (electrocution, electrical shock) and 0520 (electrical burns). An analysis of electrical injuries by either event or nature of injury data does not produce significantly different results.

1.3. Significance of including fatal and nonfatal injury data

Two previous studies (Cawley, 2001; Homce, Cawley, Yenchek, & Sacks, 2001) of fatal and nonfatal electrical incidents in the mining industry using data from the U.S. Labor Department's Mine Safety and Health Administration (MSHA) showed that both fatal and nonfatal occupational incidents must be studied to obtain an accurate picture of the circumstances that surround mine electrical incidents.

Similarly, CFOI data show that 98.5% of the 2,287 occupational electrical fatalities selected by nature of injury code that occurred between 1992 and 1998 were attributed to

[6] A detailed description of how BLS classifies incident data is available on its website at http://www.bls.gov/iif/oshoiics.htm.

electrocution, electric shock. However, 62% of an estimated 32,807 nonfatal occupational electrical injuries were classified as electrocution, electric shock and 38% as electrical burns. Fig. 1 shows that the ratio of nonfatal electrocution, electric shock to electrical burn injuries varies substantially among the nine industrial sectors tracked by BLS.

Thus, analysis based solely on fatal or nonfatal electrical incidents could lead to an inaccurate overall picture of the interventions needed to provide the greatest impact in a particular industry. Remediations that address electrical burns will have more impact on nonfatal injuries, while those that address electrical shock will primarily affect fatal injuries.

2. Electrical incident data

2.1. Background data

The top 10 CFOI event code categories for occupational fatalities from all causes from 1992 to 1998 are shown in descending order in Table 1. Fatal incidents involving electricity rank sixth among all causes of occupational fatality in the United States, totaling 2,267 (5.2%) during the study period. The number of fatal electrical incidents by CFOI event code is shown in Table 2. The event code with the most fatalities is code 3130, contact with overhead power lines, with 933 fatal cases. Contact with overhead power lines caused 41% of all occupational electrical fatalities.

The number of private industry nonfatal electrical incidents that caused days away from work between 1992 and 1998 is shown in Table 3. The two event codes with the highest number of days away injuries are code 3110, contact with electric current of a machine, tool, appliance, or light fixture, with 12,189 cases (38%) and code 3120, contact with wiring, transformers, or other electrical components, with 10,782 cases (33%). These data imply that nonfatal electrical injury occurs most often to those who work with machines or tools and around electrical wiring other than power lines. Median days away for nonfatal electrical incidents are shown in Table 4.

Table 1
Rank of top 10 CFOI causal categories by event code

CFOI event code range	Description	No. of incidents	Percentage of incidents
4000–4330	Transportation (except railway)	14,713	33.5
6000–6390	Violent acts	8,447	19.2
1000–1900	Falls	4,643	10.6
0100–0290	Struck by, against	4,043	9.2
0300–0490	Caught in	2,909	6.6
3100–3190	Electricity	2,267	5.2
4600–4690	Aircraft	2,163	4.9
3200–3900	Exposure to (except electricity)	1,838	4.2
4500–4590	Water craft	749	1.7
5200–5290	Explosions	702	1.6
All other causes		1,447	3.3
Total fatal incidents		43,921	

Table 2
Fatal electrical incidents for all industries by event code, 1992–1998

Year	Event code							
	3100	3110	3120	3130	3140	3150	3190	Total
1992	32	60	66	140	X	15	19	334
1993	32	44	100	115	5	16	12	324
1994	23	63	98	132	6	15	11	348
1995	32	55	94	139	5	17	6	348
1996	22	46	70	116	5	18	X	281
1997	14	41	71	138	5	22	7	298
1998	10	51	84	153	9	21	6	334
Total	165	360	583	933	37	124	65	2,267

X means no data or insufficient data available for this year.
Event code descriptions are as follows:

3100—Contact with electric current, unspecified
3110—Contact with electric current of machine, tool, appliance, or light fixture
3120—Contact with wiring, transformers, or other electrical components
3130—Contact with overhead power lines
3140—Contact with underground, buried power lines
3150—Struck by lightning
3190—Contact with electric current, n.e.c.

Row may not sum to total.
Source: BLS, CFOI 1992–1998.

Table 3
Nonfatal electrical incidents involving days away, private industry, by event code, 1992–1998

Year	Event code							
	3100	3110	3120	3130	3140	3150	3190	Total
1992	507	1,795	1,614	174	36	170	509	4,806
1993	453	2,111	1,531	133	74	71	620	4,995
1994	506	2,966	1,607	273	38	214	415	6,018
1995	769	1,506	1,571	155	47	172	522	4,744
1996	405	1,037	1,751	92	153	223	465	4,126
1997	365	1,413	1,390	79	52	X	386	3,710
1998	506	1,361	1,318	314	40	50	322	3,910
Total	3,511	12,189	10,782	1,220	440	900	3,239	32,309

X means no data or insufficient data available for this year.
Event code descriptions are as follows:

3100—Contact with electric current, unspecified
3110—Contact with electric current of machine, tool, appliance, or light fixture
3120—Contact with wiring, transformers, or other electrical components
3130—Contact with overhead power lines
3140—Contact with underground, buried power lines
3150—Struck by lightning
3190—Contact with electric current, n.e.c.

Rows may not sum to total.
Source: BLS website: http://www.bls.gov/iif/.

Table 4
Nonfatal electrical injuries, median days away by event code, private industry, 1992–1998

Year	Event code							
	3100	3110	3120	3130	3140	3150	3190	Total
1992	13	3	7	33	21	6	2	5
1993	10	3	8	8	2	3	5	4
1994	4	5	4	30	15	14	6	5
1995	3	2	5	13	10	2	2	3
1996	3	4	22	5	2	3	12	7
1997	1	4	4	60	14	X	8	4
1998	10	4	6	14	137	3	2	5

X means no data or insufficient data available for this year.
Event code descriptions are as follows:

3100—Contact with electric current, unspecified
3110—Contact with electric current of machine, tool, appliance, or light fixture
3120—Contact with wiring, transformers, or other electrical components
3130—Contact with overhead power lines
3140—Contact with underground, buried power lines
3150—Struck by lightning
3190—Contact with electric current, n.e.c.

Source: BLS website: http://www.bls.gov/iif/.

2.2. Occupational electrical incidents are disproportionately fatal

Electrical incidents, although a small portion of total incidents, are disproportionately fatal when they occur. During 1997, for example, there were 6.1 million nonfatal injuries and illnesses reported from all causes. Of those, 1.83 million injuries (30%) caused one or more days away. There were 3,710 days away electrical injuries reported during 1997, comprising only 0.2% of the total days away injuries reported from all causes. However, of the 6,238 fatal incidents reported from all causes during 1997, 298 (4.8%) were attributed to electricity. During 1997, approximately 1 in 494 days away injuries and illnesses were caused by electricity, but nearly 1 in 20 occupational fatalities were from electrical causes.

2.3. Voltage data

CFOI reported voltages in 623 (27%) of the electrical narratives studied. The following tallies were compiled for nominal voltage categories:

- 0–600 V—198 cases (32%) including:
  - 480 V—50 cases
  - 440 V—18 cases
  - 277 V—24 cases
  - 220/240 V—36 cases
  - 110/120 V—42 cases;
- 601–5000 V—50 cases (8%);
- 5001–10,000 V—215 cases (35%) including:
  - 7200 V—149 cases;
- 10,001–15,000 V—81 cases (13%) including:
  - 12,000 V—35 cases; and
- 15,001 and over—79 cases (13%).

Incident voltage was 15,000 V or less in 87% of reported cases.

3. CFOI narrative analysis

The objective of analyzing occupational electrical incidents is to identify problem areas and to develop strategies and techniques to reduce their frequency and severity. Many aspects of the circumstances surrounding fatal incidents are available directly from the CFOI database, such as victim, location, and activity information. It is useful, however, to attribute a primary "cause" to each incident. This is feasible for fatal electrical incidents because CFOI supplies a brief narrative description of each case. Researchers familiar with electrical safety issues in commercial/industrial work environments initially attempted to create a uniform and comprehensive analysis structure with which to assess each narrative, but this approach proved too cumbersome. Ultimately, a more subjective approach was used wherein each narrative was read and a primary cause assigned that may have been related to the work activity, personnel, or the equipment involved. This process in some cases required inference and engineering judgment by the authors, but from it emerged groupings that efficiently categorized and described the incidents under study. Fatal electrical incident narratives were divided into those incidents that occurred in the construction industry (about 44% of all fatal electrical incidents) and those that occurred in the nonconstruction industries. Additionally, the review identified each incident that occurred during "electrical work," regardless of the cause, and those incidents that occurred during nonelectrical work. These preconditions created a useful framework for the analysis due to the large number and high rate of electrical incidents in the construction industry and the disparity between circumstances surrounding incidents that occurred during electrical installation/maintenance work and those that occurred during other activities.

There were 43,921 fatal occupational incidents in the United States between 1992 and 1998. After selection by nature of injury codes for 0930 (electrocution, electrical shock) and 0520 (electrical burns), 2,287 fatal electrical incidents remained. Based on the review of CFOI narratives for these incidents, 91% of fatal occupational electrical injuries were classified into one of the following five categories:

- *Installation and maintenance of electrical systems and equipment (excluding overhead or buried power transmission/distribution lines)* (506 incidents, 22%). This group includes residential, commercial, and industrial environments, as well as personnel of varying backgrounds, and so will encompass a seemingly wide range of incident situations. The strong common thread however is that work was being performed on or adjacent to live circuits of which the worker may or may not have been aware. The activities most frequently cited were installation or maintenance of power system components (e.g., cables, transformers, and breakers), lighting fixtures, and heating, ventilating, and air conditioning (HVAC) equipment.

- *Contact with an overhead electric power line through a handheld object during activities other than electrical system installation and maintenance* (495 incidents, 22%). These incidents involved workers contacting overhead power lines with long, conductive, handheld items while performing work activities unrelated to electrical systems or components. The most common object in use was a ladder, but construction materials, tools, and scaffold members were also mentioned in numerous accounts.
- *Contact with an overhead electric power line indirectly through a piece of high-reaching mobile equipment during activities other than electrical system installation and maintenance* (387 incidents, 17%). In these incidents, mobile equipment contacted a line and was either simultaneously or subsequently contacted by workers who unintentionally completed the circuit to ground. These were incidental contacts in that work underway at the time was unrelated to the power lines. The types of equipment most commonly involved were cranes, boom trucks (light cranes on flatbed truck chasses), dumpbed trucks, and drill rigs.
- *Incidental contact with energized circuits (excluding overhead or buried power transmission/distribution lines)* (424 incidents, 19%). This category by definition covers work activities other than electrical system installation and maintenance. The electrocutions most frequently resulted from contacting bare wires and faulty or inappropriate power tools (including equipment with ineffective grounding).
- *Installation/construction and maintenance of overhead or buried power transmission/distribution lines* (253 incidents, 11%). This is a relatively narrowly defined category and includes some of the most inherently hazardous activities. In most cases, personnel were working on or adjacent to overhead high-voltage circuits from a pole/tower or elevated platform (bucket truck).

Of the remaining occupational electrical fatalities recorded in CFOI, approximately 5% were due to lightning strikes and the remainder could not be classified with the information provided.

4. Prior NIOSH research that addressed electrical hazards

NIOSH Alerts briefly present information about occupational illnesses, injuries, and deaths. Alerts urgently request assistance in preventing, solving, and controlling newly identified occupational hazards. Alerts ask workers, employers, and safety and health professionals to take immediate action to reduce risks and implement controls.

A number of NIOSH Alerts have studied various electrical problem areas (U.S. Department of Health and Human Services [US DHHS], 1984, 1986a, 1986b, 1986c, 1987, 1989). Some of the recommendations made in these NIOSH Alerts include:

- The use of ground fault circuit interrupters to prevent electrocutions among fast food restaurant workers;
- Improved training and signage to prevent grain auger electrocutions;
- Improved training in hazard recognition and cardiopulmonary resuscitation (CPR) to prevent fatalities among those workers who contact electrical energy;
- Improved hazard recognition training, use of personal protective equipment (PPE), and improved work procedures for power line workers;
- Strict adherence to Occupational Safety and Health Administration (OSHA) regulations and improved training in hazard recognition and work practices to prevent electrocutions with ladders and, in the case of scaffolds, recommendations for nonconductive scaffolding and improved signage;
- Strict adherence to OSHA and American National Standards Institute (ANSI) regulations and improved safety and CPR training to prevent electrocutions during tree-trimming operations;
- Strict adherence to OSHA regulations and improved inspection of equipment by a “competent person” to ensure that the insulation characteristics of aerial bucket trucks are adequate;
- Strict adherence to OSHA and ANSI regulations, improved hazard recognition training, use of utility services to deenergize lines, and encouragement of private industry to improve equipment to prevent electrocution of crane operators and ground crews by overhead power lines;
- Strict adherence to child labor laws, parental involvement, and improved hazard recognition training to protect adolescent workers against electrocution;
- Strict adherence to OSHA regulations, improved signage, deenergization, lockout–tagout, and grounding of electrical systems prior to beginning work on electrical systems to protect all workers from uncontrolled releases of electrical energy.

NIOSH’s Fatality Assessment and Control Evaluation (FACE) program is a research program designed to identify and study fatal occupational injuries. The goal of the FACE program is to prevent occupational fatalities across the nation by identifying and investigating work situations at high risk for injury and then formulating and disseminating prevention strategies to those who can intervene in the workplace.

FACE is a research program. Investigators do not enforce compliance with state or federal occupational safety and health standards nor do they determine fault or blame.

U.S. Department of Health and Human Services (UD DHHS, 1998) examined 224 occupational electrical incidents that resulted in 244 fatalities between 1982 and 1994 using NIOSH's FACE reports and made recommendations to reduce the number of electrical incidents. Recommendations included improvements to training procedures, adherence to existing OSHA regulations, and improved warning signage.

