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CERTIFICATE

This is to certify that project entitled **Analysis of Electric Power Distribution System of a large Nuclear Power Plant** undertaken at the Department of Electrical Engineering by **Mr. Jayakrishnan k, Mr. Sushant davane, Mr. Rahul sharma,Mr. Shamanth R , Mr. Rajesh jagatap** in partial fulfillment of B.E. (Electrical Engineering) degree Semester VIII Examination as syllabus of University of Mumbai for academic year 2014-2015.It is further certified that he has completed all required phases of the project.

Signature of Internal guide **Signature of HOD**

Signature of External Examiner

Preface

This project work mainly contains the Analysis of Electric Power Distribution System of a large Nuclear Power Plant. The Nuclear Power Plant discussed in this report contains Pressurized Water Reactor (PWR).

The Modular design scheme of PWR Nuclear Power Plant provides the redundancy to prevent the any common failure. Passive Safety System is Striking feature of this PWR Nuclear Power Plant which removes the decay heat when station blackout occurs. As the safety is very important issue in any nuclear power plant, Passive Safety System and Redundant System of plant provides the better safety for plant called as Defense in Depth.

We, have involved in this project, have worked with commitment right from initialization of the project and continuing all the way till its completion.

It may contain little errors, as there is always a scope for improvement.

ACKNOWLEDGEMENT

I owe a great many thanks to a great many people who helped and supported me during the writing of this report.

My deepest thanks to Mr. S K SEN (BARC) & Mr. KALEEM the Guide of the project for guiding and correcting various documents of mine with attention and care. He has taken pain to go through the project and make necessary correction as and when needed.

My deep sense of gratitude to the H.O.D Prof. SYED KALEEM for his support and guidance. Thanks and appreciation to the helpful people at our college for their support.

I would also thank my Institution and my faculty members without whom this project would have been a distant reality. I also extend my heartfelt thanks to my family and well wishers.

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INTRODUCTION OF PWR NULEAR POWER PLANT

There have been a considerable number of nuclear reactor concepts proposed over the thirty years of applied nuclear power. A selected number of these have been developed to the extent that one or more plants have been built. Today, only three of these concepts are considered commercially viable. Two of these concepts are based on the use of uranium enriched in the isotope U-235 with light (or ordinary) water employed for cooling and neutron moderation. Of these two concepts, one is the pressurized water reactor or PWR developed by Westinghouse. The other is the boiling water reactor or BWR developed by General Electric. The third concept is based on the use of natural uranium with heavy-water (water enriched in the deuterium isotope) for cooling and moderation. This reactor concept has been principally developed and applied by Atomic Energy of Canada Limited.

Worldwide, of the over 400 nuclear power plants operating or under construction, over 75 percent of these are of the light-water design with over 65 percent of the light-water plants being PWRs furnished by Westinghouse and its current or original licensees. The fundamental distinction between the PWR and the BWR is that in the latter the coolant moderator is allowed to boil with the resulting steam passed directly to the turbine-generator, whereas in the PWR the coolant moderator is maintained above saturation pressure such that no significant amount of boiling occurs in the reactor. The necessary steam for the turbine generator is produced in a steam generator where the reactor heat is transferred to a secondary water coolant at lower pressure. There are of course a considerable number of other less fundamental differences as well.

The importance of these differences has been examined in a large number of utility evaluations with the clearest and simplest overall result being the current commercial dominance of the PWR design. This document describes the basic design and operating characteristics of a Westinghouse PWR plant. The design is available in five ratings of approximately 600 megawatts electrical (MWe), 900 MWe, 1000 MWe, 1100 MWe, and 1200 MWe. (The exact ratings of course reflect a number of specific constraints such as heat sink characteristics.) The different ratings are attained through use of either two, three or four reactor coolant piping loops, each loop comprised of a steam generator, reactor coolant pump, or interconnecting piping. The loops are each connected to a reactor vessel sized to contain nuclear cores comprised of fuel elements of either 12 or 14 foot length with from121 to 193 assemblies.

In this manner the full range of utility requirements can be satisfied while maximizing the use of standard components The description given in this document is based on a four-loop plant with a twelve foot core (a Model 412 plant) having an electrical capacity of some 1100 MWe. The descriptions generally apply equally to the other ratings when proper consideration is given to the number of reactor coolant loops and/or core length. For all ratings, the functional system requirements and operating characteristics are essentially the same. Where system or plant operation is described, the actions and sequences are based on current Westinghouse recommendations.

PRESSURIZED WATER REACTOR DESIGN CONCEPT

A simplified schematic of the Westinghouse PWR plant design is shown in Figure 1-1. The total power cycle may be considered to be comprised of three generally independent closed cycles or loops: primary, secondary, and tertiary. The primary loop contains the heat source consisting of a nuclear fuel core positioned within a reactor vessel where the energy resulting from the controlled fission reaction is transformed into sensible heat in the coolant moderator. The coolant is pumped to the steam generator where the heat is transferred to a secondary loop through a number of U-type tubes. The reactor coolant then returns back to the reactor vessel to continue the process. An electrically heated pressurizes connected to the loop maintains a pressure above the saturation pressure so that bulk boiling does not occur. The secondary loop is the heat utilization circuit where dry steam produced in the steam generator flows to a turbine-generator where it is expanded to convert thermal energy into mechanical energy and hence electrical energy .The expanded steam exhausts to a condenser where the latent heat of vaporization is transferred to the cooling system and is condensed. The condensate is pumped back to the steam generator to continue the cycle.

The tertiary loop is the heat rejection loop where the latent heat of vaporization is rejected to the environment through the condenser cooling water. Depending on the specific site, this heat is released to a river, lake, ocean, or cooling tower system with the latter becoming the more Common within the United States. Use of a steam generator to separate the primary loop from the secondary loop largely confines the radioactive materials to a single building during normal power operation and eliminates the extensive turbine maintenance problems that would result from radioactively contaminated steam. For general discussion purposes, a nuclear power plant can be considered to be made up of two major areas: a nuclear island and a turbine island. These are described below. Each is comprised of fluid, electrical, instrumentation and control systems; electrical and mechanical components; and the buildings or structures housing them. There are also a number of shared fluids, electrical, instrumentation and control systems, as well as other areas of interconnection or interface.

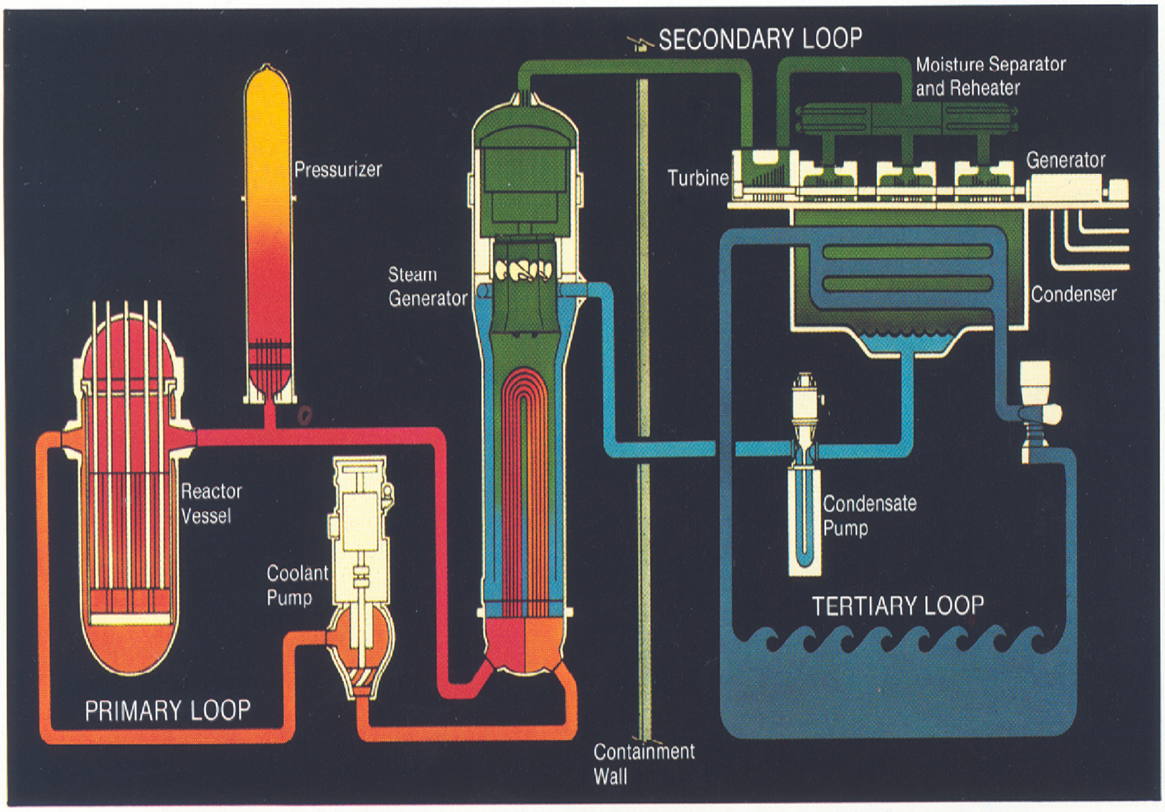


Figure 1-1. Westinghouse PWR Nuclear Power Plant, Simplified Schematic Diagram

CHAPTER1

1 PWR Nuclear Power Plant Analysis

1.1 AC Power System

The onsite ac power system is a non-Class 1E system comprised of a normal, preferred, maintenance and standby power supplies. The normal, preferred, and maintenance power supplies are included in the main ac power system. The standby power is included in the onsite standby power system. The Class 1E and non-Class 1E 208/120 Vac instrumentation power supplies as a part of uninterruptible power supply in the dc power systems.

1.1.1 Onsite AC Power System

The main ac power system is a non-Class 1E system and does not perform any safety-related functions. It has nominal bus voltage ratings of 6.9 kV, 480 V, 277 V, 208 V, and 120 V.

During power generation mode, the turbine generator normally supplies electric power to the plant auxiliary loads through the unit auxiliary transformers. The plant is designed to sustain a load rejection from 100 percent power with the turbine generator continuing stable operation while supplying the plant house loads. The load rejection feature does not perform any safety function.

During plant startup, shutdown, and maintenance the generator breaker remains open. The main ac power is provided by the preferred power supply from the high-voltage switchyard (switchyard voltage is site-specific) through the plant main step-up transformers and two unit auxiliary transformers. Each unit auxiliary transformer supplies power to about 50 percent of the plant loads.

A maintenance source is provided to supply power through two reserve auxiliary transformers.

The maintenance source and the associated reserve auxiliary transformers primary voltage are site specific. The reserve auxiliary transformers are sized so that it can be used in place of the unit auxiliary transformers.

The two unit auxiliary transformers have two identically rated 6.9 kV secondary windings. The third unit auxiliary transformer is a two winding transformer sized to accommodate the electric boiler and site-specific loads. Secondary's of the auxiliary transformers are connected to the 6.9 kV switchgear buses by no segregated phase buses.

The primary of the unit auxiliary transformer is connected to the main generator isolated phase bus duct tap. The 6.9 kV switchgear designation, location, connection, and connected loads are shown in. The buses tagged with odd numbers (ES1, ES3, etc.) are connected to one unit auxiliary transformer and the buses tagged with even numbers (ES2, ES4, etc.) are connected to the other unit auxiliary transformer.

ES7 is connected to the third unit auxiliary transformer. 6.9 kV buses ES1-ES6 are provided with an access to the maintenance source through normally open circuit breakers connecting the bus to the reserve auxiliary transformer. ES7 is not connected to the maintenance source. Bus transfer to the maintenance source is manual or automatic through a fast bus transferscheme.

The arrangement of the 6.9 kV buses permits feeding functionally redundant pumps or groups of loads from separate buses and enhances the plant operational flexibility. The 6.9 kV switchgear powers large motors and the load center transformers. There are two switchgear (ES1 and ES2) located in the annex building, and five (ES3, ES4, ES5, ES6, and ES7) in the turbine building.
The main step up transformers have protective devices for sudden pressure, neutral overcurrent, and differential current. The unit auxiliary transformers have protective devices for sudden pressure, overcurrent, differential current, and neutral overcurrent. The isophase bus duct has ground fault protection. If these devices sense a fault condition the following actions will be automatically taken:

- Trip high-side (grid) breaker
- Trip generator breaker
- Trip exciter field breaker
- Trip the 6.9 kV buses connected to the faulted transformer
- Initiate a fast bus transfer of ES1-ES6 6.9kV buses ES1-ES6.

The reserve auxiliary transformers have protective devices for sudden pressure, overcurrent, and differential current and neutral overcurrent. The reserve auxiliary transformers protective devices trip the reserve supply breaker and any 6.9 kV buses connected to the reserve auxiliary transformers.