One logical extension of past NIOSH electrical safety studies is research to develop effective engineering control solutions to address the recommended interventions. This could include work to adapt existing successful solutions from one industry to another, as well as research to conceptualize, build, and test prototype electrical safety devices.

5. Mine electrical safety research by the U.S. Bureau of Mines

The U.S. Bureau of Mines began an extensive mine electrical safety research program in response to the 1969 Coal Mine Safety and Health Act. A wide variety of electrical safety topics were addressed that were relevant not only to mining, but other industries as well. The bureau emphasized an engineering approach to electrical safety problems, working to produce, test, and document a wide variety of practical solutions for identified mine electrical hazards. Electrical system studies, trailing cable splicing improvements, mine trailing cable life studies, electrical maintenance practices, grounding practices, arcing fault detection, explosion-proof enclosure and intrinsic safety research, mitigating overhead power line hazards, and system and personnel protection devices were some of the areas studied. The interested reader can find a searchable archive of Bureau of Mines' research at the Common Information Service System (CISS) Website maintained by NIOSH.[7] This research continued until the bureau was closed in 1996. Shortly thereafter, the former bureau's mine safety and health research functions, as well as some of its remaining resources, were assumed by NIOSH.

6. Research opportunities

As the analysis in this study revealed, occupational electrical injuries occur in many industries, under widely varying circumstances, and involve nearly all occupations. This suggests that research directed toward reducing electrical injuries should include an equally diverse array of complimentary intervention concepts, each targeting a well-defined aspect of the problem, suitable for practical applications, and with potential for measurable success. Ideally, efforts should focus on the most prevalent accident scenarios, represent different approaches for reducing electrocutions, and draw on the expertise of researchers from different disciplines. No single ‘‘silver bullet’’ approach will solve the problem of electrical death and traumatic injury, but innovative ideas for engineering controls, workplace management, and training can combine to have a positive impact.

With the acquisition of the facilities and personnel of the former Bureau of Mines' Pittsburgh Research Center, NIOSH now has additional resources for electrical safety research, especially in the area of engineering controls. Indeed, the bureau's history of focused practical solutions for specific safety problems compliments the analysis and identification of hazards that typify much past NIOSH research.

To decrease the number and severity of nonfatal electrical burn injuries, direct worker exposure to electrical arc energy must be reduced. One possible approach to this problem involves engineering hazards out of electrical systems; studying and improving (where needed) management controls over electrical work; developing improved electrical hazard recognition and avoidance training focused on the injury potential of electrical arcing; implementing and evaluating such training; and identifying PPE appropriate to recognized arcing hazards and communicating its benefits to affected workers, especially in the mining industry.

While it comprises only about 7% of the U.S. workforce, the construction industry accounted for 44% of all fatal electrical injuries. Approximately one in eight construction fatalities involved electricity. As shown in Fig. 1, 25% of all nonfatal electrical injuries between 1992 and 1998 occurred in the construction industry. Of fatal incidents, 56% involved power lines. Significant effort should be expended to improve the electrical safety of construction workers, especially in the area of overhead power line hazards. About 45% of electrical fatalities in nonconstruction industries also involved power lines. Such research would have a synergistic effect in other industrial sectors as well, principally in mining where 20% of electrical fatalities during the 1990s involved cranes, trucks, and drill rigs contacting power lines (Cawley, 2001). Contact with high-reaching mobile equipment was a significant cause of electrical fatalities involving power lines. Construction industry incidents usually involved cranes, boom trucks, and drill rigs. Nonconstruction industry incidents most often involved boom trucks. Engineering control research that builds on past work in this area is needed. Research to develop a warning device to alert ground crews and equipment operators of accidental power line contact was conducted at NIOSH's Pittsburgh research laboratory. Several simple modifications to vehicles and associated equipment could significantly reduce the number of incidents in this category. For example, boom truck operator electrical safety could be improved by the increased use of remotely controlled hoisting devices or by moving the manual hoisting controls to a position that requires the operator to stand on the truck to operate them.

[7] http://outside.cdc.gov:8000/ciss/Welcome.html.

Contacting an overhead electric power line through a handheld object was another significant cause of occupational electrical fatalities. Construction industry incidents usually involved ladders, scaffolds, metallic pipes, rods, and poles, and siding, gutters, and sheet metal. Nonconstruction industry incidents typically involved landscaping and tree-trimming operations often associated with utility contractors conducting tree-trimming operations. The need to exercise safe work practices (maintenance of safe work distances, the use of insulating blankets, the use of nonconducting handheld poles/handles, ladders, etc.) must continue to be reinforced with hazard recognition and avoidance training. Engineering control research should be undertaken to provide additional protection for workers using ladders and scaffolds. Improved methods for safely handling long conductive objects (poles, antennas, pipes, etc.) in the presence of power lines also needs closer examination.

Installation, maintenance, and repair of electrical equipment were the leading causes of occupational fatality incidents that did not involve power lines. The activities most frequently cited were installation or maintenance of power system components (e.g., cables, transformers, and breakers), lighting fixtures, and HVAC equipment. Improved maintenance work practices and engineering control devices to remove hazards, where practical, are needed. Supplemental research into improved electrical lockout–tagout procedures is one potential research area. Research into arc-detecting circuit breaker technology, now emerging in residential and industrial applications for fire protection, could be more fully explored for its possible application to high-energy arcing faults. Application of sensitive ground fault protection on light fixtures could save lives of non-electrical personnel who change bulbs and fixtures in commercial establishments.

Another approach to protecting electrical maintenance workers is to limit their exposure to hazardous circuits, where possible. The use of computerized motor control center maintenance interfaces, as described by Blair, Doan, Jensen, and Kim (2001), precludes the need for a worker to open a motor control center in order to perform routine electrical maintenance. Similar maintenance techniques could be investigated for their potential to reduce exposure to electrical hazards during routine maintenance.

7. Summary

This report has presented the results of an analysis of CFOI and SOII data revealing that electricity is a serious occupational injury problem. Noteworthy among the findings is that although electrical shocks and burns do not occur as frequently as many other types of occupational injuries, they are disproportionately fatal. Analysis also concluded that the causes of most fatal electrical incidents fall into one of five categories: (a) installation and maintenance not involving power lines; (b) incidental contact of an overhead power line with a handheld object; (c) incidental contact of an overhead power line through mobile equipment; (d) incidental contact with energized circuits other than overhead or buried power lines; and (e) power line installation and maintenance work. Past electrical safety research by NIOSH and by the former U.S. Bureau of Mines was briefly reviewed, and recommendations for future electrical safety research were outlined.

8. Notes

NIOSH Alerts are available via the Internet at http://www.cdc.gov/niosh/alerts2.html or by contacting: National Institute for Occupational Safety and health, Publications Dissemination, 4676 Columbia Parkway, Cincinnati, OH 45226-1998, USA. Tel.: 1-800-35-NIOSH (1-800-356-4674); fax: +1-513-533-8573. E-mail: pubstaft@cdc.gov.

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WORKER DEATHS BY ELECTROCUTION

A Summary of NIOSH Surveillance and Investigative Findings

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

May 1998

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Ted A. Pettit, Division of Safety Research
Timothy J. Pizatella, DSR
Herbert I. Linn, DSR

Data analysis and technical review

Stephanie G. Pratt, DSR

Word processing and document preparation

Suetta J. Marsh, DSR
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Kathy J. Boyce, DSR

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Joyce R. Spiker, DSR

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Linda L. Morton, DSR

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Herbert I. Linn, DSR

PUBLIC HEALTH SUMMARY

What are the hazards?

Based on data from the NIOSH National Traumatic Occupational Fatalities (NTOF) surveillance system, electrocutions were the fifth leading cause of death from 1980 through 1992. The 5,348 deaths caused by electrocutions accounted for 7% of all fatalities and an average of 411 deaths per year.

How can a worker be exposed or put at risk?

Electricity is present at most jobsites, and many American workers, regardless of industry or occupation, are exposed to electrical energy daily during the performance of their tasks. These hazardous exposures may exist through contact with an object as seemingly innocuous as a broken light bulb to an energized overhead powerline.

What recommendations has the federal government made to protect workers' health?

The Occupational Safety and Health Administration (OSHA) addresses electrical safety in Subpart S 29 CFR 1910.302 through 1910.399 of the General Industry Safety and Health Standards. The standards contain requirements that apply to all electrical installations and utilization equipment, regardless of when they were designed or installed. Subpart K of 29 CFR 1926.402 through 1926.408 of the OSHA construction safety and health standards contain installation safety requirements for electrical equipment and installations used to provide electric power and light at the jobsite. These sections apply to both temporary and permanent installations used on the jobsite. Additionally, the National Electrical Code (NEC) and the National Electrical Safety Code (NESC) comprehensively address electrical safety regulations. NIOSH recommendations focusing on prevention are included in this Technical Document.

Where can more information be found?

The references at the end of this document provide a useful inventory of published reports and literature. Additional information from NIOSH can be obtained by calling the following number:

1-800-35-NIOSH
(800-356-4674)

INTRODUCTION

Nancy A. Stout, Ed.D.

Many American workers are exposed to electrical energy daily during the performance of their tasks. This monograph highlights the magnitude of the problem of occupational electrocutions in the U.S., identifies potential risk factors for fatal injury, and provides recommendations for developing effective safety programs to reduce the risk of electrocution.

This monograph summarizes surveillance data and investigative reports of fatal incidents involving workers who contacted energized electrical conductors or equipment. The surveillance data were derived from the National Traumatic Occupational Fatalities (NTOF) surveillance system maintained by the National Institute for Occupational Safety and Health (NIOSH). The NTOF data are based on death certificates of workers 16 years or older who died from a traumatic injury in the workplace. The fatality investigations were conducted as part of the NIOSH Fatality Assessment and Control Evaluation (FACE) program. FACE is a research program for the identification and investigation of fatal occupational injuries. The goal of the FACE program is to collect information on factors that may have contributed to traumatic occupational fatalities using an epidemiologic approach, and to develop and disseminate recommendations for preventing similar events in the future.

Based on the NTOF surveillance data for the period from 1980 through 1992, 5,348 workers died from contact with electrical energy (an average of 411 deaths per year). Electrocutions were the fifth leading cause of death, accounting for 7% of all workplace fatalities. In the 12 year period from 1982 through 1994, NIOSH investigated 224 electrocution incidents which resulted in 244 worker fatalities.

Part I of this monograph provides: an overview of electrical hazards, including the effects of electrical energy on the human body; a comprehensive summary of the epidemiology of occupational electrocutions based on NTOF and FACE data which identifies common risk factors for fatal injury due to contact with electrical energy; and recommendations for elements of an effective electrical safety program for the prevention of workplace electrocutions. Part II includes a summary abstract for all 224 FACE electrocution investigative reports prepared by NIOSH for further information and reference.

Our hope is that this monograph will serve as a valuable resource for safety and public health professionals, safety and health trainers, researchers, and others who can affect the prevention of occupational electrocutions.

PART I

ELECTROCUTION-RELATED FATALITIES

OVERVIEW OF ELECTRICAL HAZARDS

Virgil Casini, B.S.

Electricity is a ubiquitous energy agent to which many workers in different occupations and industries are exposed daily in the performance of their duties. Many workers know that the principal danger from electricity is that of electrocution, but few really understand just how minute a quantity of electrical energy is required for electrocution. In reality, the current drawn by a tiny 7.5 watt, 120-volt lamp, passed from hand to hand or hand to foot across the chest is sufficient to cause electrocution.[1] The number of people who believe that normal household current is not lethal or that powerlines are insulated and do not pose a hazard is alarming. Electrocutions may result from contact with an object as seemingly innocuous as a broken light bulb or as lethal as an overhead powerline, and have affected workers since the first electrical fatality was recorded in France in 1879 when a stage carpenter was killed by an alternating current of 250 volts.[2]

The information in the following two sections (**DEFINITIONS** and **EFFECTS OF ELECTRICAL ENERGY**) is intended as a basic explanation of electricity and the effects of electrical energy. Unless otherwise indicated, information in these sections is derived from OSHA electrical standards,[3,4] the National Electrical Code (NEC),[5] and the National Electrical Safety Code.[6] Official definitions of electrical terms can be found in these same documents.

DEFINITIONS

Electricity is the flow of an atom's electrons through a conductor. ***Electrons***, the outer particles of an atom, contain a negative charge. If electrons collect on an object, that object is ***negatively charged***. If the electrons flow from an object through a conductor, the flow is called ***electric current***. Four primary terms are used in discussing electricity: voltage, resistance, current, and ground.

Voltage is the fundamental force or pressure that causes electricity to flow through a conductor and is measured in volts. ***Resistance*** is anything that impedes the flow of electricity through a conductor and is measured in Ohms. ***Current*** is the flow of electrons from a source of voltage through a conductor and is measured in amperes (Amps). If the current flows back and forth (a cycle) through a conductor, it is called ***alternating current (AC)***. In each cycle the electrons flow first in one direction, then the other. In the United States, the normal rate is 60 cycles per second [or 60 Hertz (Hz)]. If current flows in one direction only (as in a car battery), it is called ***direct current (DC)***.

AC is most widely used because it is possible to step up or step down (i.e., increase or decrease) the current through a transformer. For example, when current from an overhead powerline is run through a pole-mounted transformer, it can be stepped down to normal household current.

Ohm's Law (Current=Voltage/Resistance) can be used to relate these three elements mathematically.

A ***ground*** is a conducting connection, whether or not unintentional, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

EFFECTS OF ELECTRICAL ENERGY

Electrical injuries consist of four main types: electrocution (fatal), electric shock, burns, and falls caused as a result of contact with electrical energy.