The onsite standby power system powered by the two onsite standby diesel generators supplies power to selected loads in the event of loss of normal, and preferred ac power supplies followed by a fast bus transfer to the reserve auxiliary transformers. Those loads that are priority loads for defense-in-depth functions based on their specific functions (permanent nonsafety loads) are assigned to buses ES1 and ES2.

These plant permanent nonsafety loads are divided into two functionally redundant load groups (degree of redundancy for each load is described in the sections for the respective systems). Each load group is connected to either bus ES1 or ES2. Each bus is backed by a non-Class 1E onsite standby diesel generator. In the event of a loss of voltage on these buses, the diesel generators are automatically started and connected to the respective buses.

In the event where a fast bus transfer initiates but fails to complete, the diesel generator will start on an under voltage signal; however, if a successful residual voltage transfer occurs, the diesel generator will not be connected to the bus because the successful residual voltage transfer will provide power to the bus before the diesel connection time of 2 minutes. The source incoming breakers on switchgear ES1 and ES2 are interlocked to prevent inadvertent connection of the onsite standby diesel generator and preferred/maintenance ac power sources to the 6.9 kV buses at the same time.

The diesel generator, however, is capable of being manually paralleled with the preferred or reserve power supply for periodic testing. Design provisions protect the diesel generators from excessive loading beyond the design maximum rating, should the preferred power be lost during periodic testing.

The control scheme, while protecting the diesel generators from excessive loading, does not compromise the onsite power supply capabilities to support the defense-in-depth loads. The 480 V load centers supply power to selected 460 V motor loads and to motor control centers. Bus tie breakers are provided between two 480 V load centers each serving predominantly redundant loads. This intertie allows restoration of power to selected loads in the event of a failure or maintenance of a single load center transformer.

The bus tie breakers are interlocked with the corresponding bus source incoming breakers so that one of the two bus source incoming breakers must be opened before the associated tie breaker is closed. Load center, associated with ES-7, does not have an equivalent match. The 480 V motor control centers supply power to 460 V motors not powered directly from load centers, while the 480/277 V, and 208/120 V distribution panels provide power for miscellaneous loads such as unit heaters, space heaters, and lighting system. The motor control centers also provide ac power to the Class 1E battery chargers for the Class 1E dc power system

1.1.2 Electric Circuit Protection

Protective relay schemes and direct acting trip devices on circuit breakers:

- Provide safety of personnel
- Minimize damage to equipment
- Minimize system disturbances
- Isolate faulted equipment and circuits from unfaulted equipment and circuits
- Maintain (selected) continuity of the power supply Major types of protection systems employed for AP1000 include the following:

1.1.3 Medium Voltage Switchgear Differential Relaying

Each medium voltage switchgear bus is provided with a bus differential relay to protect against a bus fault. The actuation of this relay initiates tripping of the source incoming circuit breaker and all branch circuit load breakers. The differential protection scheme employs
High speed relays. Motors rated 1500 hp and above are generally provided with a high dropout overcurrent relay for differential protection.

1.1.4 Over current Relaying

To provide backup protection for the buses, the source incoming circuit breakers are equipped with an inverse time overcurrent protection on each phase and a residually connected inverse time ground overcurrent protection. Each medium voltage motor feeder breaker is equipped with a motor protection relay which provides protection against various types of faults (phase and ground) and abnormal conditions such as locked rotor and phase unbalance. Motor overload condition is annunciated in the main control room. Each medium voltage power feeder to a 480 V load center has a multifunction relay. The relay provides overcurrent protection on each phase for short circuit and overload, and an instantaneous overcurrent protection for ground fault.

1.1.5 Under voltage Relaying

Medium voltage buses are provided with a set of three under voltage relays which trip motor feeder circuit breakers connected to the bus upon loss of bus voltage using two-out-of three logic to prevent spurious actuation. In addition, a protective device is provided on the line side of incoming supply breakers of buses ES1 and ES2 to initiate an alarm in the main control room if a sustained low or high voltage condition occurs on the utility supply system. The alarm is provided so that the operator can take appropriate corrective measures.

1.1.6 480-V Load Centers

Each motor-feeder breaker in load centers is equipped with a trip unit which has long time, instantaneous, and ground fault tripping features. Overload condition of motors is annunciated in the main control room.

The circuit breakers feeding the 480V motor control centers and other

time, short time, and ground fault tripping features. Each load center bus has an under voltage relay which initiates an alarm in the main control room upon loss of bus voltage. Load center transformers have transformer winding temperature relays which give an alarm on transformer overload.

1.1.7 480-V Motor Control Center

Motor control center feeders for low-voltage (460 V) motors have molded case circuit breakers (magnetic or motor circuit protectors) and motor starters. Motor starters are provided with thermal units (overload heaters) or current sensors. Other feeders have molded case circuit breakers with thermal and magnetic trip elements for overload and short circuit protection. Non-Class 1E ac motor-operated valves are protected by thermal overload devices. Thermal overload devices are selected and sized so as to provide the necessary protection while minimizing the probability of spurious interruptions of valve actuation.

1.1.8 Standby AC Power Supply

1.1.8.1 Onsite Standby Diesel Generators

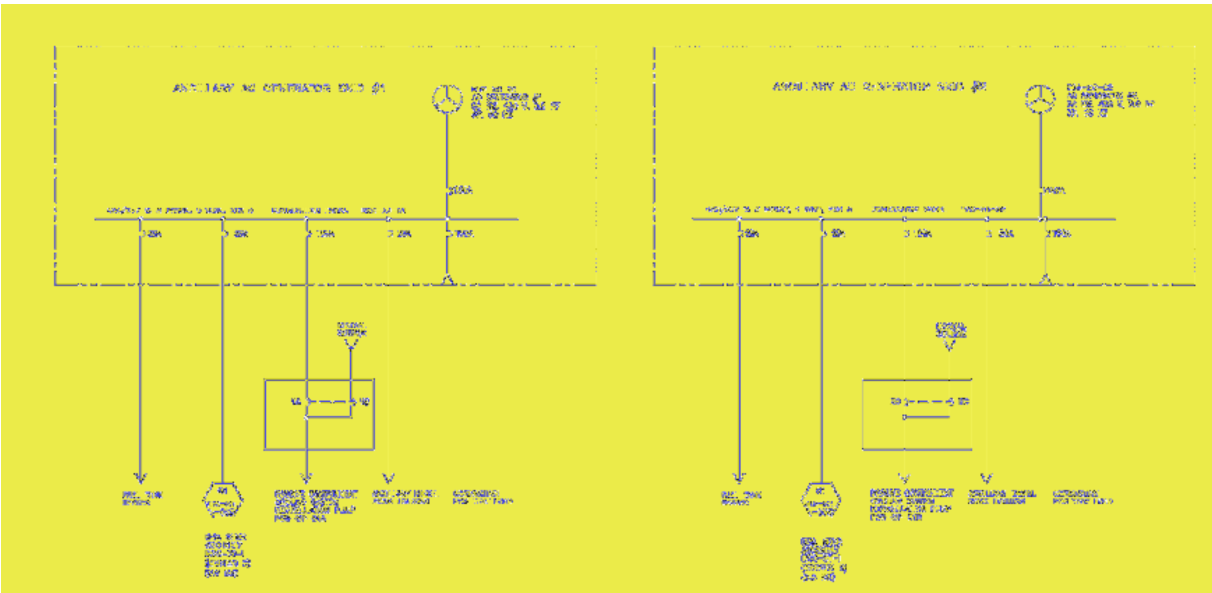
Two onsite standby diesel generator units, each furnished with its own support subsystems, provide power to the selected plant non safety-related ac loads. Power supplies to each diesel generator subsystem components are provided from separate sources to maintain reliability and operability of the onsite standby power system. These onsite standby diesel generator units and their associated support systems are classified as AP1000 Class D, defense-in-depth systems. The onsite standby diesel generator function to provide a backup source of electrical power to Onsite equipment needed to support decay heat removal operation during reduced reactor coolant system inventory, mid loop, operation is identified as an important non safety-related function each diesel generator unit is an independent self-contained system complete with necessary support subsystems that include:

- Diesel engine starting subsystem
- Combustion air intake and engine exhaust subsystem
- Engine cooling subsystem
- Engine lubricating oil subsystem
- Engine speed control subsystem
- Generator, exciter, generator protection, monitoring instruments, and controls subsystems

1.1.8.2 Ancillary ac Diesel Generators

Power for Class 1E post-accident monitoring, MCR lighting, MCR and divisions B and C I&C room ventilation and for refilling the PCS water storage tank and the spent fuel pool when no other sources of power are available is provided by two ancillary ac diesel generators located in the annex building. The ancillary generators are not needed for refilling the PCS water storage tank, spent fuel pool makeup, post-accident monitoring or lighting for the first 72 hours following a loss of all other ac sources.

The fuel for the ancillary generators is stored in a tank located in the same room as the generators. The fuel tank, piping, and valves are analyzed to show that they withstand an SSE. The tank includes provisions for venting to the outside atmosphere and for refilling from a truck or other mobile source of fuel. The tank is seismic Category II and holds sufficient fuel for 4 days of operation.



Temporary Electric Power One Line Diagram

1.1.8.3 Onsite Standby Power System Performance

The onsite standby power system provides reliable ac power to the various plant system electrical loads shown these loads represent system components that enhance an orderly plant shutdown under emergency conditions.

Additional loads that are for investment protection can be manually loaded on the standby power supply after the loads required for orderly shutdown have been satisfied. The values listed in the "Operating Load (kW)". Both the diesel engine and the associated generator are rated based on 104°F ambient temperature at 1000 ft elevation as standard site conditions.

The selected unit rating has a design margin to accommodate possible de rating resulting from other site conditions. The diesel generator unit is able to reach the rated speed and voltage and be ready to accept electrical loads within 120 seconds after a start signal. Each generator has an automatic load sequencer to enable controlled loading on the generator. The automatic load sequencer connects selected loads at predetermined intervals. This feature allows recuperation of generator voltage and frequency to rated values prior to the connection of the next load.

To enable periodic testing, each generator has synchronizing equipment at a local panel as well as in the main control room.

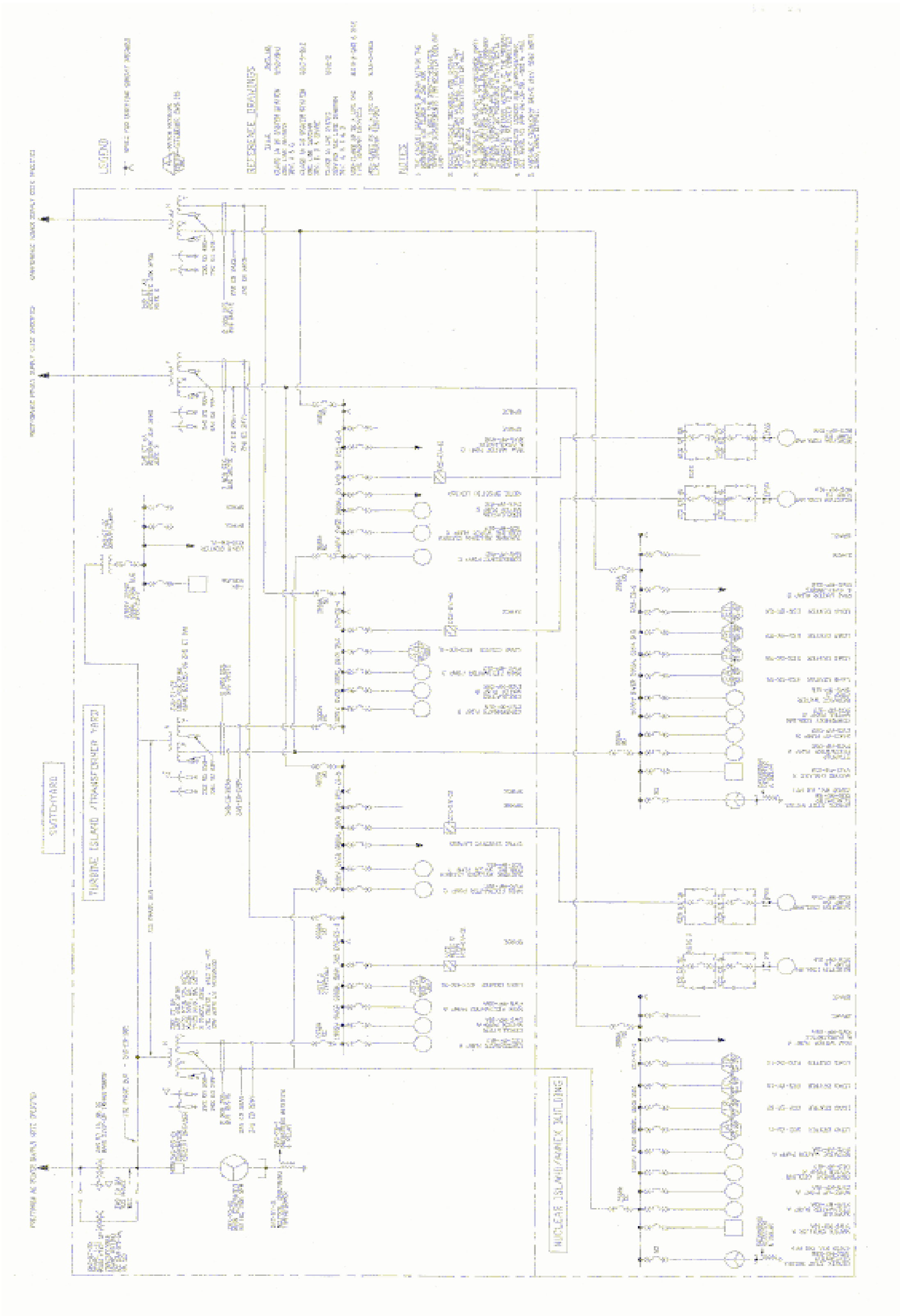
1.1.9 Electrical Equipment Layout

The main ac power system distributes ac power to the reactor, turbine, and balance of plant (BOP) auxiliary electrical loads for startup, normal operation, and normal/emergency shutdown. The medium voltage switchgear ES1 and ES2 are located in the electrical switchgear rooms 1 and 2 of the annex building. The incoming power is supplied from the unit auxiliary transformers ET2A and ET2B (X windings) via non segregated buses.