Electrocution results when a human is exposed to a lethal amount of electrical energy. To determine how contact with an electrical source occurs, characteristics of the electrical source before the time of the incident must be evaluated (pre-event). For death to occur, the human body must become part of an active electrical circuit having a current capable of overstimulating the nervous system or causing damage to internal organs. The extent of injuries received depends on the current's magnitude (measured in Amps), the pathway of the current through the body, and the duration of current flow through the body (event). The resulting damage to the human body and the emergency medical treatment ultimately determine the outcome of the energy exchange (post-event).[7]

Electrical injuries may occur in various ways: direct contact with electrical energy, injuries that occur when electricity arcs (an arc is a flow of electrons through a gas, such as air) to a victim at ground potential (supplying an alternative path to ground), flash burns from the heat generated by an electrical arc, and flame burns from the ignition of clothing or other combustible, nonelectrical materials. Direct contact and arcing injuries produce similar effects. Burns at the point of contact with electrical energy can be caused by arcing to the skin, heating at the point of contact by a high-resistance contact, or higher voltage currents. Contact with a source of electrical energy can cause external as well as internal burns. Exposure to higher voltages will normally result in burns at the sites where the electrical current enters and exits the human body. High voltage contact burns may display only small superficial injury; however, the danger of these deep burns destroying tissue subcutaneously exists.[8] Additionally, internal blood vessels may clot, nerves in the area of the contact point may be damaged, and muscle contractions may cause skeletal fractures either directly or in association with falls from elevation.[9] It is also possible to have a low-voltage electrocution without visible marks to the body of the victim.

Flash burns and flame burns are actually thermal burns. In these situations, electrical current does not flow through the victim and injuries are often confined to the skin.

Contact with electrical current could cause a muscular contraction or a startle reaction that could be hazardous if it leads to a fall from elevation (ladder, aerial bucket, etc.) or contact with dangerous equipment.[10]

The NEC describes high voltage as greater than 600 volts AC.[5] Most utilization circuits and equipment operate at voltages lower than 600 volts, including common household circuits (110/120 volts); most overhead lighting systems used in industry or office buildings and department stores; and much of the electrical machinery used in industry, such as conveyor systems, and manufacturing machinery such as weaving machines, paper rolling machines or industrial pumps.

Voltages over 600 volts can rupture human skin, greatly reducing the resistance of the human body, allowing more current to flow and causing greater damage to internal organs. The most common high voltages are transmission voltages (typically over 13,800 volts) and distribution voltages (typically under 13,800 volts). The latter are the voltages transferred from the power generation plants to homes, offices, and manufacturing plants.

Standard utilization voltages produce currents passing through a human body in the milliampere (mA) range (1,000 mA=1 Amp). Estimated effects of 60 Hz AC currents which pass through the chest are shown in Table 1.

Table 1. *Estimated Effects of 60 Hz AC Currents*

1 mA	Barely perceptible
16 mA	Maximum current an average man can grasp and "let go"
20 mA	Paralysis of respiratory muscles
100 mA	Ventricular fibrillation threshold
2 Amps	Cardiac standstill and internal organ damage
15/20 Amps	Common fuse or breaker opens circuit*

*Contact with 20 milliamps of current can be fatal. As a frame of reference, a common household circuit breaker may be rated at 15, 20, or 30 amps.

When current greater than the 16 mA "let go current" passes through the forearm, it stimulates involuntary contraction of both flexor and extensor muscles. When the stronger flexors dominate, victims may be unable to release the energized object they have grasped as long as the current flows. If current exceeding 20 mA continues to pass through the chest for an extended time, death could occur from respiratory paralysis. Currents of 100 mA or more, up to 2 Amps, may cause ventricular fibrillation, probably the most common cause of death from electric shock.[11] Ventricular fibrillation is the uneven pumping of the heart due to the uncoordinated, asynchronous contraction of the ventricular muscle fibers of the heart that leads quickly to death from lack of oxygen to the brain. Ventricular fibrillation is terminated by the use of a defibrillator, which provides a pulse shock to the chest to restore the heart rhythm. Cardiopulmonary resuscitation (CPR) is used as a temporary care measure to provide the circulation of some oxygenated blood to the brain until a defibrillator can be used.[23]

The speed with which resuscitative measures are initiated has been found to be critical. Immediate defibrillation would be ideal; however, for victims of cardiopulmonary arrest, resuscitation has the greatest rate of success if CPR is initiated within 4 minutes and advanced cardiac life support is initiated within 8 minutes (National Conference on CPR and ECC, 1986).[6]

The presence of moisture from environmental conditions such as standing water, wet clothing, high humidity, or perspiration increases the possibility of a low-voltage electrocution. The level of current passing through the human body is directly related to the resistance of its path through the body. Under dry conditions, the resistance offered by the human body may be as high as 100,000 Ohms. Wet or broken skin may drop the body's resistance to 1,000 Ohms. The following illustrations of Ohm's law demonstrates how moisture affects low-voltage electrocutions. Under dry conditions, Current=Volts/Ohms = 120/100,000 = 1 mA, a barely perceptible level of current. Under wet conditions, Current=Volts/Ohms = 120/1,000 = 120 mA, sufficient current to cause ventricular fibrillation. Wet conditions are common during low-voltage electrocutions.

High-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to 500 Ohms. Once the skin is punctured, the lowered resistance results in massive current flow, measured in Amps. Again, Ohm's law is used to demonstrate the action. For example, at 1,000 volts, Current=Volts/Ohms = 1000/500 = 2 Amps, which can cause cardiac standstill and serious damage to internal organs.

CONCLUSIONS

Electrical hazards represent a serious, widespread occupational danger; practically all members of the workforce are exposed to electrical energy during the performance of their daily duties, and electrocutions occur to workers in various job categories. Many workers are unaware of the potential electrical hazards present in their work environment, which makes them more vulnerable to the danger of electrocution.

The Occupational Safety and Health Administration (OSHA) addresses electrical safety in Subpart S 29 CFR 1910.302 through 1910.399 of the General Industry Safety and Health Standards.[3] The standards contain requirements that apply to all electrical installations and utilization equipment, regardless of when they were designed or installed. Subpart K of 29 CFR 1926.402 through 1926.408 of the OSHA Construction Safety and Health Standards[4] contain installation safety requirements for electrical equipment and installations used to provide electric power and light at the jobsite. These sections apply to both temporary and permanent installations used on the jobsite.

Additionally, the National Electrical Code (NEC)[5] and the National Electrical Safety Code (NESC)[6] comprehensively address electrical safety regulations. The purpose of the NEC is the practical safeguarding of persons and property from hazards arising from the use of electricity. The NEC contains provisions considered necessary for safety and applies to the installation of electric conductors and equipment within or on public or private buildings or other structures, including mobile homes, recreational vehicles, and floating buildings; and other premises such as yards; carnival, parking, and other lots; and industrial substations. The NEC serves as the basis for electrical building codes across the United States.

The NESC contains rules necessary for the practical safeguarding of persons during the installation, operation, or maintenance of electric supply and communication lines and associated equipment. These rules contain the basic provisions that are considered necessary for the safety of employees and the public under the specified conditions. Unlike the NEC, the NESC contains work rules in addition to installation requirements.

EPIDEMIOLOGY OF ELECTROCUTION FATALITIES

Suzanne Kisner, B.S., Virgil Casini, B.S.

Occupational fatalities associated with electrocutions are a significant, ongoing problem. Data from the NIOSH National Traumatic Occupational Fatality (NTOF) surveillance system indicated that an average of 6,359 traumatic work-related deaths occurred each year in the United States from 1980 through 1989; an estimated 7% of these fatalities were due to electrocutions.[12] In 1995, the Bureau of Labor Statistics reported that electrocutions accounted for 6% of all worker deaths.[13] For the year 1990, the National Safety Council reported that electrocutions were the fourth leading cause of work-related traumatic death.[14]

A review of hazards in the farming industry showed that electrocutions accounted for about 7% of all agricultural work-related deaths.[15] The specific hazards involved in these electrocutions include internal wiring in farm buildings, buried electrical cables, and overhead powerlines.[15] A study of work-related electrocution deaths was conducted using data from the Occupational Safety and Health Administration (OSHA) Integrated Management Information System (IMIS).[16] This study identified 944 work-related electrocutions for the period 1984 to 1986; 61% of these fatalities were caused by contact with high-voltage powerlines. From 1980 through 1989, NIOSH reported an average of 15 electrocutions each year were caused by contact between cranes or some other type of boomed vehicles and energized, overhead powerlines.[17]

NTOF ANALYSIS

Methods

The National Traumatic Occupational Fatalities (NTOF) surveillance system is composed of information taken from death certificates for decedents 16 years of age or older with a positive response to the “Injury at Work?” item, and an external cause of death (International Classification of Diseases, Ninth Revision [ICD-9]; E800-E999).[18] Electrocutions which occurred from 1980 through 1992 were identified by selecting those cases which had an ICD-9 code of “E925-accident caused by electrical current.”

An initial manual review identified certain events that occurred with greater frequency. Based on this review, 17% of the cases with specific circumstances were grouped through keyword searches of the literal information from the death certificates. A keyword search was done for “crane,” “boom,” “hoist,” and “rigging” to identify electrocutions involving boomed vehicles. Electrocutions involving ladders and scaffolds were identified through a search for “ladders” and “scaffolds.” A keyword search was conducted for “short cir,” “faulty,” “shorted,” “defective,” “malfunctioning,” “short,” and “damaged,” to identify those electrocutions involving contact with a short-circuited, damaged, or improperly installed wire or equipment. Contacts with a truck or other vehicle were located using the keywords “truck” and “vehicle.” Electrocutions involving grain augers and elevators were found through a search for “auger” and “elevator.” Because of the level of detail contained on death certificates, specific circumstances surrounding most of the deaths were not as easily categorized. For most of the remaining cases, the circumstances surrounding the electrocutions were missing, incomplete, or vague. While these cases were not removed from the analysis, to assign them to specific groups would involve a much more detailed review, which is not possible with death certificate data alone.

Industry was coded into division-level industry categories using the 1987 Standard Industrial Classification System.[19] Occupation was grouped into major occupation divisions according to the 1980 and 1990 Bureau of the Census Occupational Classification System.[20,21] Employment estimates used to calculate fatality rates were extracted from the Bureau of Labor Statistics' *Employment and Earnings* annual average employment data.[22] The employment data from *Employment and Earnings* are based on the annual averages from the Current Population Survey, a sample survey of the population 16 years of age and over.

A detailed description and the limitations of the NTOF surveillance system have been reported previously.[12] Because the amount of detail on death certificates is sometimes limited and death certificates are known to capture approximately 81% of all work-related deaths,[23] the number of electrocutions presented should be considered the minimum number of deaths.

Results

A total of 5,348 workers were electrocuted in 5,180 incidents from 1980 through 1992. One-hundred fifty-three (3%) of the fatal incidents resulted in multiple fatalities: 140 incidents involved 2 victims each, 11 incidents involved 3 victims each, and 2 incidents involved 4 victims each.

An average of 411 workers were electrocuted each year, with an average annual rate of 0.4 per 100,000 workers. Figure 1 provides the frequency and rate per 100,000 workers of electrocutions by year of death. The substantial decrease is noteworthy, but it varies by industry. While total work-related fatalities decreased 23% from 1980 to 1989,[24] the number of electrocution deaths have decreased by more than 50% from 1980 to 1992.

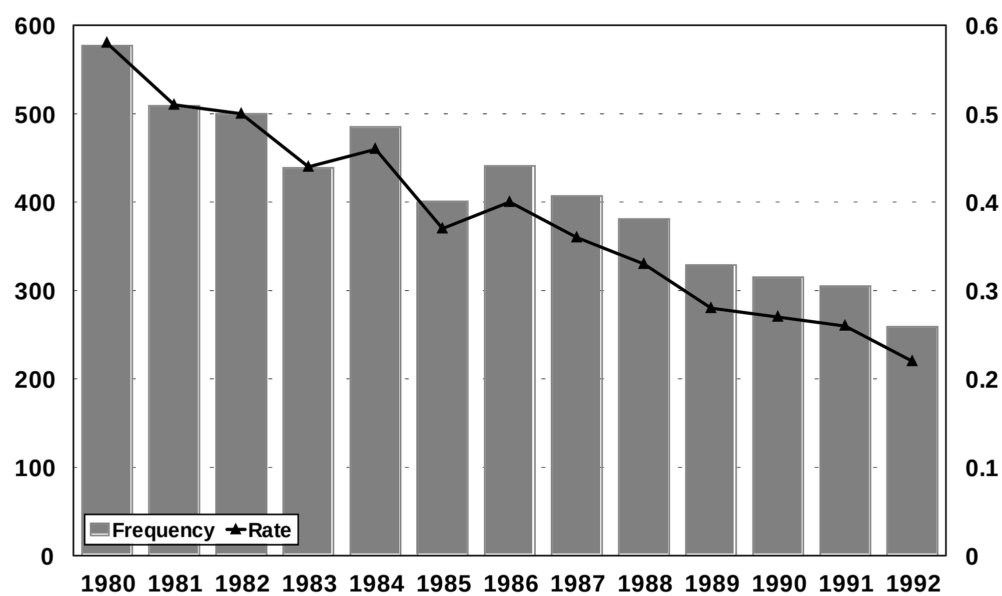

Figure 1. *Frequencies and Rates of Electrocution Deaths Identified by NTOF by Year, 1980-1992*

Sixty percent of the electrocutions occurred to workers less than 35 years of age. Figure 2 provides frequencies and rates per 100,000 workers of electrocutions by age group.

Ninety-nine percent of the electrocutions occurred among men. Whites accounted for 86% of the electrocutions, followed by Blacks (7.1%), Hispanics (5.3%), Asians (0.4%), Native Americans (0.3%), and other and unknown races (0.8%).