The non segregated buses are routed from the transformer yard to the annex building in the most direct path practical. The switchgear ES3, ES4, ES5, and ES6 are located in the turbine building electrical switchgear rooms. The incoming power is supplied from the unit auxiliary transformers ET2A and ET2B (Y windings) via non segregated buses to ES3 and ES4 and from ET2A and ET2B (X windings) to ES5 and ES6. Switchgear ES7 is located in the auxiliary boiler room in the turbine building.

The Class 1E medium voltage circuit breakers, ES31, ES32, ES41, ES42, ES51, ES52, ES61, and ES62, for four reactor coolant pumps are located in the auxiliary building. The 480 V load centers are located in the turbine building electrical switchgear rooms 1 and 2 and in the annex building electrical switchgear rooms 1 and 2 based on the proximity of loads and the associated 6.9 kV switchgear.

Load center 71 is located in the auxiliary boiler room in the turbine building. The 480 V motor control centers are located throughout the plant to effectively distribute power to electrical loads. The load centers and motor control centers are free standing with top or bottom cable entry and front access. The number of stacks/cubicles varies for each location.



AC Power Station Single Line Diagram

1.1.10 Grounding System

The grounding system consists of the following
Four subsystems:

- Station grounding grid
- System grounding
- Equipment grounding
- Instrument/computer grounding

The station grounding grid subsystem consists of buried, interconnected bare copper conductors and ground rods (Copper weld) forming a plant ground grid matrix. The subsystem will maintain a uniform ground potential and limit the step-and-touch potentials to safe values under all fault conditions.

The system grounding subsystem provides grounding of the neutral points of the main generator, main step-up transformers, auxiliary transformers, load center transformers, and onsite standby Diesel generators. The main and diesel generator neutrals will be grounded through grounding transformers providing high-impedance grounding. The main step-up and load center transformer Neutrals will be grounded solidly.

The auxiliary (unit and reserve) transformer secondary winding neutrals will be resistance grounded. The equipment grounding subsystem provides grounding of the equipment enclosures, metal structures, metallic tanks, ground bus of switchgear assemblies, load centers, MCCs, and control Cabinets with two ground connections to the station ground grid. The instrument/computer grounding subsystem provides plant instrument/computer grounding through separate radial grounding systems consisting of isolated instrumentation ground buses and Insulated cables. The radial grounding systems are connected to the station grounding grid at one point only and are insulated from all other grounding circuits.

1.1.11 Lightning Protection

The lightning protection system, consisting of air terminals and ground conductors, will be provided for the protection of exposed structures and buildings housing safety-related and fire protection equipment in accordance with NFPA 780.Also, lightning arresters are provided in each phase of the transmission lines and at the high-voltage terminals of the outdoor transformers.

The isophase bus connecting the main generator and the main transformer and the medium-voltage switchgear is provided with lightning arresters. In addition, surge suppressors are provided to protect the plant instrumentation and monitoring system from lightning-induced surges in the signal and power cables connected to devices located outside.

Direct-stroke lightning protection for facilities is accomplished by providing a low-impedance path by which the lightning stroke discharge can enter the earth directly. The direct-stroke lightning protection system, consisting of air terminals, interconnecting cables, and down conductors to ground, are provided external to the facility in accordance with the guidelines included in NFPA 780.

The system is connected directly to the station ground to facilitate dissipation of the large current of a direct lightning stroke. The lightning arresters and the surge suppressors connected directly to ground provide a low-impedance path to ground for the surges caused or induced by lightning. Thus, fire or damage to facilities and equipment resulting from a lightning stroke is avoided.

1.1.12 Inspection and Testing

Preoperational tests are conducted to verify proper operation of the ac power system. The preoperational tests include operational testing of the diesel load sequencer and diesel generator capacity testing.

1.1.12.1 Diesel Load Sequencer Operational Testing

The load sequencer for each standby diesel generator is tested to verify that it produces the appropriate sequencing signals within five (5) seconds of the times The five second margin is sufficient for proper diesel generator transient response.

1.1.12.2 Standby Diesel Generator Capacity Testing

Each standby diesel generator is tested to verify the capability to provide 4000 kW while maintaining the output voltage and frequency within the design tolerances of 6900±10% Vac and 60±5% Hz. The 4000 kW capacity is sufficient to meet the loads The test duration will be the time required to reach engine temperature equilibrium plus 2.5 hours. This duration is sufficient to demonstrate long-term capability.

1.2 DC Power Systems

➢ Description

The plant dc power system is comprised of independent Class 1E and non-Class 1E dc power systems. Each system consists of ungrounded stationary batteries, dc distribution equipment, and uninterruptible power supply (UPS).

The Class 1E dc and UPS system provides reliable power for the safety-related equipment required for the plant instrumentation, control, monitoring, and other vital functions needed for shutdown of the plant. In addition, the Class 1E dc and UPS system provides power to the normal and emergency lighting in the main control room and at the remote shutdown workstation.

The Class 1E dc and UPS system is capable of providing reliable power for the safe shutdown of the plant without the support of battery chargers during a loss of all ac power sources coincident with a design basis accident (DBA).

The system is designed so that no single failure will result in a condition that will prevent the safe shutdown of the plant. The non-Class 1E dc and UPS system provides continuous, reliable electric power to the plant non-Class 1E control and instrumentation loads and equipment that are required for plant operation and investment protection and to the hydrogen igniters located inside containment. Operation of the non-Class 1E dc and UPS system is not required for nuclear safety.

1.2.1 Class 1E DC and UPS System

1.2.1.1 Class 1E DC Distribution

The Class 1E dc components are housed in seismic Category I structures. For system configuration and equipment rating, see Class 1E dc one-line diagram, Nominal ratings of major Class 1E dc equipment There are four independent, Class 1E 250 Vdc divisions, A, B, C, and D. Divisions A and D are each comprising one battery bank, one switchboard, and one battery charger.

The battery bank is connected to Class 1E dc switchboard through a set of fuses and a disconnect switch. Divisions B and C are each composed of two battery banks, two switchboards, and two battery chargers. The first battery bank in the four divisions, designated as 24-hour battery bank, provides power to the loads required for the first 24 hours following an event of loss of all ac power sources concurrent with a design basis accident (DBA).

The second battery bank in divisions B and C, designated as 72-hour battery bank, is used for those loads requiring power for 72 hours following the same event. Each switchboard connected with a 24-hour battery bank supplies power to an inverter, a 250 Vdc distribution panel, and a 250 Vdc motor control center.

Each switchboard connected with a 72-hour battery bank supplies power to an inverter. No load shedding or load management program is needed to maintain power during the required 24-hour safety actuation period. A single spare battery bank with a spare battery charger is provided for the Class 1E dc and UPS system.

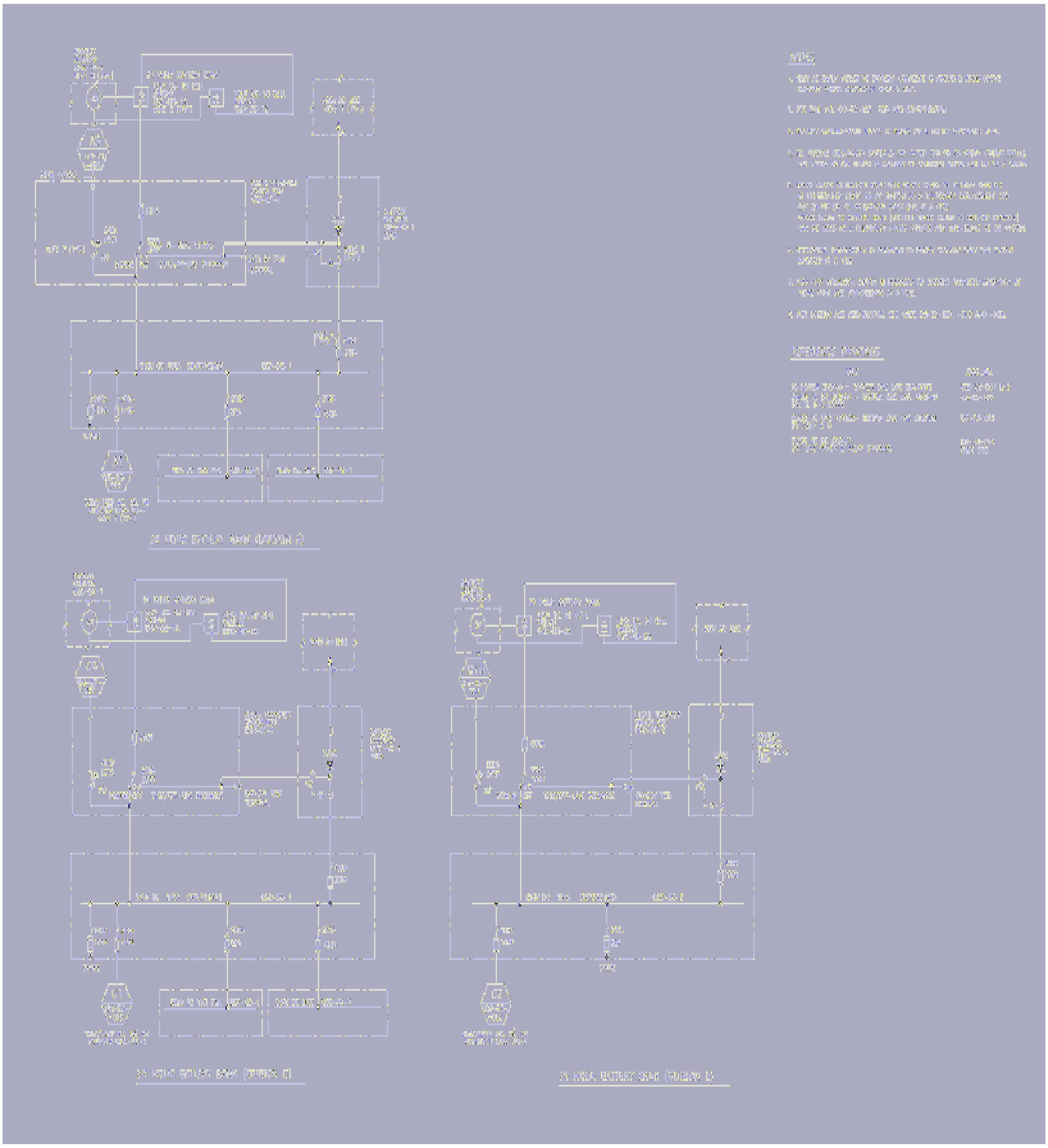
In the case of a failure or unavailability of the normal battery bank and the battery charger, permanently installed cable connections allow the spare to be connected to the affected bus by plug-in locking type disconnect along with kirk-key interlock switches.

The plug-in locking type disconnect and kirk-key interlock switches permit connection of only one battery bank and battery charger at a time so that the independence of each battery division is preserved.

The spare battery and the battery charger can also be utilized as a substitute when offline testing, maintenance, and equalization of an operational battery bank are desired. Each battery bank, including the spare, has a battery monitor system that detects battery open circuit conditions and monitors battery voltage.

The battery monitor provides a trouble alarm in the main control room. The battery monitors are not required to support any safety-related function. Monitoring and alarming of dc current and voltages are through the plant control system which includes a battery discharge rate alarm. AP1000 generally uses fusible disconnect switches in the Class 1E dc system.

If molded-case circuit breakers are used for dc applications, they will be sized to meet the dc interrupting rating requirements. The Class 1E dc switchboards employ fusible disconnect switches and have adequate short circuit and continuous-current ratings. The main bus bars are braced to withstand mechanical forces resulting from a short-circuit current. Fused transfer switch boxes, equipped with double pole double throw transfer switches, are provided to facilitate battery testing, and maintenance



Class 1E DC System One Line Diagram

1.2.1.2 Class 1E Uninterruptible Power Supplies

The Class 1E UPS provides power at 208 Y/120 Vac to four independent divisions of Class 1E instrument and control power buses. Divisions A and D each consist of one Class 1E inverter associated with an instrument and control distribution panel and a backup voltage regulating transformer with a distribution panel.

The inverter is powered from the respective 24-hour battery bank switchboard. Divisions B and C each consist of two inverters, two instrument and control distribution panels, and a voltage regulating transformer with a distribution panel.

One inverter is powered by the 24-hour battery bank switchboard and the other, by the 72-hour battery bank switchboard. For system configuration and equipment rating. The nominal ratings of the Class 1E inverters and the voltage regulating transformers. Under normal operation, the Class 1E inverters receive power from the associated battery bank. If an inverter is inoperable or the Class 1E 250 Vdc input to the inverter is unavailable, the power is transferred automatically to the backup ac source by a static transfer switch featuring a make-before-break contact arrangement.

The backup power is received from the diesel generator backed non-Class 1E 480 Vac bus through the Class 1E voltage regulating transformer. In addition, a manual mechanical bypass switch is provided to allow connection of backup power source when the inverter is removed from service for maintenance. In order to supply power during the post-72-hour period following a design basis accident, provisions are made to connect a ancillary ac generator to the Class 1E voltage regulating transformers (divisions B and C only).

This powers the Class 1E post-accident monitoring systems and the lighting in the main control room and ventilation in the MCR and divisions B and C I&C rooms. The non-Class 1E dc and UPS system consists of the electric power supply and distribution equipment that provide dc and uninterruptible ac power to the plant non-Class 1E dc and ac loads that are critical for plant operation and investment protection and to the hydrogen igniters located inside containment. The non-class 1E dc and UPS system is comprised of two subsystems representing two separate power supply trains.

The subsystems are located in separate rooms in the annex building each of the EDS1 and 3, and 2 and 4 subsystems consists of separate dc distribution buses. These two buses can be connected by a normally open circuit breaker to enhance the power supply source availability. Each dc subsystem includes battery chargers, stationary batteries, dc distribution equipment, and associated monitoring and protection devices.

DC buses 1, 2, 3, and provide 125 Vdc power to the associated inverter units that supply the ac power to the non-Class 1E uninterruptible power supply ac system. An alternate regulated ac power source for the UPS buses is supplied from the associated regulating transformers. DC bus 5 supplies large dc motors. This configuration isolates the large motors.

The onsite standby diesel generator backed 480 Vac distribution system provides the normal ac power to the battery chargers. Industry standard stationary batteries that are similar to the Class 1E design are provided to supply the dc power source in case the battery chargers fail to supply the dc distribution bus system loads.

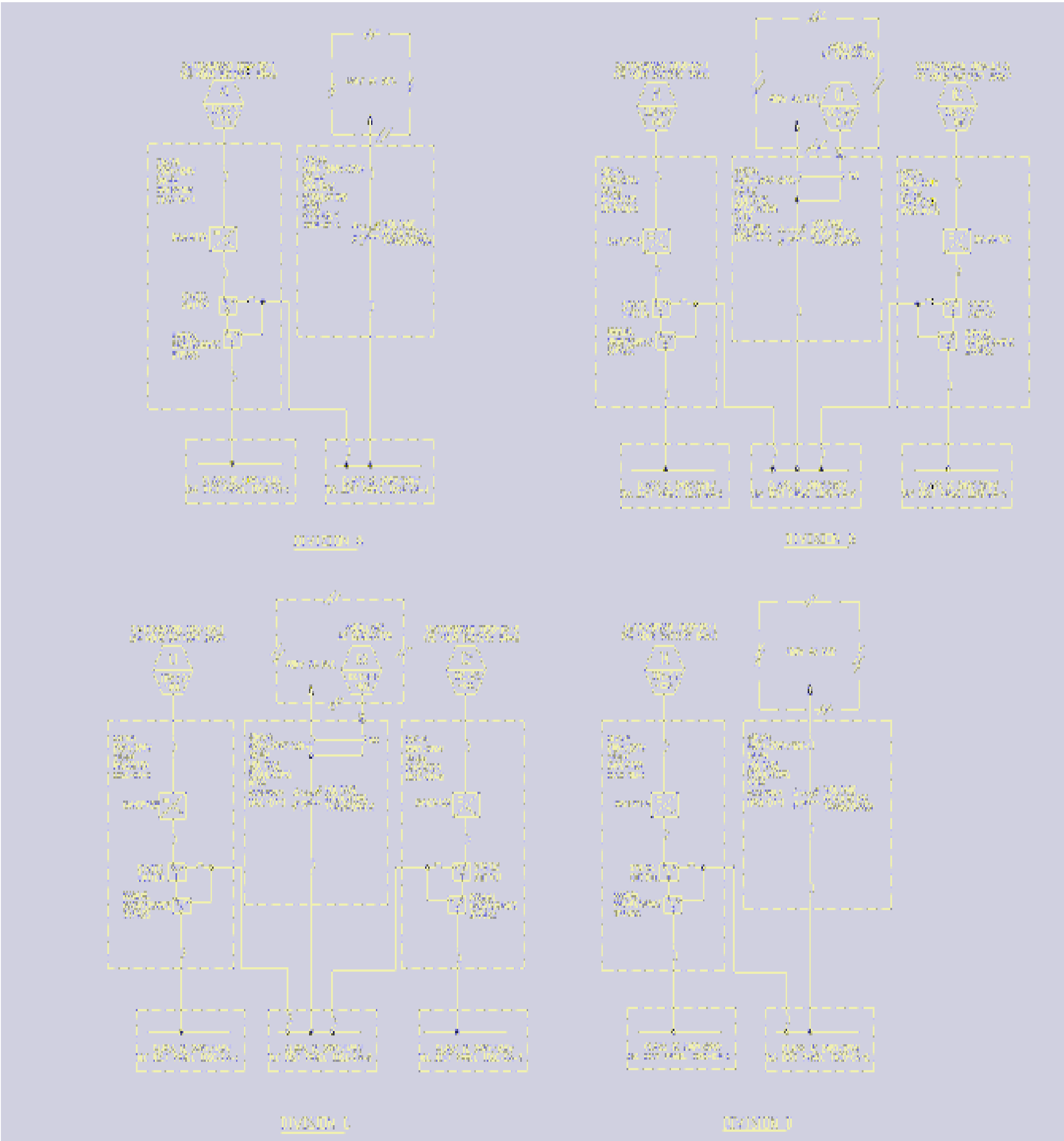
The batteries are sized to supply the system loads for a period of at least two hours after loss of all ac power sources. The dc distribution switchboard houses the dc feeder protection device, dc bus ground fault detection, and appropriate metering.

The component design and the current interrupting device selection follow the circuit coordination principles. Each of the EDS1 through 4 non-Class 1E dc distribution subsystem bus has provisions to allow the connection of a spare non-Class 1E battery charger should its non-Class 1E battery charger be unavailable due to maintenance, testing, or failure. EDS5 does not require this capability because the only load on the charger is the battery.

The non-Class 1E dc system uses the Class 1E spare battery bank as a temporary replacement for any primary non-Class 1E battery bank. In this design configuration, the spare Class 1E battery bank would be connected to the non-Class 1E dc bus, but could not simultaneously supply Class 1E safety loads not perform safety-related functions.

For EDS1 through EDS4, this is accomplished by opening the disconnect switch between the two 125 Vdc battery cell strings, which together, comprise the 250 Vdc spare battery. Additionally, the design includes two current interrupting devices placed in series with the main feed from the spare battery that are fault-current activated.

This will preserve the spare Class 1E battery integrity should the non-Class 1E bus experience an electrical fault. This arrangement will not degrade the electrical independence of the Class 1E safety circuits.



Class 1E UPS One Line Diagram

1.2.2 Non-Class 1E DC and UPS System

The non-Class 1E dc and UPS system consists of the electric power supply and distribution equipment that provide dc and uninterruptible ac power to the plant non-Class 1E dc and ac loads that are critical for plant operation and investment protection and to the hydrogen igniters located inside containment.

The non-class 1E dc and UPS system is comprised of two subsystems representing two separate power supply trains. The subsystems are located in separate rooms in the annex building. Each of the EDS1 and 3, and 2 and 4 subsystems consist of separate dc distribution buses. These two buses can be connected by a normally open circuit breaker to enhance the power supply source availability. Each dc subsystem includes battery chargers, stationary batteries, dc distribution equipment, and associated monitoring and protection devices.

DC buses 1, 2, 3, and 4 provide 125 Vdc power to the associated inverter units that supply the ac power to the non-Class 1E uninterruptible power supply ac system. An alternate regulated ac power source for the UPS buses is supplied from the associated regulating transformers. DC bus 5 supplies large dc motors. This configuration isolates the large motors.

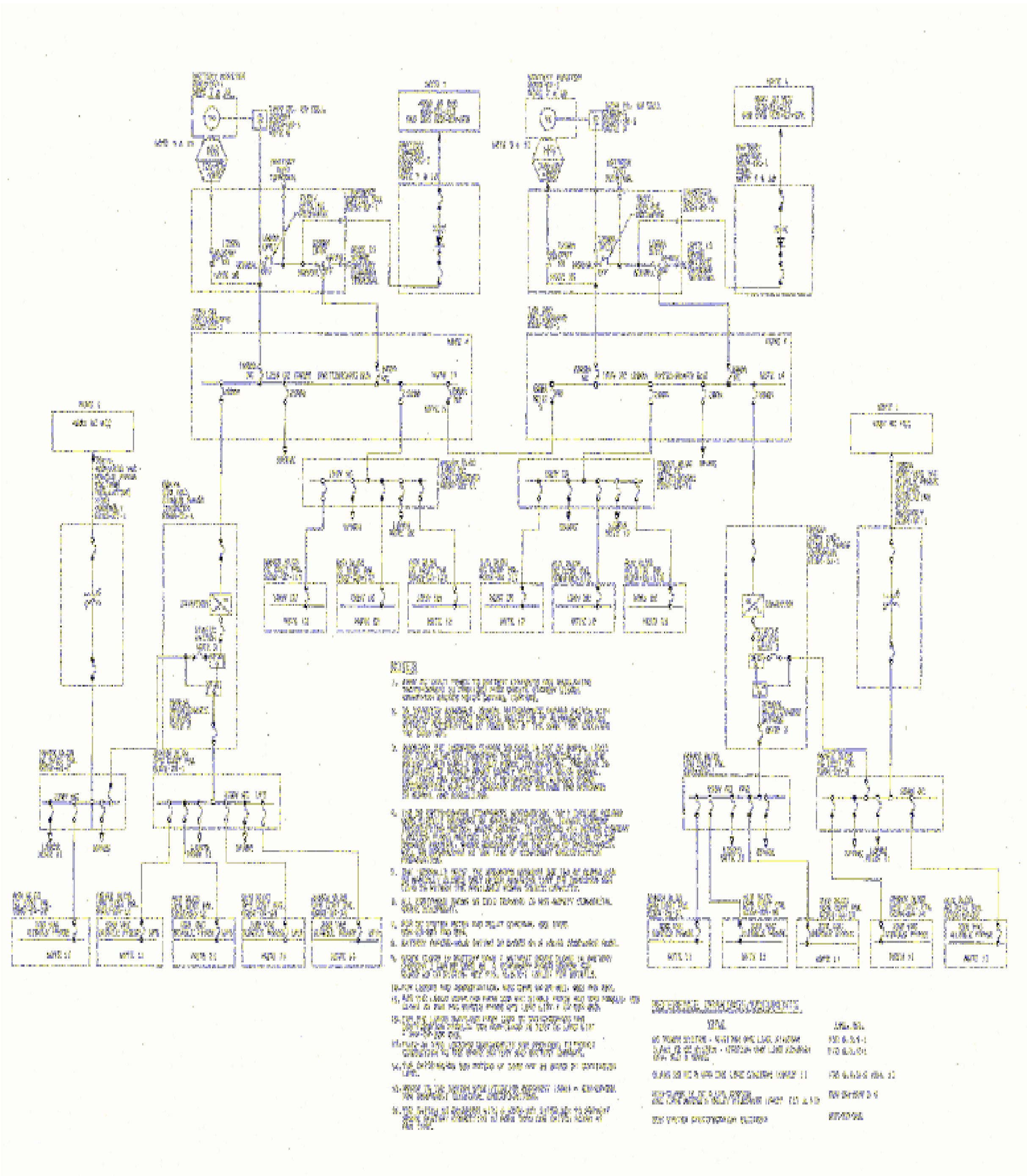
The onsite standby diesel generator backed 480 Vac distribution system provides the normal ac power to the battery chargers. Industry standard stationary batteries that are similar to the Class 1E design are provided to supply the dc power source in case the battery chargers fail to supply the dc distribution bus system loads.