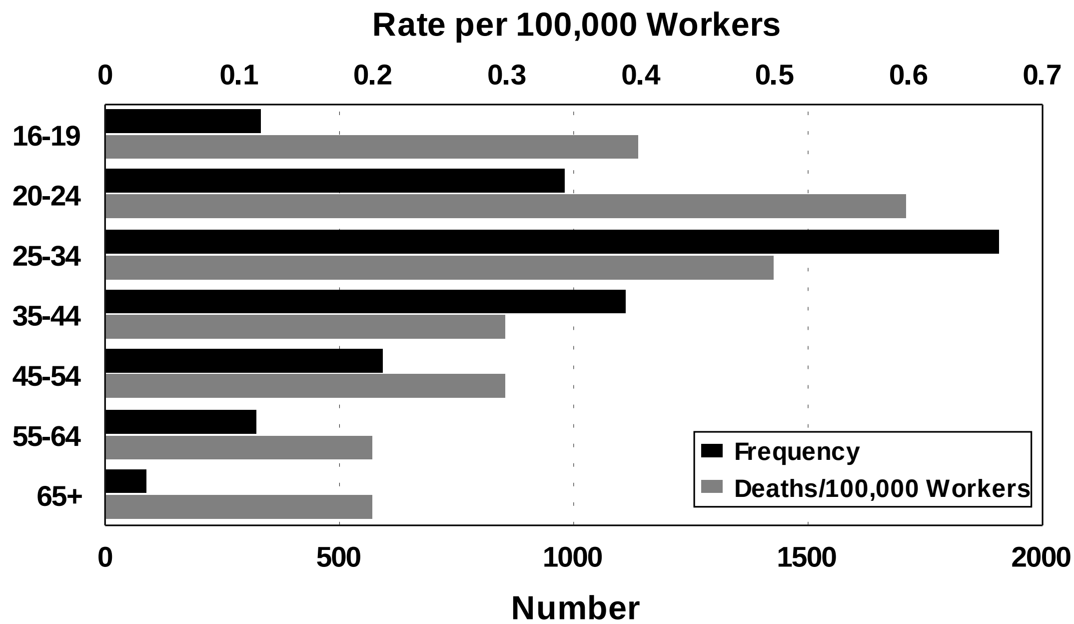

Figure 2. *Frequencies and Rates of Electrocution Deaths Identified by NTOF by Age Group, 1980-1992*

The industries with the highest percentage of electrocutions were construction (40%), transportation/communication/public utilities (16%), manufacturing (12%), and agriculture/forestry/fishing (11%) (Figure 3). The construction industry had a rate of 2.4 per 100,000 workers, followed closely by mining which had a rate of 2.2 (Figure 3).

Over the 13-year period, 61% of the electrocutions occurred in two occupation divisions: 46% among craftsmen and 15% among laborers (Figure 4). These two groups also had the highest rates of electrocution death: 1.4 per 100,000 workers each (Figure 4).

Much of the information from death certificates for decedents involved in electrocutions is vague. However, certain circumstances were easily identifiable. Three-hundred thirty-seven (6%) of the victims contacted a boomed vehicle that was in contact with an energized power source. Two-hundred seventeen (4%) contacted a ladder or scaffold that was in contact with an energized power source. One-hundred fifty-three (3%) contacted short-circuited, damaged, or improperly installed wire or equipment. One-hundred twenty-nine (2%) contacted a truck or other vehicle, other than a boomed vehicle, which was in contact with an energized power source. Eighty-two (2%) contacted an energized grain auger or grain elevator. As previously described, the specific circumstances surrounding the electrocutions in the remaining 83% of the deaths were not categorized in these data.

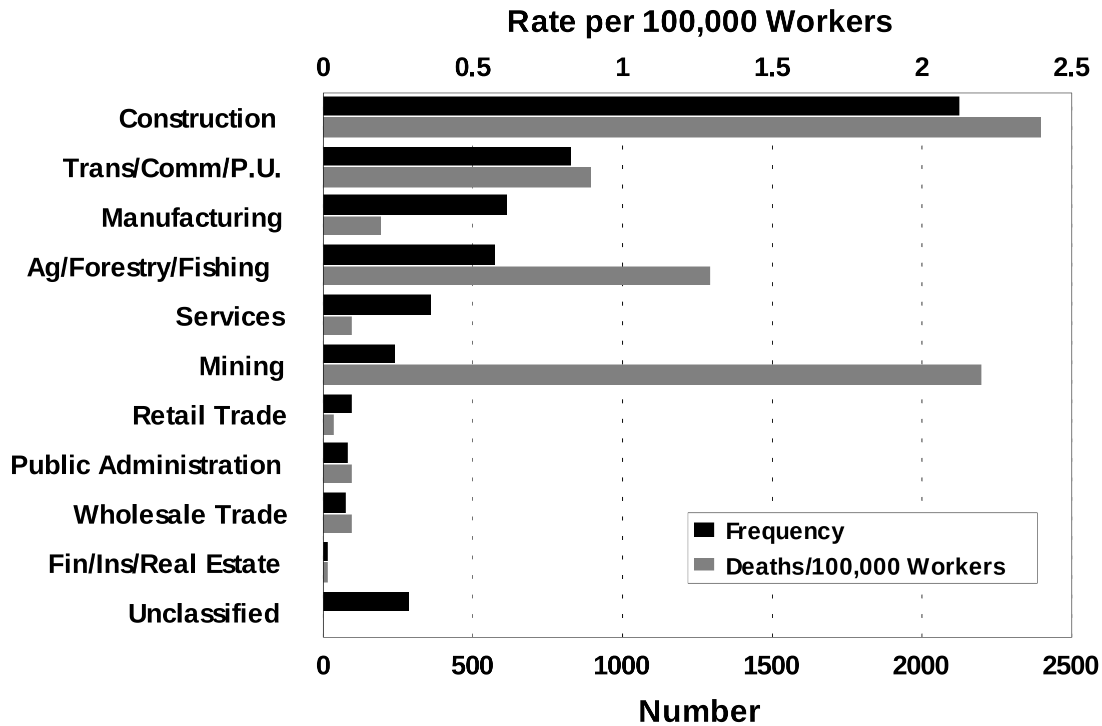

Figure 3. *Frequencies and Rates of Electrocution Deaths Identified by NTOF by Industry, 1980-1992*

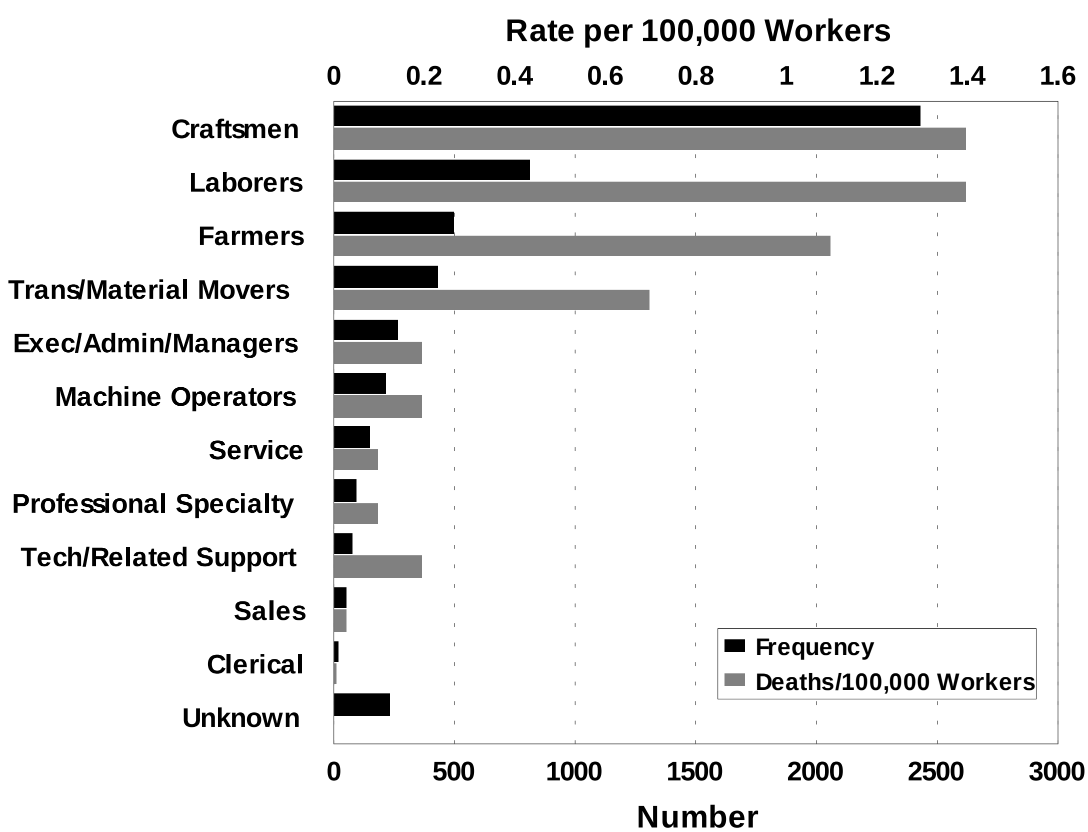

Figure 4. *Frequencies and Rates of Electrocution Deaths Identified by NTOF by Occupation, 1980-1992*

FATALITY ASSESSMENT AND CONTROL EVALUATION (FACE) INVESTIGATIONS

Methods

During the period from November 1982 to December 1994, NIOSH investigated 224 electrocution incidents resulting in 244 occupational fatalities.[25] These investigations were undertaken as part of the Fatality Assessment and Control Evaluation (FACE) program conducted by (NIOSH). The FACE program was initiated in 1982 and directed from its inception by the NIOSH Division of Safety Research. FACE is a research program for the identification and investigation of fatal occupational injuries.

Derived from the research conducted by William Haddon, Jr. (the Haddon model), this approach reflects the public health perception that the etiology of injuries is multifactorial and largely preventable.[26] For each case, factors associated with the agent (mode of energy exchange), the host (the worker who died) and the environment are identified during the pre-event, event, and post-event time phases. These contributory factors are investigated in detail in each FACE incident, and are summarized in each FACE summary report, along with recommendations for preventing future incidents of a similar nature.

Investigators conducted investigations at the incident sites, evaluating each event's circumstances, including agent, host, and environmental characteristics. When an incident involved multiple fatalities, data were collected for each victim. Percentages presented here describe frequencies of incident characteristics. Rates could not be calculated due to the lack of comparable denominator data. Percentages do not necessarily reflect the risk to workers, but rather describe the problem's proportional magnitude.

Industry was coded into categories using the 1987 Standard Industrial Classification System[31] and occupations were grouped using the 1980 Bureau of the Census Occupational Classification System.[32]

Results

The victims (243 men and 1 woman) ranged in age from 17 to 70 years, and the mean age was 34 years. The loss of years of potential life before age 65 was substantial; for the 244 victims discussed in this analysis, the years of potential life lost (YPLL) equaled 7,903 years or an average of 33 years per victim. Sixty-four percent of the victims died prior to age 35 (Figure 5).

The industries with the highest number of electrocutions were Construction (121); followed by Manufacturing (40); Transportation, Communications, Public Utilities (30); and Public Administration (19) (Figure 6).

Figure 7 shows the 10 job classifications (occupations) with the highest number of fatalities. Although utility line workers (linemen) typically receive extensive training in electrical safety and the hazards associated with electrical energy, they had the highest number of fatal injuries. Twenty-six (55%) utility line worker fatalities were due to the failure to utilize required personal protective equipment (gloves, sleeves, mats, blankets, etc.). Laborers, who generally receive little or no electrical training, were the next highest classification.

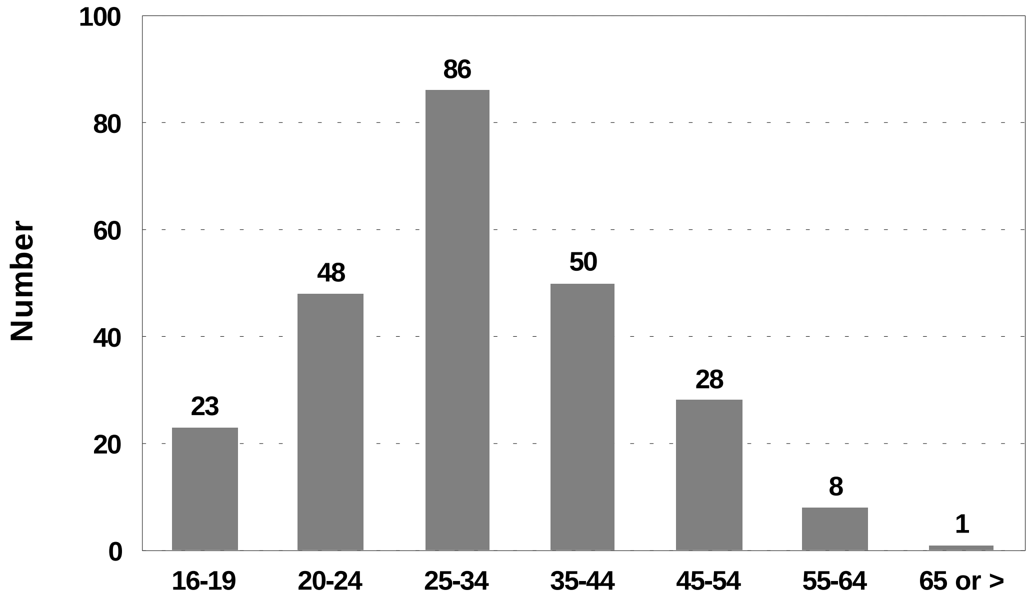

Figure 5. *Frequencies of Electrocution Deaths Identified by FACE by Age Group, 1982-1994*