The batteries are sized to supply the system loads for a period of at least two hours after loss of all ac power sources. The dc distribution switchboard houses the dc feeder protection device, dc bus ground fault detection, and appropriate metering. The component design and the current interrupting device selection follow the circuit coordination principles.

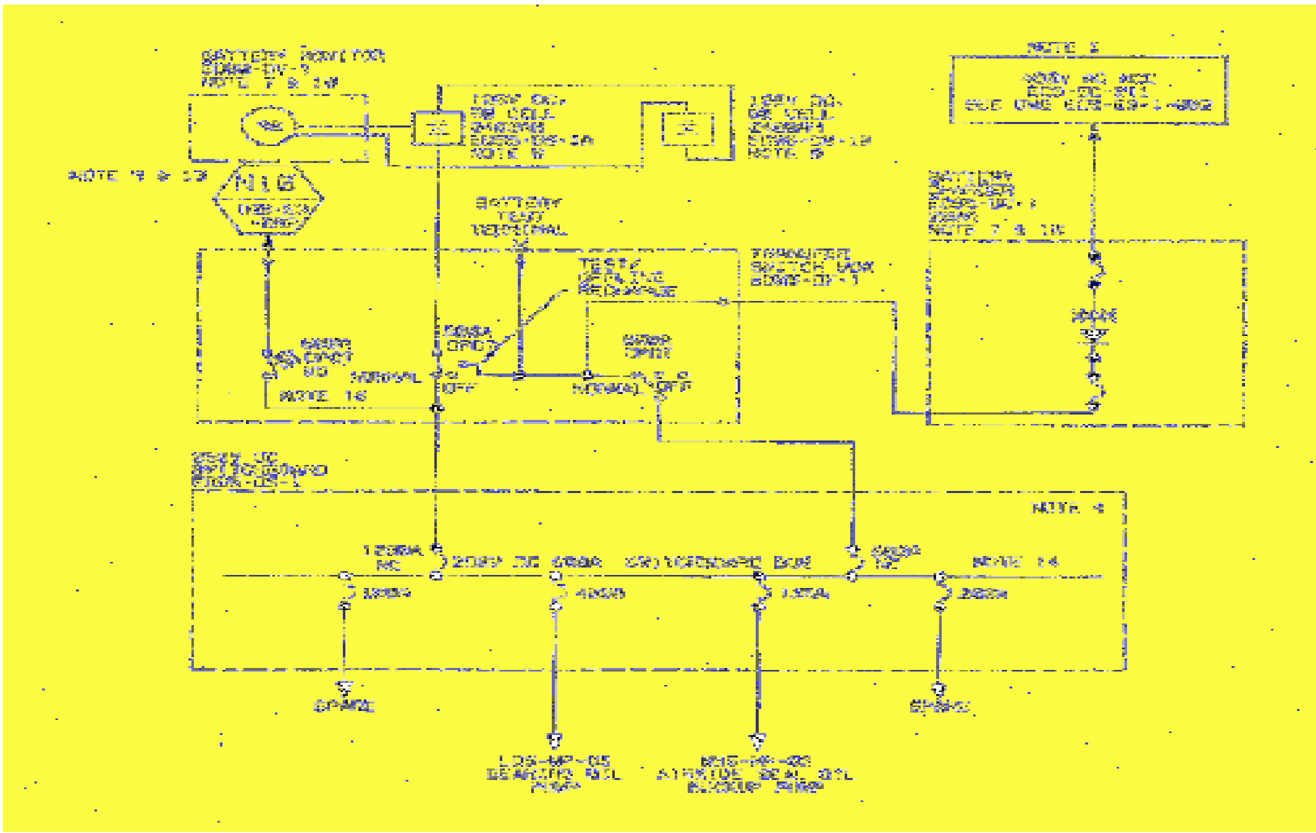
Each of the EDS1 through 4 non-Class 1E dc distribution subsystem bus has provisions to allow the connection of a spare non-Class 1E battery charger should its non-Class 1E battery charger be unavailable due to maintenance, testing, or failure.

EDS5 does not require this capability because the only load on the charger is the battery. The non-Class 1E dc system uses the Class 1E spare battery bank as a temporary replacement for any primary non-Class 1E battery bank. In this design configuration, the spare Class 1E battery bank would be connected to the non-Class 1E dc bus, but could not simultaneously supply Class 1E safety loads nor perform safety-related functions.

For EDS1 through EDS4, this is accomplished by opening the disconnect switch between the two 125 Vdc battery cell strings, which together, comprise the 250 Vdc spare battery. Additionally, the design includes two current interrupting devices placed in series with the main feed from the spare battery that are fault-current activated. This will preserve the spare Class 1E battery integrity should the non-Class 1E bus experience an electrical fault. This arrangement will not degrade the electrical independence of the Class 1E safety circuits.



Non-Class1E DC And UPS System Single Line Diagram.



Non-Class1E DC And UPS System Single Line Diagram

1.2.3 Separation and Ventilation

For the Class 1E dc system, the 24-hour and the 72-hour battery banks are housed in the auxiliary building in ventilated rooms apart from chargers and distribution equipment. The battery rooms are ventilated to limit hydrogen accumulation. Each of the four divisions of dc systems are electrically isolated and physically separated to prevent an event from causing the loss of more than one division.

1.2.4 Maintenance and Testing

Components of the 125 Vdc and 250 Vdc systems undergo periodic maintenance tests to determine the condition of the system. Batteries are checked for electrolyte level, specific gravity and cell voltage, and are visually inspected. The surveillance testing of the Class 1E 250 Vdc system is performed as required by the Technical Specifications. The inverter DC input protection will be set at least 10% higher than the battery charger trip set points to prevent the inverter tripping before the battery charger. The time delay for the inverter high dc input voltage trip will be set higher than the time delay for the battery charger to prevent the inverter tripping before the battery charger.

Testing of battery, inverter, transformer and battery charger.

1.2.4.1 Class 1E 24-Hour Battery Capacity Testing

Each Class 1E 24-hour battery is tested to verify the capability to provide its load for 24 hours while maintaining the battery terminal voltage above the minimum voltage. Analysis will be performed based on the design duty cycle, and testing will be performed with loads which envelope the analyzed battery bank design duty cycle. Each battery is
Connected to a charger maintained at 270±2 V for a period of at least 24 hours prior to the test to assure the battery is fully charged.

1.2.4.2 Class 1E 72-Hour Battery Capacity Testing

Each Class 1E 72-hour battery is tested to verify the capability to provide its load for 72 hours while maintaining the battery terminal voltage above the minimum voltage. Analysis will be performed based on the design duty cycle, and testing will be performed with loads which envelope the analyzed battery bank design duty cycle. Each battery is
connected to a charger maintained at 270±2 V for a period of at least 24 hours prior to the test to assure the battery is fully charged.

1.2.4.3 Class 1E 24-Hour Inverter Capacity Testing

Eac Class 1E 24-hour inverter is tested to verify the capability to provide 12 kW while maintaining the output voltage and frequency within the tolerances. The 12 kW capacity is sufficient to meet the 24-hour inverter loads. The inverter input voltage will be no more than 210 Vdc during the test to represent the conditions at the battery end of life.

1.2.4.4 Class 1E 72-Hour Inverter Capacity Testing

Each Class 1E 72-hour inverter is tested to verify the capability to provide 7 kW while maintaining the output voltage and frequency within the tolerances The 7 kW capacity is sufficient to meet the 72-hour inverter loads. The inverter input voltage will be no more than 210 Vdc during the test to represent the conditions at the battery end of life

1.2.4.5 Class 1E 24-Hour Charger Capacity Testing

Each Class 1E 24-hour charger is tested to verify the capability to provide 150 A while maintaining the output voltage within the range. The 150 A is sufficient to meet the 24-hour loads while maintaining the corresponding battery charged.

1.2.4.6 Class 1E 72-Hour Charger Capacity Testing

Each Class 1E 72-hour charger is tested to verify the capability to provide 125 A while maintaining the output voltage within the range. The 125 A is sufficient to meet the 72-hour loads, while maintaining the corresponding battery charged.

1.2.4.7 Class 1E Regulating Transformer Capacity Testing

Each Class 1E regulating transformer is tested to verify the capability to provide 30 kW while maintaining the output voltage within the tolerance. The 30 kW capacity is sufficient to meet the inverter loads

1.2.4.8 Motor-Operated Valves Terminal Voltage Testing

The operating voltage supplied to Class 1E motor-operated valves is measured to verify the motor starter input terminal voltage is above the minimum design value of 200 Vdc. The battery terminal voltage will be no more than 210 Vdc during the test to represent the conditions at the battery end of life.

1.2.4.9 Non-Class 1E Battery Capacity Testing

Each load group 1, 2, 3, and 4 non-Class 1E battery is tested to verify the capability to provide 500 A for two hours while maintaining the battery terminal voltage above the minimum voltage. The 500 A is sufficient to meet the loads. Each battery is connected to a charger maintained at 135±1 V for a period of at least 24 hours prior to the test to assure the battery is fully charged.

1.2.4.10 Non-Class 1E Inverter Capacity Testing

Each load group 1, 2, 3, and 4 non-Class 1E inverter is tested to verify the capability to provide35 kW while maintaining the output voltage and frequency within the tolerances The 35 kW capacity is sufficient to meet the loads

1.2.4.11 Non-Class 1E Charger Capacity Testing

Each load group 1, 2, 3, and 4 non-Class 1E charger is tested to verify the capability to provide 550 A while maintaining the output voltage within the range. The 550 A is sufficient to meet the loads while maintaining the corresponding battery charged

1.3 Offsite Power System

1.3.1 System Description

A transmission system to supply offsite ac energy for startup and normal shutdown through a site-specific transmission switchyard. This offsite ac power system is not required for plant safety. The normal ac power supply to the main ac power system is provided from the main generator.

When the main generator is not available, plant auxiliary power is provided from the switchyard by back feeding through the main step up and unit auxiliary transformers. This is the preferred power supply. When neither the normal or the preferred power supply is available due to an electrical fault at either the main step up transformer, unit auxiliary transformer, isophase bus, or 6.9kv non segregated bus duct, fast bus transfer will be automatically initiated to transfer the loads to the reserve auxiliary transformers powered by maintenance sources of power.

In addition, two non-Class 1E onsite standby diesel generators supply power to selected plant loads in the event of loss of the normal, preferred, and maintenance power sources. The reserve auxiliary transformers also serve as a source of maintenance power. The maintenance sources are site-specific.

Maintenance power is provided at the medium voltage level (6.9 kV) through normally open circuit breakers. Bus transfer to the maintenance source is automatic under fast bus transfer logic or may be initiated manually. Connection of the preferred and maintenance power supplies to the utility grid or other power sources is site-specific. The main generator is connected to the offsite power system via three single-phase main step up transformers.

The normal power source for the plant auxiliary ac loads is provided from the isophase generator bus through the two unit auxiliary transformers of identical ratings. In the event of a loss of the main generator, the power is maintained without interruption from the preferred power supply by an auto-trip of the main generator breaker.

Power then flows from the transformer area to the auxiliary loads through the main and unit auxiliary transformers. The transmission system is site-specific. The transmission line structures associated with the plant are designed to withstand standard loading conditions for the specific-site as provided. Automatic load dispatch is not used at the plant and does not interface with safety-related action required of the reactor protection system.

1.3.2 Transformer Area

The transformer area contains the main step up transformers, the unit auxiliary transformers, and the reserve auxiliary transformers. Protective relaying and metering required for this equipment is located in the turbine building. The necessary power sources (480 Vac, 120 Vac, and 125 Vdc) to the equipment are supplied from the turbine building. One feeder connects the transformer area with the switchyard to supply power to/from the main step up transformers for the unit.

1.3.3 Grid Stability

The AP1000 is designed with passive safety-related systems for core cooling and containment integrity and, therefore, does not depend on the electric power grid for safe operation. This feature of the AP1000 significantly reduces the importance of the grid connection and the requirement for grid stability. The AP1000 safety analyses assume that the reactor coolant pumps can receive power from either the main generator or the grid for a minimum of 3 seconds following a turbine trip.

The AP1000 main generator is connected to the generator bus through the generator circuit breaker. The grid is connected to the generator bus through the main step-up transformers and the grid breakers. The reactor coolant pumps are connected to the generator bus through the reactor coolant pump breakers, the 6.9 kV switchgear, and the unit auxiliary transformers.

During normal plant operation the main generator supplies power to the generator bus. Some of this power is used by the plant auxiliary systems (including the reactor coolant pumps); the rest of the power is supplied to the grid. If, during power operation of the plant, a turbine trip occurs, the motive power (steam) to the turbine will be removed.

The generator will attempt to keep the shaft rotating at synchronous speed (governed by the grid frequency) by acting like a synchronous motor. The reverse-power relay monitoring generator power will sense this condition and, after a time delay of at least 15 seconds, open the generator breaker. During this delay time the generator will be able to provide voltage support to the grid if needed. The reactor coolant pumps will receive power from the grid for at least 3 seconds following the turbine trip.