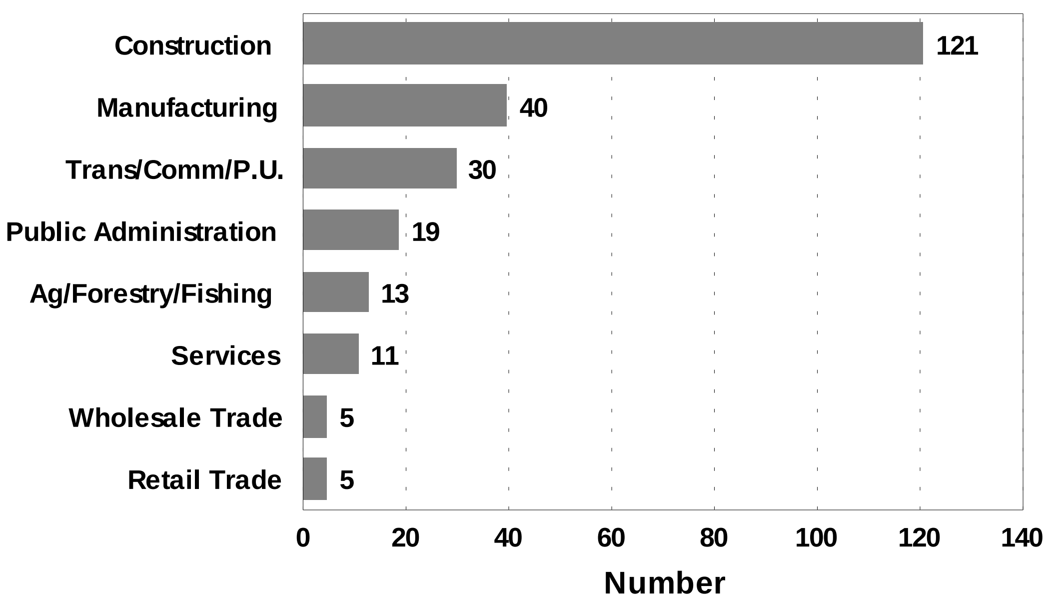

Figure 6. *Frequencies of Electrocution Deaths Identified by FACE by Industry, 1982-1994*

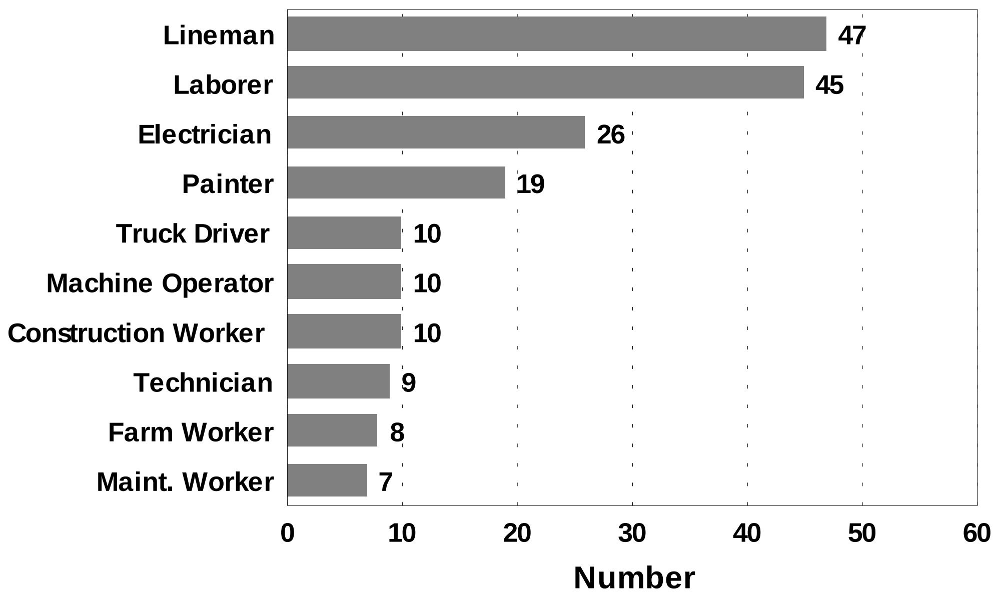

Figure 7. *Frequencies of Electrocution Deaths Identified by FACE by Occupation, 1982-1994*

The number of investigated electrocution incidents by month of occurrence are provided in Figure 8. The largest number of incidents occurred in months where weather conditions were most favorable for the highest level of outside activity.

In 79 (35%) of the incidents, no safety program or established, written safe work procedures existed.

Factors common to these incidents included the lack of enforcement of existing employer policies concerning the use of personal protective equipment, and the lack of supervisory intervention when existing safety policies were being violated. Supervision was present at the site in 120 (53%) of the incidents, and 42 victims were supervisors.

Of the 244 victims, 194 (80%) had some type of electrical safety training. On-the-job training, received by 102 victims, was the most common type of training. Thirty-nine victims received no training at all. One hundred (41%) of the victims had been on the job for less than 1 year.

Fifty-one (23%) of the incidents occurred at establishments that employed 500 or more workers. Eighty-five (38%) of the incidents occurred at establishments that employed less than 50 workers.

Two hundred twenty-one (99%) of the incidents involved alternating current (AC). One incident involved direct current (DC). Two incidents involved AC arcs. Of the 221 AC electrocutions, 74 (33%) involved less than 600 volts and 147 (66%) involved 600 volts or more. The number of electrocutions by voltage level is listed in Figures 9 and 10. Forty (54%) of the lower-voltage electrocutions involved household current of 120 to 240 volts. Manufacturing companies accounted for 40 (54%) of the lower-voltage incidents. This is particularly disturbing due to safety features such as electrical safety interlocks, emergency stop devices, and electrical guarding inherently designed into manufacturing equipment.

Of the 147 higher-voltage incidents, 111 (76%) involved distribution voltages (7,200-13,800 volts) and 21 incidents involved transmission voltages (above 13,800 volts). Of the incidents involving at least 7,200 volts, 41 (28%) resulted from contacting an energized powerline with a boomed vehicle. Thirty-five incidents occurred when conductive equipment such as an aluminum ladder or scaffold contacted an energized powerline. The weight of this equipment sometimes required more than one worker to move or position it, resulting in multiple fatalities. Thirteen deaths occurred in six separate incidents when workers erected or moved scaffolds that came in contact with energized, overhead powerlines. Electric powerline line mechanics were victims in 47 (36%) of the incidents involving transmission and distribution voltages.

Almost all American workers are exposed to electrical energy at sometime during their work day, and the same electrical hazards can affect workers in different industries. Based on the analysis of these cases, NIOSH identified five case scenarios that describe the incidents resulting in the 244 fatalities: (1) direct worker contact with an energized powerline (28%); (2) direct worker contact with energized equipment (21%); (3) boomed vehicle contact with an energized powerline (18%); (4) improperly installed or damaged equipment (17%); (5) conductive equipment contact with an energized powerline (16%).

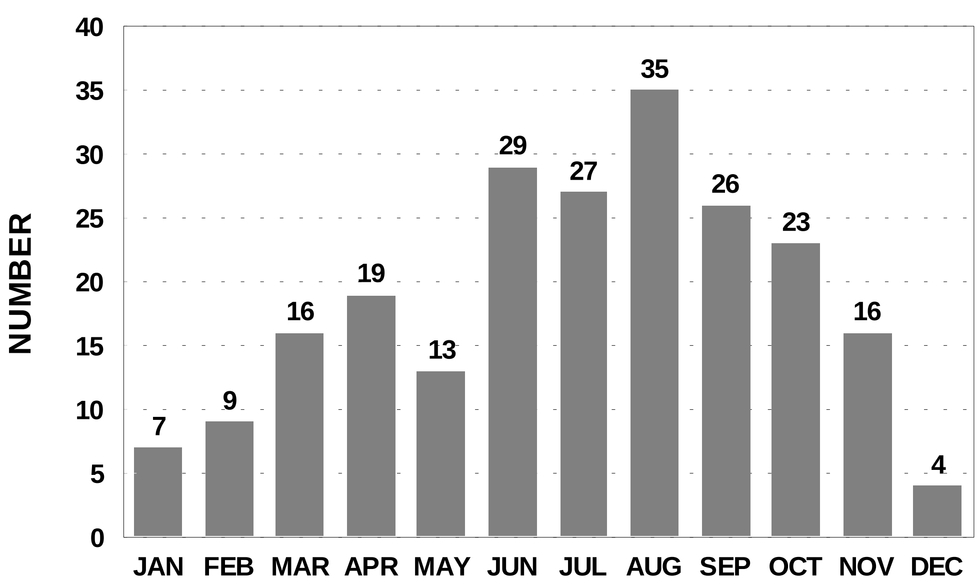

Figure 8. *Frequencies of Electrocution Incidents Identified by FACE by Month, 1982-1994*

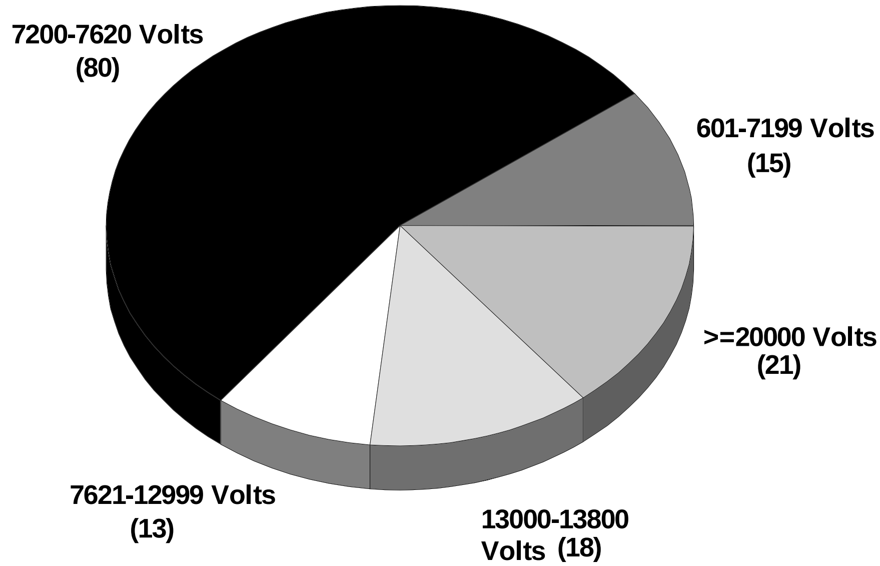

Figure 9. *Frequencies of Electrocution Incidents Identified by FACE by High Voltage Level (>600 Volts), 1982-1994*

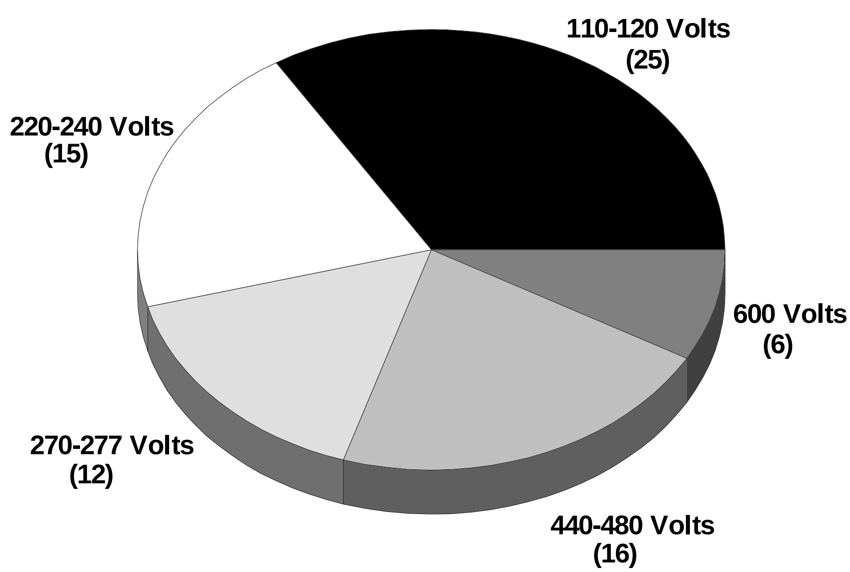

Figure 10. *Frequencies of Electrocution Incidents Identified by FACE by Low Voltage Level (<600 Volts), 1982-1994*

Scenario 1

Workers in various occupations such as sign technicians, tree trimmers, utility line workers, and telecommunication workers are often exposed to overhead powerlines. These exposures can be greatly reduced by isolating or insulating the energy source from the worker. This can be accomplished by erecting a physical barrier, by insulating the powerline, or by following required clearance distances. More than once during FACE investigations, co-workers interviewed did not know the powerlines posed a hazard, i.e., they thought the powerlines were insulated.

Scenario 2

Direct worker contact with energized equipment can occur in a variety of ways. Maintenance technicians might inadvertently contact overhead crane runway conductors. Electricians or technicians troubleshooting or testing electric circuitry might contact an energized circuit. Maintenance workers may fail to replace an isolating plate covering electrical conductors, exposing passing workers. Compliance with the applicable articles of the National Electrical Code and lockout/tagout procedures established by OSHA could eliminate the potential for such contact, thereby reducing the risk of electrocution.

Scenario 3

Workers guiding suspended loads, or standing against or near a crane or other boomed vehicle—such as a concrete pumping truck, or derrick truck—whose boom contacts a powerline are in danger of electrocution. The risk of electrocution could be reduced if OSHA regulations regarding clearance distances [(29 CFR 1926.550 (a)(15)] are observed, or if the required lookout person [29 CFR 1926.550 (a)(15)(iv)] is utilized.

Scenario 4

Improperly installed or damaged equipment can be responsible for occupational electrocutions in a variety of ways. The most frequently cited OSHA electrical regulation is improper grounding of equipment or electrical circuitry. If the frame of a piece of electrical equipment or machinery does not have a grounding conductor attaching the frame to ground, as required to divert dangerous fault current to ground, and an electrical fault occurs, anyone touching that frame and any other object at ground potential would receive an electrical shock. Should a fault occur with a grounding conductor present, the circuit would open or trip as an alert that a problem existed, except in high-resistance grounding applications. Damaged guards can expose workers to energized conductors in proximity to their work areas. Additionally, damaged extension cords or extension cords with their ground prong removed can expose workers to the danger of electrocution.

Failure to maintain a continuous path to ground can expose entire electrical systems to damage and can expose the structures within which they are housed and workers within these structures to electrical and fire hazards.

For example, many electrical systems are installed in a manner that allows a structure's water pipes or other conductive conduit to serve as a continuous path to ground in compliance with the NEC. However, FACE investigations have identified cases of electrocution or fire as a result of an interruption in a continuous path to ground. During renovation or repair activities, conductive components may be replaced by nonconductive components such as PVC pipe, which will interrupt the path to ground. This may result in fire due to the intense overheating of components of the electrical system. Additionally, workers contacting improperly grounded components while being at ground potential would be exposed to electric shock.

Scenario 5

The task of positioning or repositioning conductive equipment may place more than one worker at risk. The weight of mobile scaffolding, grain augers, or aluminum extension ladders equipped with pendant-operated lifts often requires more than one worker for positioning or repositioning, resulting in multiple electrocutions if contact with an overhead powerline occurs. Using a lookout person, observing required clearance distances, or lowering this equipment before transport would greatly reduce worker exposure to any potential electrical hazards present.

DISCUSSION

The fatality data from NTOF help to illustrate the magnitude of the electrocution problem nationally and allow a comparison of the potential risks in various industries. The information from FACE investigations allows for the identification of more detailed information on electrocution hazards, such as contact with overhead powerlines, contact with exposed conductors, inadequate personal protective equipment, and nonexistent lockout/tagout procedures, or other measures necessary for working around energized conductors and equipment.

FACE reports and NTOF death certificates identified many of the same hazards for fatal electrocutions. The largest number of deaths were in Construction, Transportation/Communication/Public Utilities, and Manufacturing, while the highest fatality rates were in the Construction and Mining industries. Linemen were involved in the largest number of electrocutions.

Direct worker contact with an energized powerline caused the largest number of electrocution deaths. Almost all of the incidents investigated by FACE involved alternating current. Over half of these incidents involved voltages over 600 volts. Of the 147 higher-voltage electrocutions, over two-thirds involved distribution voltages (7,200-13,800 volts).

While progress has been made in reducing the number of work-related electrocutions, (50% decrease from 1980-1992), additional efforts are needed if we are to continue progress towards preventing deaths due to electrocution.

PREVENTION: ELEMENTS OF AN ELECTRICAL SAFETY PROGRAM

Virgil Casini, B.S.

At least one of the following five factors was present in all 224 incidents evaluated by the FACE program: (1) established safe work procedures were either not implemented or not followed; (2) adequate or required personal protective equipment was not provided or worn; (3) lockout/tagout procedures were either not implemented or not followed; (4) compliance with existing OSHA, NEC, and NESC regulations were not implemented; and (5) worker and supervisor training in electrical safety was not adequate. These subjects are addressed in various NIOSH Alerts[26-36] and related publications.[37]

Most of the 224 occupational electrocution incidents investigated as part of the FACE program could have been prevented through compliance with existing OSHA, NEC, and NESC regulations; and/or the use of adequate personal protective equipment (PPE). All workers should receive hazard awareness training so that they will be able to identify existing and potential hazards present in their workplaces and relate the potential seriousness of the injuries associated with each hazard. Once these hazards are identified, employers should develop measures that would allow for their immediate control.

Based on an analysis of these data, to reduce occupational electrocutions, employers should:

- Develop and implement a comprehensive safety program and, when necessary, revise existing programs to thoroughly address the area of electrical safety in the workplace.

- Ensure compliance with existing OSHA regulations Subpart S of 29 CFR 1910.302 through 1910.399 of the General Industry Safety and Health Standards[3] and Subpart K of 29 CFR 1926.402 through 1926.408 of the OSHA Construction Safety and Health Standards.[4]

- Provide all workers with adequate training in the identification and control of the hazards associated with electrical energy in their workplace.

- Provide additional specialized electrical safety training to those workers working with or around exposed components of electric circuits. This training should include, but not be limited to, training in basic electrical theory, proper safe work procedures, hazard awareness and identification, proper use of PPE, proper lockout/tagout procedures, first aid including CPR, and proper rescue procedures. Provisions should be made for periodic retraining as necessary.

- Develop and implement procedures to control hazardous electrical energy which include lockout and tagout procedures and ensure that workers follow these procedures.

- Provide those workers who work directly with electrical energy with testing or detection equipment that will ensure their safety during performance of their assigned tasks.

- Ensure Compliance with the National Electrical Code[5] and the National Electrical Safety Code.[6]

- Conduct safety meetings at regular intervals.

- Conduct scheduled and unscheduled safety inspections at worksites.

- Actively encourage all workers to participate in workplace safety.

- In a construction setting, conduct a jobsite survey before starting any work to identify any electrical hazards, implement appropriate control measures, and provide training to employees specific to all identified hazards.

- Ensure that proper personal protective equipment is available and worn by workers where required (including fall protection equipment).

- Conduct job hazard analyses of all tasks that might expose workers to the hazards associated with electrical energy and implement control measures that will adequately insulate and isolate workers from electrical energy.

- Identify potential electrical hazards and appropriate safety interventions during the planning phase of construction or maintenance projects. This planning should address the project from start to finish to ensure workers have the safest possible work environment.

The FACE data indicate that although many companies had comprehensive safety programs, in many cases they were not completely implemented. This underscores the need for increased management and worker understanding, awareness, and ability to identify the hazards associated with working on or in proximity to electrical energy. It is the responsibility of management to provide a safe workplace for their workers and to develop and implement a comprehensive safety program. In some cases, this may entail the development of additional worker training, and/or the evaluation and restructuring of existing safety programs. Management should also provide adequate training in electrical safety to all workers and strictly enforce adherence to established safe work procedures and policies. Additionally, adequate personal protective equipment should be available where appropriate. Information or assistance in accomplishing these measures can be provided by OSHA, electrical safety consultants, or other agencies or associations that deal with electrical safety. A strong commitment to safety by both management and workers is essential in the prevention of severe occupational injuries and death due to contact with electrical energy.

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PART II

FATALITY ASSESSMENT AND CONTROL EVALUATION (FACE) SUMMARY REPORT ABSTRACTS, 1982-1994 ELECTROCUTIONS

FACE ELECTROCUTION CASES FOR MONOGRAPH

The following pages contain short summaries of the FACE cases summarized in this monograph. The first two numbers preceding the case denote the year in which the case was investigated. The following two numbers identify a sequential file number for a particular year.

Copies of the complete FACE reports may be accessed through the NIOSH homepage at the following address: http://www.cdc.gov/niosh/

82-03 Truck driver standing on the ground directing crane operator electrocuted when crane cable contacted 7200V powerline. Victim on the ground helping to guide a ladder being positioned by the crane.

83-08 Electrician electrocuted at coal-fired power plant while replacing limit switch on coal sampler. Lockout procedures not followed. Contact with 220V line.

83-09 Painter working on electrical transmission tower electrocuted after direct contact with a grounding line that held a static charge.

84-17 Fast food restaurant employee electrocuted while plugging a portable electric toaster into a 110V/20 amp receptacle.

85-01 Worker electrocuted through direct contact with overhead 69000V powerline while dismantling electric substation tower. Co-worker had advised victim that lines not yet deenergized by power company.

85-03 Transportation worker electrocuted when iron rod used to measure asphalt level in storage tank contacted overhead 7200V powerline.

85-04 Electrical line construction foreman electrocuted by electric arc while attempting to cut 7200V powerline and attach it to new pole.

85-06 Warehouse worker electrocuted after coming in contact with bare 440V runway conductor (trolley wire) and grounded metal pallet storage rack. Victim at top of storage rack helping to remove mining auger by attaching a chain to it so it could be lowered by a crane.

85-07 Two steel erection workers electrocuted while using a crane with a telescoping boom to move an assembly of steel framing members. Contact with 23000V overhead powerline.

85-08 Construction worker electrocuted when crane load line contacted 7200V overhead powerline. Victim in process of hooking a load to the crane.

85-11 Mushroom cannery worker electrocuted while attempting to unclog a drain beneath a processing table. Victim contacted motor connection box while kneeling in water.

85-14 Construction worker electrocuted when crane cable contacted 13800V overhead powerline. Victim in contact with crane's outrigger.

85-15 Carpenter electrocuted and another worker severely burned when crane with telescoping boom contacted 34000V overhead powerline while he was setting metal forms for a highway retaining wall. Electricity passed from cable through form through victim to ground.

85-16 Foreman electrocuted after contacting one phase of a 23000V conductor within a switch cabinet. Replacing high-voltage distribution switch at the time of the incident.

85-17 Foreman electrocuted, three crewmen critically injured during erection of 36-foot traffic control device pole which contacted 26000V overhead powerline as derrick truck operator attempted to place it.

85-18 Construction worker electrocuted when 7200V overhead powerline fell on trailer attached to utility truck.

85-19 Driver unloading concrete blocks at building supply mart electrocuted when boom of truck-mounted crane apparently contacted 9000V overhead powerline. Outriggers on truck not set. Truck tipped while boom only 12 to 18 inches from powerline.

85-21 Worker on billboard electrocuted when 24-foot metal hook ladder contacted an overhead powerline.

85-22 Volunteer firefighter electrocuted after contacting 7200V overhead powerline while rappelling down the front of a fire station.

85-24 Video store owner electrocuted when he contacted an energized circuit while repairing an air conditioning thermostat. Victim grounded through aluminum ladder.

85-25 Lineman electrocuted after contacting a distribution system he believed to be deenergized.

85-28 Maintenance worker electrocuted as he attempted to turn off a welder. Exposed cable, broken insulation, water on floor.

85-29 Two construction laborers electrocuted when a crane contacted a 13400V overhead powerline under installation by another firm.

85-30 Sign service worker working from aerial ladder truck electrocuted by direct contact with 7200V overhead powerline.

85-32 Construction worker electrocuted when backhoe broke utility pole, causing 7200V overhead powerline to fall a few feet from where he was standing.

85-34 Billboard worker electrocuted as scaffold contacted 13800V overhead powerline. Working from "stage"-type scaffold positioned between catwalk and billboard.

85-35 Textile worker electrocuted while adding a new supply roll of warp to a weaving loom after contacting a loom and a feeder. Faulty receptacle to feeder.

85-36 Electrical worker electrocuted when he slipped and fell into a 7200V, 240/120V single-phase, step-down transformer he was wiring.

85-37 Brick company worker electrocuted when boom on a truck-mounted crane he was operating with a pendant controller contacted a 7200V overhead powerline.

85-38 Production welder plugged cord of a portable welder into a defective extension cord and was electrocuted.

85-39 Maintenance worker electrocuted when 20-foot piece of angle iron he was carrying struck an uninsulated supply wire on an electrical transformer.

85-41 Mobile home assembly-line worker electrocuted when he contacted the exterior of a mobile home energized by a short circuit in the wiring of an adjacent home.

85-42 While drilling horizontally under a road to install new gas lines, a gas utility worker was electrocuted after a drill contacted a 4160V powerline. Co-worker injured.

85-43 County highway worker electrocuted when the 20-foot steel handle of a modified post-hole digger he was holding contacted a 7200V overhead powerline.

85-46 Soldier electrocuted while installing WD-1 communication wire across road on military firing range. Threw wire across 440V powerlines that crossed the road.

85-47 Iron worker electrocuted after touching ceiling fixture as he was transported from work station in a truck-mounted aerial bucket.

85-48 Service technician electrocuted in crawlspace at private home while performing maintenance on an oil furnace.

86-01 Electronic technician electrocuted as he demonstrated how feeders were to be connected to bus bars. Contact with 380 volts.

86-02 Electrician electrocuted after contacting 277 volts while making a connection in a 4-inch junction box at a construction site.

86-03 Lineman electrocuted while attaching a guy wire to a utility pole during installation of a 7200V powerline between adjoining poles.

86-04 Utility worker electrocuted while trying to open a pole-mounted, ground-level air switch on a three-phase, 69000V powerline.

86-05 School maintenance worker electrocuted after contacting transformer wire.

86-06 Three farm workers electrocuted when grain auger they were moving contacted a 7200V overhead powerline.

86-07 Two farm workers electrocuted when grain auger they were moving contacted a 7200V overhead powerline.

86-08 Apprentice electrician electrocuted after contacting 277V uninsulated wire during installation of overhead junction box.

86-09 Lineman electrocuted while working from an aerial bucket truck to install a transformer. Direct contact with 13200V overhead powerline. Truck not grounded.

86-11 Two electrical workers in aerial bucket electrocuted while attaching transformer to utility pole. Operator on ground inadvertently moved boom upward, causing victims to directly contact high-voltage overhead powerline.

86-14 Operator of plastic extrusion machine electrocuted after contacting metal machine part energized at 10000V (used for treating plastic sheeting). Incident occurred while another worker performing maintenance on machine.

86-16 Bindery machine operator electrocuted when he contacted a 480V circuit inside a panel box while trying to check an electrical relay.

86-17 Truck driver electrocuted when crane boom on his truck contacted a 7200V overhead powerline. Unloading precast concrete manhole assemblies.

86-18 Telephone construction worker electrocuted and two other workers injured when the boom of a truck crane contacted a 7200V overhead powerline. Victim was groundman repairing a guy wire section laying across the truck crane's outrigger.

86-20 Lineman electrocuted after contacting a lightning arrester conductor while working from an aerial bucket. Contact with 7200V overhead powerline.

86-21 Lineman electrocuted when he contacted a 7200V powerline at an electrical substation. Line erroneously assumed to be dead.

86-22 Warehouse worker guiding grain auger by hand electrocuted as auger contacted 12470V distribution system.