A grid stability analysis to show that, with no electrical system failures, the grid will remain stable and the reactor coolant pump bus voltage will remain above the voltage required to maintain the flow analyses for a minimum of 3 seconds following a turbine trip.

If the initiating event is an electrical system failure (such as failure of the isophase bus), the analyses do not assume operation of the reactor coolant pumps following the turbine trip. The responsibility for setting the protective devices controlling the switchyard breakers with consideration given to preserving the plant grid connection following a turbine trip.

1.4 Redundancy of system

1.4.1 Physical Identification of Safety-Related Equipment

Each safety-related circuit and raceway is given a unique identification number to distinguish between circuits and raceways of different voltage level or separation groups. Each raceway is color coded with indelible ink, paint, or adhesive markers (adhesive markers are not used in the containment) at intervals of 15 feet or less along the length of the raceway and on both sides of floor or wall penetrations. Each cable is color coded at a maximum of 5 feet intervals along the length of the cable and cable markers showing the cable identification number are applied at each end of the cable. The following color coding is used for identification purposes:

Division	Color Code
A	Brown
B	Green
C	Blue
D	Yellow

1.4.2 Independence of Redundant Systems

The routing of cable and the design of raceways prevents a single credible event from disabling a redundant safety-related plant function.

1.4.3 Raceway and Cable Routing

There are five separation groups for the cable and raceway system: group A, B, C, D, and N. Separation group A contains safety-related circuits from division A. Similarly, separation group B contains safety-related circuits from division B; group C from division C; group D from division D; and group N from nonsafety-related circuits. Cables of one separation group are run in separate raceway and physically separated from cables of other separation groups. Group N raceways are separated from safety-related groups A, B, C and D. Raceways from group N are routed in the same areas as the safety-related groups.

- Within the main control room and remote shutdown room (no hazard areas), the minimum vertical separation for open top cable tray is 3 inches and the minimum horizontal separation is 1 inch.

- Within general plant areas (limited hazard areas), the minimum vertical separation is 12 inches, and the minimum horizontal separation is 6 inches for open top cable trays with low-voltage power circuits for cable sizes <2/0 AWG. For configurations that involve exclusively limited energy content cables (instrumentation and control), these minimum distances are reduced to 3 inches and 1 inch respectively.

- Within panels and control switchboards, the minimum horizontal separation between components or cables of different separation groups (both field-routed and vendor-supplied internal wiring) is 1 inch, and the minimum vertical separation distance is 6 inches.

- For configurations involving an enclosed raceway and an open raceway, the minimum vertical separation is 1 inch if the enclosed raceway is below the open raceway.

Separate trays are provided for each voltage service level: 6.9 kV, low voltage power (480 Vac, 208Y/120 Vac, 125 Vdc, 250 Vdc), high-level signal and control (120 Vac, 125 Vdc, 250 Vdc), and low level signal (instrumentation).

A tray designed for a single class of cables shall contain only cables of the same class except that low voltage power cables may be routed in raceways with high level signal and control cables if their respective sizes do not differ greatly and if they have compatible operating temperatures.

When this is done in trays, the power cable ampacity is calculated as if all cables in the tray are power cable. Low voltage power cable and high level signal and control cable will not be routed in common raceways if the fault current, within the breaker or fuse clearing time, is sufficient to heat the insulation to the ignition point.

In general, a minimum of 12 inches vertical spacing is maintained between trays of different service levels within the stack.

1.5 Hazard Protection

Where hazards to safety-related raceways are identified, a predetermined minimum separation is maintained between the break and/or missile source and any safety-related raceway, or a barrier designed to withstand the effects of the hazard is placed to prevent damage to raceway of redundant systems. Redundant circuits, devices, or equipment (different separation groups) are exposed to the same external hazard(s), predetermined spatial separation is provided. Where the spatial Separation cannot be met, qualified barriers are installed.

CHAPTER 2

2 Motor protection

The electric motor is most essential drive in modern era of industrialization. From fractional hp AC motor used for different home appliances to giant motor and induction motor of up to 10,000 hp used for different industrial applications, should be protected against different electrical and mechanical faults for serving their purposes smoothly. The motor characteristics must be very carefully considered in selecting the right **motor protection** scheme.

The abnormalities in motor or motor faults may appear due to mainly two reasons-

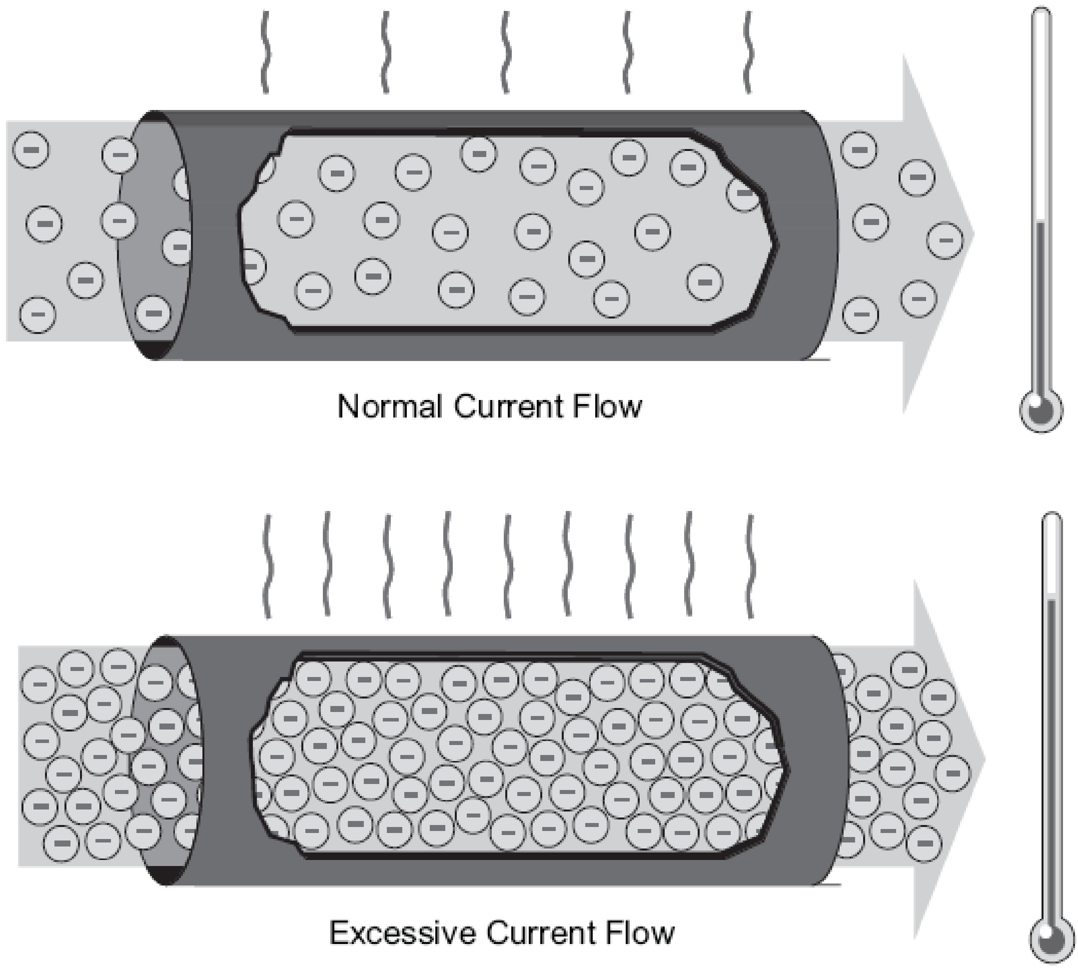
1. Conditions imposed by the external power supply network,
2. Internal faults, either in the motor or in the driven plan

Unbalanced supply voltages, under-voltage, reversed phase sequence and loss of synchronism (in the case of synchronous motor) come under former category. The latter category includes bearing failures, stator winding faults, motor earth faults and overload etc.

2.1 Need for Motor Circuit Protection

2.1.2Current and Temperature

Current flow in a conductor always generates heat. The greater the current flow in any one size conductor, the hotter the conductor. Excess heat is damaging to electrical components and conductor insulation. For that reason, conductors have a rated, continuous current-carrying capacity or **ampacity**. Overcurrent protection devices, such as fuses, are used to protect conductors from excessive current flow.



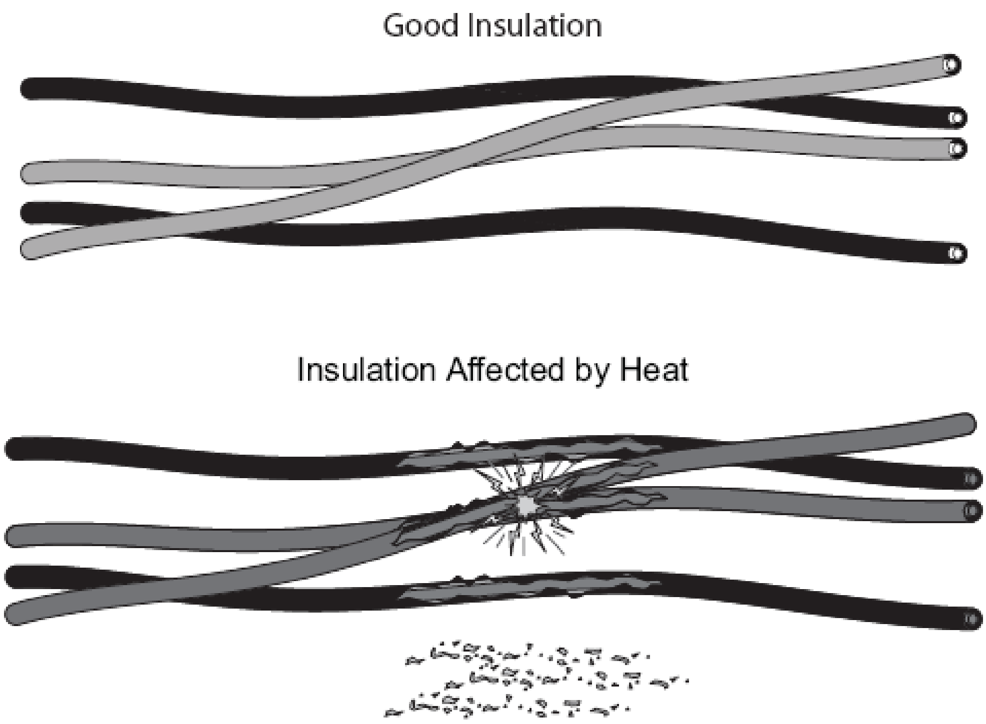
Excessive current is referred to as **overcurrent**. The overcurrent is any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault.

2.1.3 Overloads

An **overload** occurs when too many devices are operated on a single circuit or when electrical equipment is made to work harder than its rated design. For example, a motor rated for 10 amperes may draw 20, 30, or more amperes in an overload condition. In the following illustration, a package has become jammed on a conveyor, causing the motor to work harder and draw more current. Because the motor is drawing more current, it heats up. Damage will occur to the motor in a short time if the problem is not corrected or if the circuit is not shut down by an overcurrent protection device.

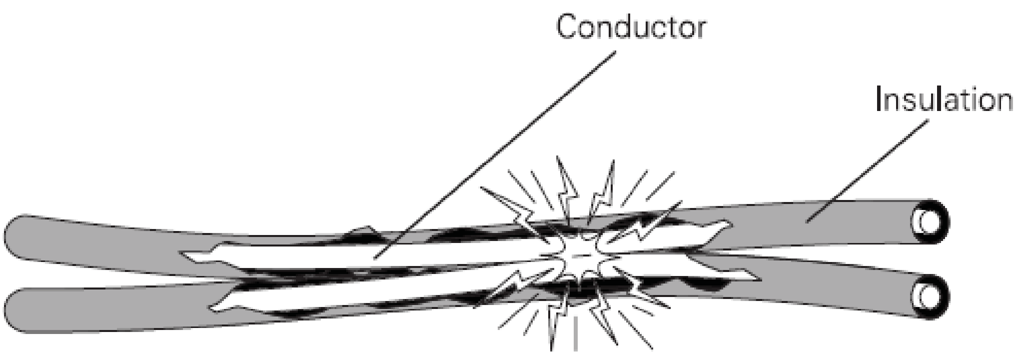
2.1.4 Conductor Insulation

Motors, of course, are not the only devices that require circuit protection for an overload condition. Every circuit requires some form of protection against overcurrent. Heat is one of the major causes of insulation failure of any electrical component. High levels of heat to insulated wire can cause the insulation to breakdown, melt, or flake off, exposing conductors.



2.1.5 Short Circuits

When two bare conductors touch, a **short circuit** occurs. When a short circuit occurs, resistance drops to almost zero. Short circuit current can be thousands of times higher than normal operating current.



Ohm's Law demonstrates the relationship of current, voltage, and resistance. For example, a 240 volt motor with 24 Ω (ohms) of resistance would normally draw 10 amperes of current.

$$I = \frac{E}{R}$$

$$I = \frac{240}{24}$$

$$I = 10 \text{ amperes}$$

When a short circuit develops, resistance drops. If resistance drops to 24 milliohms, current will be 10,000 amperes.

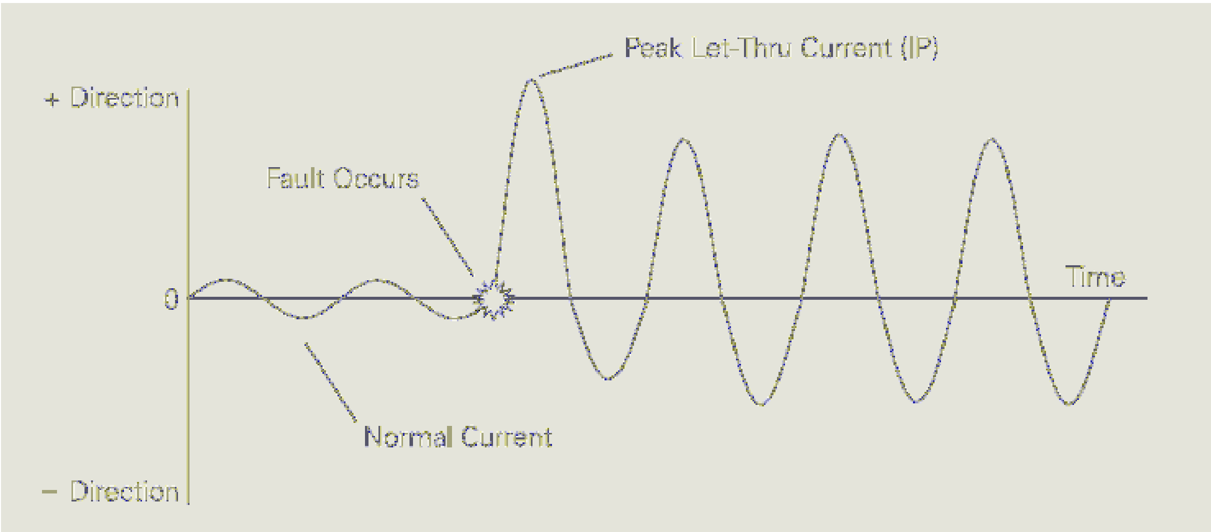
$$I = \frac{240}{0.024}$$

$$I = 10{,}000 \text{ amperes}$$

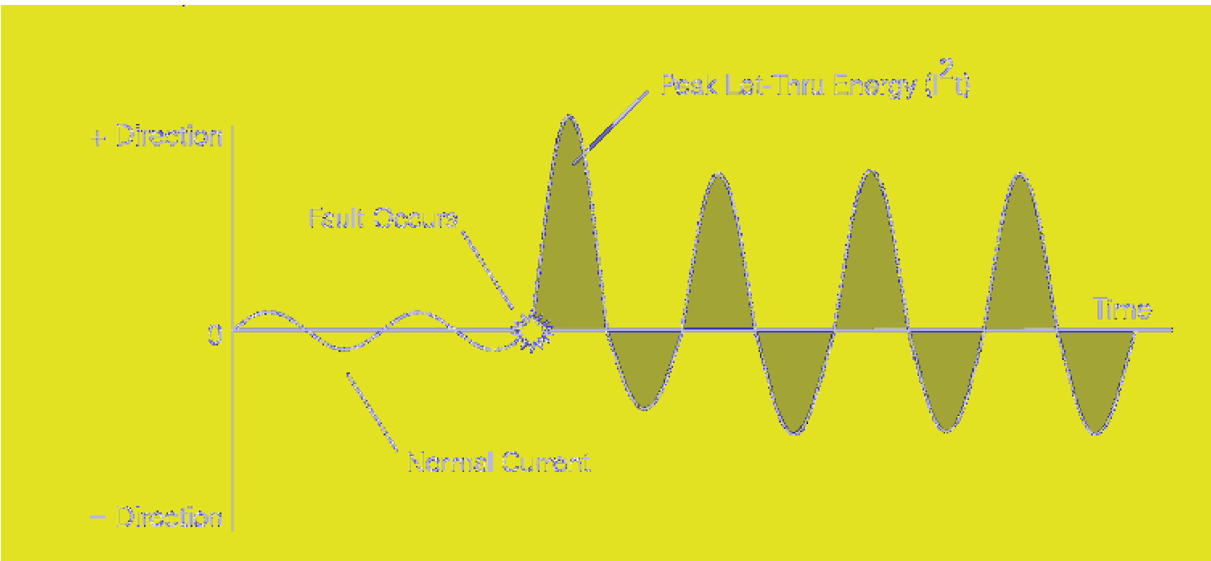
2.1.5.1 Short-Circuit Current on unprotected electrical circuit

When a short circuit occurs, current will continue to flow in an unprotected electrical circuit. The peak short-circuit

Circuits current of the first cycle is the greatest and is referred to as **peak let-thru current (IP)**. The force of this current can cause damage to wires, switches, and other electrical components of a circuit.

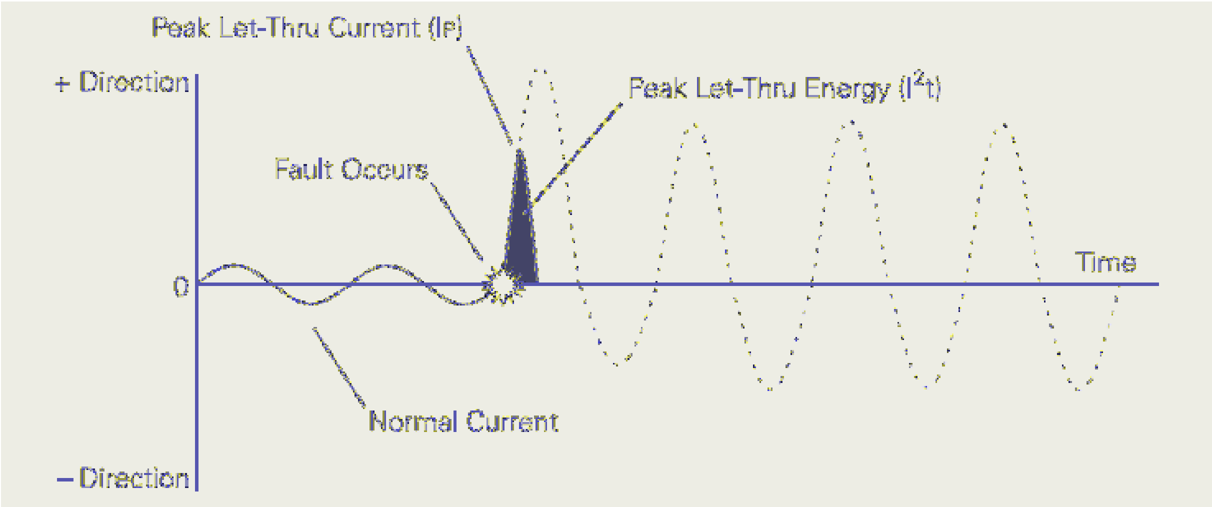


Associated with the peak let-thru current is **peak let-thru energy (I2t)**. For an unprotected circuit, this energy is often capable of dramatic destruction of equipment and is a serious safety concern.



2.1.5.2 Short-Circuit Current on Protected Electrical Circuits

Fortunately, if a circuit has a properly applied overcurrent
Protection device, the device will open the circuit quickly when if a short circuit occurs, limiting peak let-thru current (IP) and energy (I^2 ×t).



The degree of **motor protection system** depends on the costs and applications of the electrical.

2.2 Small Motor Protection Scheme

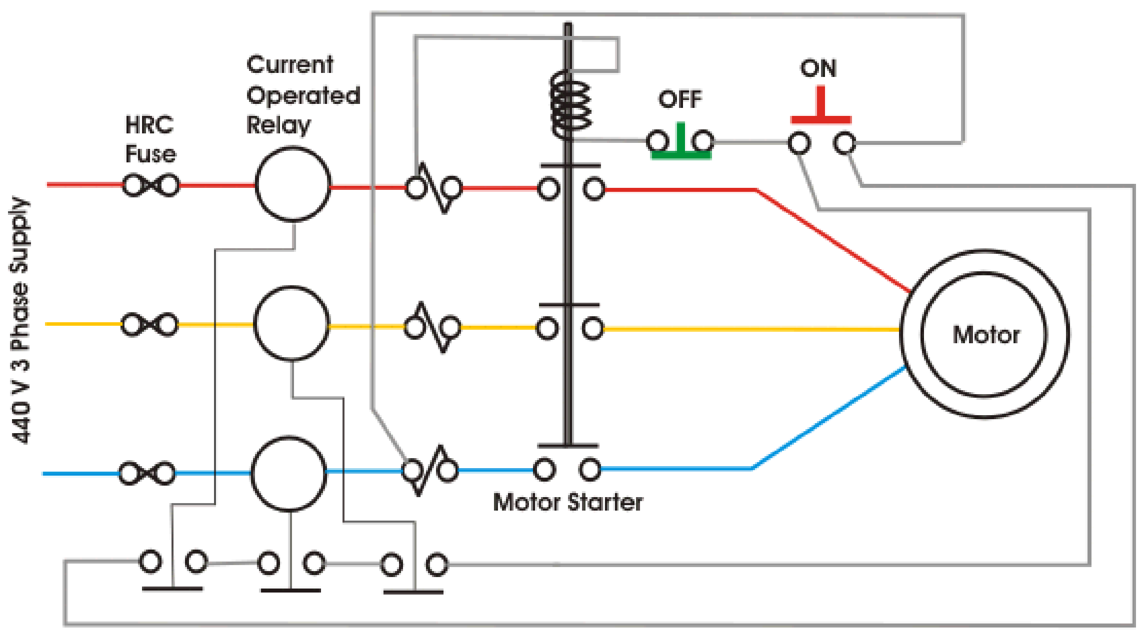
Generally motors up to 30 hp are considered in small category. The **small motor protection** in this case is arranged by HRC fuse, bimetallic relay and under voltage relay – all assembled into the motor contractor – starter itself.

Most common cause of motor burn outs on LV fuse protected system is due to single phasing. This single phasing may remain undetected even if the motors are protected by conventional bimetallic relay. It cannot be detected by a set of voltage relays connected across the lines. Since, even when one phase is dead, the motor maintains substantial back emf on its faulty phase terminal and hence voltage across the voltage relay is prevented from dropping – off.

The difficulties of detecting single phasing can be overcome by employing a set of three current operated relays as shown in the **small motor protection** circuit given below.

The current operated relays are very simple instantaneous relays. There are mainly two parts in this relay one is a current coil and other is one or more normally open contacts (NO Contacts). The NO contacts are operated by the mmf of the current coil. This relay is connected in series with each phase of the supply and backup by HRC fuse.

When the electrical motor starts and runs the supply current passes through the current coil of the protective. The mmf of the current coil makes the NO contacts closed. If suddenly a single phasing occurs the corresponding current through the current coil will falls and the contacts of the corresponding relay will become to its normal open position. The NO contacts of the all three relays are connected in series to hold – in the motor contractor. So if any one relay contact opens, results to release of motor contractor and hence motor will stop running.



2.3 Large Motor Protection

Large motor especially induction motors require protection against-

1. **Motor bearing failure,**
2. **Motor overheating,**
3. **Motor winding failure,**
4. **Reverse motor rotation.**

1. Motor Bearing Failure

Ball and roller bearings are used for the motor up to 500 hp and beyond this size sleeve bearings are used. Failure of ball or roller bearing usually causes the motor to a standstill very quickly. Due to sudden mechanical jamming in motor bearing, the input current of the motor becomes very high.

Current operated protection, attached to the input of the motor cannot serve satisfactorily. Since this motor protection system has to be set to override the high motor starting current. The difficulty can be overcome by providing thermal over load relay.

As the starting current of the motor is high but exists only during starting so for that current the there will be no overheating effect. But over current due mechanical jamming exists for longer time hence there will be a overheating effect. So stalling motor protection can be offered by the thermal overload relay.

Stalling protection can also be provided by separate definite time over current relay which is operated only after a certain predefined time if over current persists beyond that period. In the case of sleeve bearing, a temperature sensing device embedded in the bearing itself.
This scheme of motor protection is more reliable and sensitive to **motor bearing failure** since the thermal withstand limit of the motor is quite higher than that of bearing. If we allow the bearing overheating and wait for motor thermal relay to trip, the bearing may be permanently damaged. The temperature sensing device embedded in the bearing stops the motor if the bearing temperature rises beyond its predefined limit.