86-24 Scale technician electrocuted while helping a crane operator prepare to lift a platform scale frame. Wire winch cable extending from boom tip contacted a 7200V overhead powerline.

86-25 Superintendent electrocuted while inspecting electrical relays in an electrical control panel box.

86-26 Utility worker electrocuted when aerial bucket in which he was working contacted a 7200V overhead powerline.

86-27 Laborer electrocuted when metal pole he was carrying (used to scrape soot from plant smokestacks) contacted a 7200V overhead powerline. Co-worker apparently attempting rescue seriously burned.

86-28 Worker electrocuted while using a 110V auger to install tie-down rods for a manufactured home. Auger had no continuous grounding system. Co-worker received shock, after which auger fell across victim, electrocuting him.

86-29 Mechanic electrocuted when he contacted a grounded horizontal conductor with one hand and an energized three-way connector with the other. Performing maintenance on electrical distribution system.

86-30 Maintenance worker electrocuted when aluminum pruning pole with a saw attached to it contacted a 7200V overhead powerline while he was trimming a tree.

86-31 Groundman electrocuted while transferring electric distribution lines and a transformer to a new utility pole. Co-worker seriously injured.

86-32 Laborer at pickle plant electrocuted when he contacted a faulty splice on a 440V power cord for a portable pump while filling a tank with brine.

86-33 Electrician's helper electrocuted while wiring a fluorescent light fixture in a suspended ceiling. Procedures for deenergizing and testing of circuits not followed.

86-35 Maintenance worker electrocuted while replacing a ballast in a fluorescent light fixture. Conductor not deenergized, polarity reversed because of installation error.

86-36 Carpenter electrocuted when portable electric saw apparently developed a ground fault. Engaged in construction of laundry building for apartment complex.

86-39 Painter and carpenter electrocuted when a tubular metal scaffold they were rolling to another work area contacted a 12000V overhead powerline.

86-40 Lineman on utility pole electrocuted while reaching overhead with a hot-stick to place a jumper line on one phase of a three-phase 7200V primary line.

86-41 Electrical technician electrocuted while testing circuits in a metal cabinet housing power transmission and distribution equipment. Contact with 10000V energized resistor.

86-42 Groundman electrocuted while cleaning connectors that linked overhead powerlines to service lines to a private home. Victim working without rubber gloves from aerial bucket truck.

86-43 Restaurant manager electrocuted after contacting handle of refrigerator that had a ground fault. Slipped on wet, soapy floor he was cleaning.

86-45 Maintenance worker electrocuted when he contacted an energized circuit in the control box of a popsicle-wrapping machine that was not working. Victim performing diagnostic tests while standing on a metal platform one foot above a wet floor.

86-46 Groundman electrocuted when truck's aerial boom contacted a 7200V overhead powerline while he was in contact with the truck.

86-47 Electrician electrocuted while repairing airport runway lights. Co-worker misinterpreted signal, reenergizing circuit before electrician finished.

86-49 National Guard commander electrocuted when he climbed a tower supporting 46000V transmission lines and contacted a jumper line. Engaged in demolition of tower as training exercise.

86-50 Meter technician, working as a lineman, electrocuted while attempting to repair a fallen 120V powerline. Powerline splice caught victim's glove, exposing his arm to direct 120-volt current.

86-51 Truck driver electrocuted while operating remote control of a truck-mounted crane boom that contacted overhead 7200V powerline. Electric current traveled through controller to victim to ground.

86-53 Electrician electrocuted while performing preventive maintenance on a high-voltage circuit breaker at electrical substation.

86-55 Line mechanic electrocuted after contacting energized tap while replacing a fuse holder.

87-02 Laborer electrocuted when he contacted a 7200V overhead powerline. Standing on roof of house as it was being moved to another location, lifting overhead wires so they would clear the house.

87-03 Mechanic electrocuted when 25-foot two-way radio antenna he was helping to load contacted a 7200V overhead powerline.

87-04 Sheet metal apprentice electrocuted while guiding a powered scaffold that was being unloaded from the flatbed of a truck with a truck-mounted crane. Hoist cable contacted 6500V overhead powerline, and was engulfed in flames. Victim standing on wet ground nearby.

87-07 Machine operator electrocuted when he contacted an energized conductor in a motor control box that had had the cover plate removed. Using gang slitter machine to cut bulk rolls of fiberglass at time of incident.

87-08 Laborer electrocuted when 21-foot aluminum flagpole he was installing contacted a 7200V overhead powerline. Victim carrying flagpole upright.

87-09 Laborer electrocuted when he contacted a 13000V underground powerline while digging with a pneumatic clay spade.

87-10 Pump operator electrocuted when the boom on the truck-mounted concrete pump he was operating contacted a 7600V overhead powerline. Incident unwitnessed, but victim probably standing beside truck using a pendant controller.

87-11 Laborer in oil recycling plant electrocuted when he contacted a pump housing that had become energized due to faulty wiring. Engaged in pumping oil from a filtering tank to an analysis kettle.

87-12 Four maintenance workers at a naval installation electrocuted, and a crew chief critically injured, when the tubular welded-frame scaffold they were wheeling into position contacted a 12000V overhead powerline.

87-13 Laborer helping to unload sewer pipe electrocuted when the boom cable of a truck-mounted crane contacted an overhead powerline, causing an electrical arc. Victim grasping pipe and wire choker at time of incident.

87-14 Stagehand electrocuted when he contacted an exposed electrical wire protruding from a junction box. Victim lying on a metal catwalk reaching out to replace a ceiling tile when incident occurred.

87-15 Laborer painting a concrete silo electrocuted when his telescoping paint roller contacted a 7200V overhead powerline.

87-16 Fire chief electrocuted while trying to remove an injured person from a car which had hit a pole carrying a 7200V powerline.

87-18 Laborer electrocuted while steam-cleaning a rubber mill (converts bulk rubber to strips). Contacted machine, which had energized switch, while standing in water with a metal cleaning wand.

87-19 Bricklayer engaged in construction of brick wall electrocuted when tubular welded-frame scaffold contacted 7620V overhead powerline. Electric current flowed from the powerline to a section of wire reinforcement carried by a co-worker to the scaffold to victim to ground.

87-21 Worker setting up injection molding machine in plastics manufacturing plant electrocuted when he contacted an adjacent grinding machine that had a ground fault.

87-22 Mold-maker apprentice electrocuted while trying to repair and install a fluorescent light fixture that had a short circuit.

87-24 Apprentice lineman electrocuted while attaching a wooden cross arm to a new utility pole. Direct contact with 12000V powerline on an existing pole.

87-28 Two painters electrocuted while painting a 20-foot metal light pole from an aluminum ladder. One victim on ladder, the other on ground steadying ladder. Ladder apparently slipped, then slid along crossbar of light pole, placing victim on ladder in contact with 12460V overhead powerline and electrocuting the victim on the ground.

87-29 Lathe operator electrocuted when he contacted the frame of a lathe energized by a ground fault, presumably while walking between two lathes.

87-31 Electronic technician died of burns sustained in explosion in a 20000V switch compartment at a rail car maintenance shop. Victim sprayed cleaning fluid on energized circuits causing ignition.

87-32 Painter electrocuted when 24-foot aluminum ladder he was positioning contacted 7200V overhead powerline. Victim working alone to paint gutters on apartment building .

87-34 Electrician's apprentice electrocuted when he contacted live conductors while disassembling an energized switch box in an office building. Victim apparently believed box to be deenergized.

87-35 Lineman electrocuted while changing jumper wire at electrical substation, contacting energized switch (34500V lines).

87-36 Truck driver electrocuted when his truck-mounted crane contacted a 7600V overhead powerline. Standing at rear of truck operating crane with conductive pendant controller.

87-37 Truck driver electrocuted when the bed of his dump truck contacted a 7200V overhead powerline. Presumably stepped out of truck to inspect exploded tires. He grasped the truck door handle, which provided a path to ground.

87-38 Lineman electrocuted when the boom of a derrick truck contacted a 7200V overhead powerline while he was leaning against the truck. Co-worker raised boom before grounding rods were in place.

87-40 Painter electrocuted when he began wrapping plastic around an insulator in preparation for painting a steel structure at a substation. Contacted 11000V conductor while standing on steel beam.

87-41 Pipe layer electrocuted when the boom of a backhoe contacted a 13200V overhead powerline. Victim was guiding load attached to backhoe bucket.

87-42 Lineman trainee electrocuted when he attempted to remove a ground wire from a 230000V transmission circuit. Grasped tower end of ground still attached to powerline.

87-43 Electrician electrocuted while replacing a socket on an energized fluorescent light fixture. Victim was stripping insulation from an improperly grounded wire on a ballast.

87-44 Construction foreman electrocuted while guiding a boring machine attached to a crane into a ditch. Crane boom contacted 13000V overhead powerline.

87-48 Carpenter and laborer electrocuted when section of tubular welded-frame scaffolding they were helping to move came loose and contacted 13750V overhead powerline.

87-52 Driller electrocuted when boom of hydraulic well drilling machine he was operating contacted a 34500V overhead powerline.

87-53 Groundman electrocuted when energized 13200V powerline broke and fell onto pole trailer onto which he was loading a pole. Trailer was not grounded.

87-54 Truck driver electrocuted when he raised the bed of his dump truck into a 12000V overhead powerline. Victim standing to the side of the truck operating lever that controlled bed.

87-55 Electrician electrocuted when he contacted an energized wire in a fluorescent light fixture at a private residence.

87-56 Utility worker electrocuted while disconnecting power source to a knitting machine motor, inadvertently touching an energized prong on the damaged plug.

87-58 Apprentice electrician electrocuted when he contacted an energized circuit while installing lights on an ocean pier. Victim ignored instructions not to proceed until circuits verified to be deenergized.

87-60 Maintenance manager electrocuted as he attempted to make a connection in an energized air conditioner at an apartment complex.

87-61 Laborer/truck driver electrocuted while holding onto a hook suspended from the hoist cable of a truck-mounted crane. Cable contacted 19900V overhead powerline.

87-62 Handyman electrocuted when he apparently contacted an energized cap on a well while searching for a water leak.

87-63 Electrician electrocuted when he contacted an energized conductor while installing wiring for a refrigeration system.

87-65 Tree trimmer electrocuted when he directly contacted a 7200V overhead powerline while working in a tree.

87-66 Laborer electrocuted when the mast of a well-drilling rig he was operating contacted a 7200V overhead powerline. Victim saw smoke coming from rig's tires, then tried to enter truck cab to shut off truck.

87-68 Electrician electrocuted after contacting a 110V conductor while working in a crawlspace to install a furnace in a cottage.

87-69 Electrician electrocuted when he contacted 480V power supply to a generator that supplied power to a glue machine.

87-70 Electrician electrocuted when he contacted the energized metal frame of a foundry stoker he was trying to repair.

88-02 Painter electrocuted when he contacted the housing of an energized fluorescent light fixture at a textile plant. Ground wire apparently disconnected in the past.

88-03 Apprentice lineman electrocuted while stringing a new length of overhead powerline that contacted an existing 12000V powerline above him. Electricity passed from new line to a trailer through the victim to ground.

88-04 Painter electrocuted when aluminum extension ladder he and a co-worker were raising contacted 7200V overhead powerline.

88-05 Construction worker electrocuted when aluminum extension ladder he was standing on contacted 7200V overhead powerline as it tipped backwards.

88-11 Maintenance supervisor electrocuted when he contacted a 22000V energized conductor in a control box. Victim evaluating malfunction of laser-guided cutting machine. Advised operator to stop the equipment, but not to deenergize it.

88-13 Cement finisher electrocuted when the metal handle of a cement-finishing tool he was using contacted an overhead powerline.

88-19 Deputy sheriff electrocuted while moving a 7200V powerline that fell when a car struck a utility pole.

88-21 Maintenance worker trainee electrocuted when he contacted an energized conductor in a junction box left uncovered the day before when a motor on a textile machine was replaced. Victim engaged in replacement of a plastic vacuum hose on the same machine.

88-22 Two pipefitters electrocuted when the boom of the crane moving a metal welding shed contacted a 12400V overhead powerline. Victims standing on the ground grasping the shed to guide it into place.

88-23 Lineman electrocuted when his hands contacted both sides of a switch on a pole-mounted capacitor bank. Victim inexplicably raised aerial bucket into overhead powerlines after removing gloves.

88-24 Laborer electrocuted when he contacted 115 volts while adjusting the limit switches on an overhead door opener.

88-25 Apprentice lineman engaged in relocation of powerlines electrocuted when he contacted a 13200V overhead powerline. Climbed pole before lines fully deenergized.

88-26 Maintenance worker for structural steel firm electrocuted when the boom of a crane moving a steel I-beam he was guiding contacted a 13000V overhead powerline. Crew engaged in cleanup of storage yard chose to stack I-beams directly below powerlines.

88-31 Welder/pipefitter killed when he contacted an energized 110V conductor while removing a fluorescent light fixture, and fell 29 feet to the floor. Cut into energized wire with uninsulated metal wire cutters.

88-32 Welder electrocuted when he contacted a conductor on an overhead crane. Engaged in adding reinforcing steel to the bridge of an overhead crane at a steel fabrication firm. Victim believed crane to be deenergized.

88-34 Laborer electrocuted when metal basket he was working from apparently damaged insulation on power supply to overhead crane. Steel I-beam with which victim had contact became energized. Victim engaged in repairing security system.

88-35 Assistant manager at municipal swimming pool electrocuted when she contacted a mixing motor that had a ground fault. Engaged in mixing chemical solution to be added to pool.

88-37 Electrician electrocuted when he touched the uninsulated part of a wire stripper that was in contact with a 110-volt circuit that had not been deenergized at the panel box. Installing residential floodlighting.

88-40 Construction laborer electrocuted when he touched the hoist cable of a crane whose boom was in contact with a 2400V overhead powerline. Engaged in removing forms from newly poured concrete wall and placing them on the crane's choker cable.

88-41 Electrician working in crawlspace electrocuted when his shoulder contacted a broken light bulb in an unguarded ceiling-mounted socket, and his head contacted a steel water pipe. Engaged in tracing wiring at a tobacco manufacturing plant.

88-45 Crew leader for electrical contractor electrocuted while installing transformers on concrete pads for an underground transmission system for a housing development. Failure to place grounds.

88-47 Equipment operator/lineman electrocuted when the wooden crossarm on a utility pole gave way, dropping energized wires on him. Engaged in replacing an electrical distribution system.

89-01 Steelworker electrocuted when he contacted a ventilation fan with damaged insulation on the power cord that had allowed the entire frame of the fan to become energized.

89-04 Equipment operator electrocuted when he directly contacted a 7600V overhead powerline while installing a traffic light. Raised aerial bucket from which he was working, apparently misjudging height of powerline.

89-06 Lineman electrocuted when he contacted a 12000V overhead powerline while installing "squirrel guards" on a transformer. Apparently slipped and contacted the energized side of a cut-out switch while working with bare hands.

89-08 Sign technician electrocuted when steel hoist cable attached to the extended ladder on his truck contacted a 12000V overhead powerline as he was driving. Victim apparently realized there was contact, stopped the truck, and stepped outside, still holding the door of the cab.

89-09 Hydroelectric supervisor died as a result of burns he suffered in an electrical fire. While calibrating analog meter, co-worker dropped overheated voltameter onto exposed high-voltage bus bars, creating a short circuit and a fire which ignited clothing. Co-worker seriously burned.

89-10 Machine operator electrocuted when crane boom contacted a 12000V overhead powerline as he was guiding a steel pipe by hand. Victim's firm working at a pit directly under powerline positioning a boring machine that was to drill under a road.

89-11 Lineman supervisor electrocuted when he contacted an energized fuse holder while on a utility pole. Engaged in rebuilding powerlines for rural electric cooperative. No personal protective equipment used.

89-15 Laborer standing on ground electrocuted when the boom of an aerial bucket truck with which he was in contact touched a 7200V overhead powerline. Two workers engaged in clearing tree branches away from powerline, co-worker working in bucket.

89-16 Roofer electrocuted when a 40-foot aluminum ladder he was positioning contacted a 7200V overhead powerline. Engaged in replacing shingles on church roof.

89-17 Electrical foreman and groundman electrocuted when the groundman removed a guy wire from its anchor and began to place it on the ground. Wire apparently contacted a 13200V powerline while both victims were touching it.

89-18 Electrician electrocuted after he contacted an energized 50000V transformer. After deenergizing identical system, mistakenly entered energized area. Performing scheduled maintenance at pulp and paper mill.

89-19 Maintenance mechanic at meat packing plant electrocuted when he contacted a strapping machine power cord with damaged insulation. Current passed through victim to wet floor.

89-26 Apprentice lineman working from aerial bucket electrocuted when he contacted a 13700V overhead powerline while upgrading an electrical distribution system. Holding a clamp in one hand, victim may have pushed a cable off the bucket with the other hand and contacted the powerline.

89-27 Electrical distribution line technician died as a result of injuries suffered when he directly contacted an overhead powerline while repositioning his aerial bucket. Failure to place insulating hose on lines.

89-36 Distribution line technician electrocuted and a co-worker seriously burned when a powerline they were installing contacted an energized 7200V powerline overhead. Both victims on the ground helping to pull slack out of the new line when line snagged in tree, contacting energized line.

89-37 Laborer electrocuted when he contacted a 4160V powerline after inexplicably entering a restricted power service enclosure. Victim engaged in sandblasting air conditioning unit on roof of plant prior to incident.

89-39 Apprentice lineman electrocuted when he touched a 7200V overhead powerline while attempting to transfer lines to a new utility pole. No personal protective equipment or guards used.

89-40 Service operations technician electrocuted after he contacted an energized 7680V switch while working to restore power to a shopping mall. No personal protective equipment used.

89-42 Cable TV installer electrocuted when his head contacted a 7280V overhead powerline that ran 5 feet above the roof of a house. Installing TV cable on existing utility poles at time of incident.

89-43 Foundry laborer electrocuted when a piece of scrap metal he was helping to load into a damaged electric induction furnace became energized. Current passed from scrap metal through victim through furnace frame to ground.

89-48 Truck driver electrocuted when the boom of a truck-mounted crane he was raising by remote control contacted a 14400V overhead powerline. Current passed through power cord of controller through victim to ground.

89-50 Apprentice electrician electrocuted when he apparently contacted an energized conductor in a junction box while in contact with metal gridwork. While installing light fixture at office complex under construction, victim may have inadvertently cross-wired two neutral conductors.

90-01 Three construction workers electrocuted and three others seriously burned when the mobile elevating work platform they were moving contacted a 69000V overhead powerline. Victims moved platform from location where adequate clearance existed but made contact with powerline where ground sloped upward.

90-02 Leader of tree-trimming crew electrocuted during hurricane cleanup when he contacted a downed powerline he believed to be deenergized. Electric current from portable generator operating at gas station nearby reenergized powerline.

90-03 Lineman, working at night, electrocuted during hurricane cleanup when he directly contacted a powerline dangling from a pole. Victim either did not see the line, or believed it to be deenergized.

90-04 Meter reader electrocuted when he grasped a metal clothesline energized by a downed powerline in an effort to regain his balance after tripping over a chain-link fence.

90-05 Lineman electrocuted while attaching a 2400V powerline to a pole-mounted insulator. Victim assured by supervisor that line was deenergized, but it was in fact energized by portable generator.

90-06 Lineman electrocuted when the boom of bucket of the bucket truck from which he was working rotated into an energized 4800V powerline and secondary fuse box. Victim reattaching tool basket to bucket. Basket hook caught on lever controlling boom, swinging boom into powerline.

90-08 Line technician electrocuted after his head directly contacted an energized jumper wire while restoring power after a hurricane. Victim positioned between powerlines trying to locate transmission problem.

90-09 Painter electrocuted when the aluminum extension ladder he was positioning tipped backwards and contacted a 7200V overhead powerline. Engaged in house painting.

90-10 Carpenter working from aluminum ladder jack scaffold electrocuted when a piece of aluminum drip edging he was installing on a roof contacted a 7200V overhead powerline.

90-22 Electrician electrocuted when he inexplicably switched a circuit breaker to the "on" position and contacted an energized bus bar while performing repairs at a hotel following a hurricane. Victim and co-worker assigned to clear ground fault.

90-26 Lineman electrocuted when he contacted a reenergized cutout switch on a utility pole. Had climbed back up pole to remove piece of electrical tape without putting gloves and safety belt back on. Reached for tape, boots slipped, and hand contacted switch.

90-27 Lineman electrocuted when he contacted a 7200V overhead powerline while installing a guy wire. Arm contacted an existing powerline three inches beyond an insulating line hose.

90-29 Driver of cement truck stopped truck below powerline, crane operator (not aware of truck position) swung cement bucket under line, and laborer (victim) pushed down on handle of bucket door, bringing crane cable in contact with 7200V powerline. Crew about to wash out cement bucket with water.

90-31 Laborer died from injuries suffered when the galvanized pipe he was carrying contacted an energized 12500V jumper wire at a electrical substation.

90-34 Tree trimming groundsman electrocuted when the guy wire he was grasping swayed (due to slack in the wire) and contacted an energized pole-mounted jumper wire. Victim had just finished cutting trees and brush from around guy wire, one end of which was secured to utility pole, other end to steel rod in the ground.

90-36 Concrete worker at manufacturing plant electrocuted when he climbed a steel column, stepped onto a steam pipe, and grasped a conductor that powered a wall crane. Attempting to untangle the hoist chain of an overhead crane that was caught on an I-beam.

90-37 Steelworker electrocuted when he contacted the energized casing of a toaster oven in an employee lunchroom while resting his arm on an air conditioner.

90-38 Well driller electrocuted when a metal pipe being hoisted by a truck-mounted crane made direct contact with a 12000V overhead powerline. Victim standing at side of truck using pendant remote controller. Crew engaged in repair of submersible pump for water well at private home.

90-39 Telecommunications company foreman electrocuted when he grasped the door handle of a burning truck mounted with a crane, the boom of which was in contact with a 7200V overhead powerline. Powerline contact occurred when poles supporting billboard were being pulled out of the ground.

90-40 Lineman electrocuted when he simultaneously contacted both sides of a fused powerline jumper. Working from aerial bucket repositioning powerlines after tree trimming operation.

91-01 Distribution line technician electrocuted while clearing branches from a 7200V overhead powerline he believed to be deenergized. Victim positioned in tree, co-worker heard arcing sound, and victim fell to the ground.

91-03 Tree trimming groundsman electrocuted when the boom of an aerial bucket truck with which he was in contact touched a 23000V overhead powerline.

91-05 Construction laborer electrocuted when he apparently contacted a damaged extension cord that became energized. Constructing waterfront bulkhead for residence at edge of lake.

91-08 Truck driver electrocuted when he raised the bed of his dump truck into a 7200V overhead powerline. Standing on the ground operating the lever that raised and lowered the bed.

91-10 Lineman working from aerial bucket electrocuted while restoring power after a storm. Victim grasped supply end of conductor with one hand, chain hoist in other hand contacted neutral jumper. Failure to ground energized line.

91-20 Lineman trainee electrocuted when he grasped the door handle of a pickup truck energized through a powerline on the ground that had contact with a jumper wire. Victim was apparently planning to try to move the truck.

91-21 Construction laborer electrocuted while grasping a wire rope load choker attached to a crane cable with one hand and a vertical steel rod with the other hand. Crane contacted 7200V overhead powerline. Crew engaged in placement of steel roof joist on roof of school under construction.

91-22 Laborer electrocuted while painting a section of support steel for a conveyor system at a plant under construction. Victim and co-worker failed to report receiving minor shocks from conveyor prior to incident.

91-25 Lineman working on ground operating trailer-mounted line tensioner electrocuted when the tensioner became energized. Jerking, then swaying, of new powerline caused it to contact existing 14200V powerline. Possible improper tension on new powerline, or failure of tensioner braking system.

91-28 Textile worker electrocuted when he contacted an energized conductor inside the control box of a carding machine. While inspecting malfunctioning machine, victim directed air from hose with metal nozzle into control box. Nozzle contacted conductor.

91-29 Crew foreman electrocuted when he contacted an energized conductor on a utility pole while attempting to retrieve TV cable wire tangled in overhead powerline.

91-32 Refrigeration technician performing maintenance tasks electrocuted when he contacted the improperly grounded refrigeration unit of a walk-in cooler at a restaurant.

92-01 Line mechanic electrocuted while working from an aerial bucket in hot, humid conditions to attach an energized conductor to a cross-arm-mounted insulator. Co-worker observed current arcing across a cross-arm bolt in contact with victim’s chest.

92-02 Lineman electrocuted when he contacted an energized powerline while working from the bucket of an aerial bucket truck. Rubber glove caught in wire and partially pulled off, causing wrist to directly contact powerline.

92-06 Roofing mechanic trainee electrocuted when he inadvertently contacted an energized service entrance conductor on the roof of a warehouse. Incident occurred as victim stood up after kneeling on corner of roof to take measurements.

92-07 Electrical technician electrocuted when he inadvertently contacted an energized conductor inside a voltage regulating control cabinet at a new rolling mill. Victim attempting to identify voltage regulation problem, tracing wiring that was not color-coded.

92-12 Powerline worker electrocuted when he grasped an energized jumper wire he apparently believed to be deenergized. Victim impaired by marijuana, using no personal protective equipment. Assigned to repair section of lines plagued by intermittent outages.

92-16 Textile machine operator electrocuted while directing compressed air from hose with metal nozzle in an attempt to cool the electrical components inside the control panel of a sueder machine at a textile plant. Control panel left uncovered.

92-20 Electrical supervisor electrocuted at a plastic-bottle packaging plant when he contacted an energized conductor inside a control panel. Tracing wiring in control panel for a compressor motor starter without deenergizing unit.

92-24 Roofer's helper electrocuted and a co-worker injured when the metal ladder platform hoist they were positioning contacted a powerline. Moving hoist in preparation for placement of new shingles on roof of residence.

92-25 Electrician electrocuted when he contacted an energized powerline while working from an aerial bucket truck to replace cutout switches on a utility pole. No personal protective equipment used, nor were lines covered with insulating blankets or line sleeves.

92-27 Painter electrocuted when the metal ladder he was moving contacted an overhead powerline. Engaged in job site cleanup after painting exterior of private home.

92-30 Apprentice lineman electrocuted when he slipped on wet ground, allowing his unprotected upper body to fall against the utility pole he was helping to set, as the top of the pole was in contact with an overhead powerline.

93-14 Truck driver and company president electrocuted when the boom of a truck-mounted crane contacted a 7200V overhead powerline. Driver using remote control for unloading of concrete blocks at residential construction site. President attempted to assist him upon observing contact, inadvertently contacting energized truck himself.

93-18 Apprentice electrician electrocuted when he apparently lost his balance while standing on a metal ladder attached to operator's cab of an overhead crane and contacted a conductor on another overhead crane. Climbing ladder to reach second crane to perform maintenance on hoisting motor.

94-08 Department of Transportation foreman is electrocuted and a highway maintenance worker severely burned when truck bed contacts overhead 7,200-volt powerline. The dump truck containing asphalt was backed against a paving machine the men were leaning on.

94-10 Journeyman wireman electrocuted after contacting energized switch gear components at a power plant. The journeyman simultaneously contacted two 6.9 kV buss terminals.

94-17 A HVAC contractor and his employee were electrocuted while installing aluminum straps to anchor ductwork to floor joists in a crawlspace. The victim contacted an energized strap, then was grabbed by the contractor. Electrical energy flowed through both men to ground.