2. Motor over Heating

The main reason of **motor over heating** that means over heating of motor winding is due to either of mechanical over loading, reduced supply voltage, unbalanced supply voltage and single phasing. The overheating may cause deterioration of insulation life of motor hence it must be avoided by providing proper motor protection scheme. To avoid overheating, the motor should be isolated in 40 to 50 minutes even in the event of small overloads of the order of 10 %. The protective relay should take into account the detrimental heating effects on the motor rotor due to negative sequence currents in the stator arising out of unbalance in supply voltage. The motor should also be protected by instantaneous **motor protection relay** against single phasing such as a stall on loss of one phase when running at full load or attempting to start with only two of three phases alive.

3. Motor Winding Failure

The **motor protection relay** should have instantaneous trip elements to detect **motor winding failure** such as phase to phase and phase to earth faults. Preferably phase to phase fault unit should be energized from positive phase sequence component of the motor current and another instantaneous unit connected in the residual circuit of the current be used for earth faults protection.

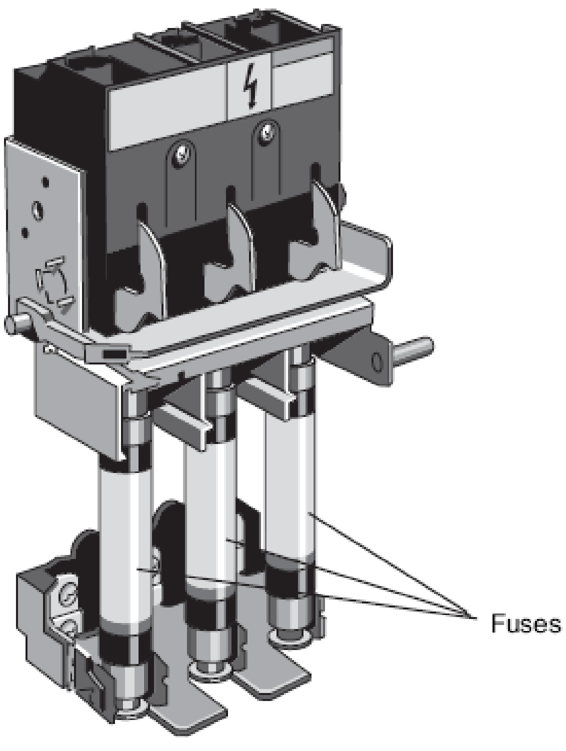
4. Reverse Motor Rotation

Especially in the case of conveyor belt, the **reverse motor rotation** must be avoided. The reverse rotation during starting can be caused due to inadvertent reversing of supply phases. A comprehensive motor protection relay with an instantaneous negative sequence unit will satisfy this requirement. If such relay has not been provided, a watt-meter type relay can be employed.

2.4 Overcurrent Protection Devices

An overcurrent protection device must be able to recognize the difference between an overcurrent and short circuit and respond in the proper way. Slight overcurrents can be allowed to continue for some period of time; but as the current magnitude increases, the protection device must open faster. Short circuits must be interrupted instantly.

Fusible Disconnect Switch A fusible disconnect switch is one type of device used to provide overcurrent protection. Properly sized fuses located in the switch open the circuit when an overcurrent condition exists.



Fusible Disconnect Switch

A fuse is a one-shot device. The heat produced by overcurrent causes the current carrying element to melt open, disconnecting the load from the source voltage

Fuse During Fault Fuse After Fault

2.4.1 Non-time-delay

Non-time-delay fuses provide excellent short-circuit protection. When an overcurrent occurs, heat builds up rapidly in the fuse. Non-time-delay fuses usually hold 500% of their rating for approximately one-fourth second, after which the current-carrying element melts. This means that these fuses should not be used in motor circuits which often have inrush currents greater than 500%.

2.4.2 Time-delay fuses

Time-delay fuses provide overload and short-circuit protection. Time-delay fuses usually allow several times the rated current to flow for a short time to allow a motor to start.

2.4.3 Fuse Classes

Fuses are grouped into classes based on their operating and construction characteristics. Each class has an interrupting rating (IR) in amperes which is the amount of fault current this class of fuses is capable of interrupting without destroying the fuse casing.

Fuses are also rated according to the maximum continuous current and maximum voltage they can handle. Underwriters Laboratories (UL) establishes and standardizes basic performance and physical specifications to develop its safety-test procedures.

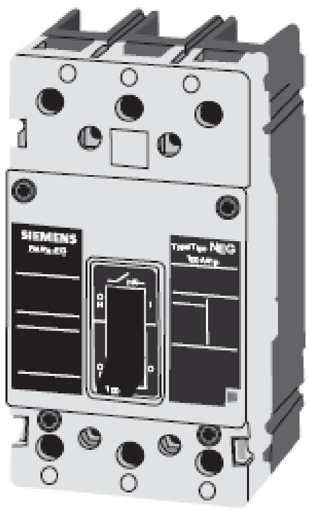
These standards have resulted in distinct classes of low-voltage fuses rated at 600 volts or less. The following chart lists the fuse class and its ratings.

Class	Voltage Rating	Ampere Rating	Interrupting Rating (Amps)	Sub Classes	UL Standard
R	250, 600	0-600	200,000	RK1 and RK5	UL 248 12
J	600	0-600	200,000		UL 248 B
L	600	601-6000	200,000		UL 248 10
CC	600	0-30	200,000		UL 248 4

2.5 Circuit Breakers

Another device used for overcurrent protection is a circuit breaker. The circuit breaker is a device designed to open and close the circuit by no automatic means and to open the circuit automatically on predetermined overcurrent without damage to itself when properly applied within its rating.

Circuit breakers provide a manual means of energizing and de-energizing a circuit. In addition, circuit breakers provide automatic overcurrent protection of a circuit. One key advantage of a circuit breaker is that it allows a circuit to be reactivated quickly after a short circuit or overload is cleared by simply resetting the breaker.



Circuit Breaker

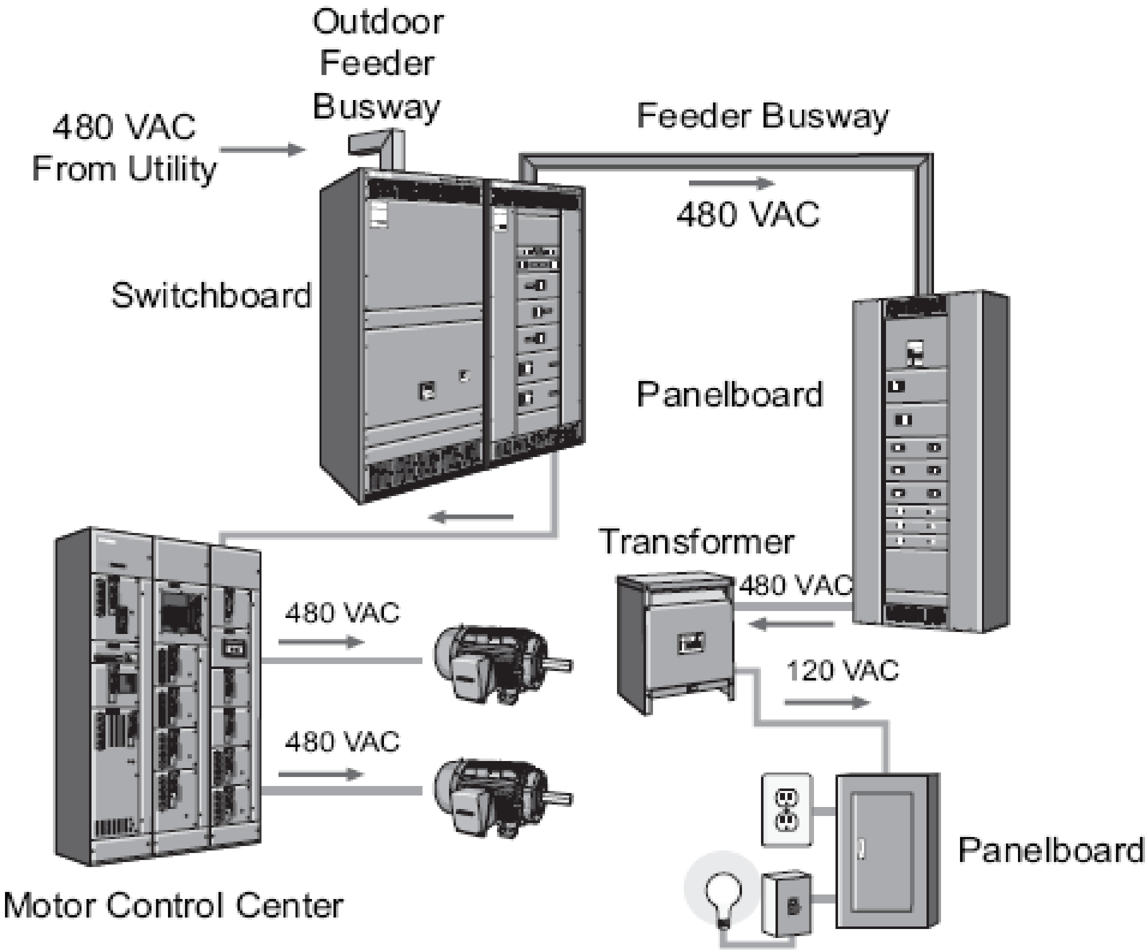
Ampere Rating Like fuses; every circuit breaker has ampere, voltage, and interrupting ratings. The ampere rating is the maximum continuous current a circuit breaker can carry without exceeding its rating. In general, the circuit breaker ampere rating should not exceed the conductor ampere rating.

For example, if the conductor is rated for 20 amps, the circuit breaker rating should not exceed 20 amps. Siemens breakers are rated on the basis of using 60° C or 75° C conductors. This means that even if a conductor with a higher temperature rating were used, the ampacity of the conductor must be figured on its 60° C or 75° C rating.

Voltage rating the voltage rating of the circuit breaker must be at least equal to the supply voltage. The voltage rating of a circuit breaker can be higher than the supply voltage, but never lower. For example, a 480 VAC circuit breaker could be used on a 240 VAC circuit. A 240 VAC circuit breaker could not be used on a 480 VAC circuit. The voltage rating is a function of the circuit breakers ability to suppress the internal arc that occurs when the circuit breakers contacts open.

Fault-Current Circuit breakers are also rated according to the level of fault
Interrupting Rating current they can interrupt. When applying a circuit breaker, one must be selected to sustain the largest potential short-circuit current which can occur in the selected application. Siemens circuit breakers have interrupting ratings from 10,000 to 200,000 amps.

Motor Control Center (Diagram)



CHAPTER3

3. Transformer Area

There are different kinds of transformers such as two winding or three winding electrical power transformers, auto transformer, regulating transformers, ear thing, rectifier transformers etc. Different transformers demand different schemes of transformer protection depending upon their importance, winding connections, earthing and mode of operation etc.

It is common practice to provide Buchholz relay protection to all 0.5 MVA and above transformers. While for all small size distribution transformers, only high voltage fuses are used as main protective device. For all larger rated and important distribution transformers, over current protection along with restricted earth fault protection is applied. Differential protection should be provided in the transformers rated above 5 MVA.

Depending upon the normal service condition, nature of transformer faults, degree of sustained over load, scheme of tap changing, and many other factors, the suitable transformer protection schemes are chosen.

3.1 Nature of Transformer Faults

Although an electrical power transformer is a static device, but internal stresses arising from abnormal system conditions, must be taken into consideration.

A transformer generally suffers from following types of transformer fault-

1. Over current due to overloads and external short circuits,
2. Terminal faults,
3. Winding faults,
4. Incipient faults.

The entire above mentioned transformer faults cause mechanical and thermal stresses inside the transformer winding and its connecting terminals. Thermal stresses lead to overheating which ultimately affect the insulation system of transformer. Deterioration of insulation leads to winding faults. Some time failure of transformer cooling system, leads to overheating of transformer. So the transformer protection schemes are very much required.The short circuit current of an electrical transformer is normally limited by its reactance and for low reactance, the value of short circuit current may be excessively high. The duration of external short circuits which a transformer can sustain without damage as given in BSS 171:1936.

TRANSFORMER % REACTANCE	**PERMITTED FAULT DURATION IN SECONDS**
4 %	2
5 %	3
6 %	4
7 % and over	5

The general winding faults in transformer are either earth faults or inter-turns faults. Phase to phase winding faults in a transformer is rare. The phase faults in an electrical transformer may be occurred due to bushing flash over and faults in tap changer equipment. Whatever may be the faults, the transformer must be isolated instantly during fault otherwise major breakdown may occur in the electrical power system. Incipient faults are internal faults which constitute no immediate hazard. But it these faults are over looked and not taken care of, these may lead to major faults. The faults in this group are mainly inter-lamination short circuit due to insulation failure between core lamination, lowering the oil level due to oil leakage, blockage of oil flow paths. All these faults lead to overheating. So transformer protection scheme is required for incipient transformer faults also. The earth fault, very nearer to neutral point of transformer star winding may also be considered as an incipient fault.

Influence of winding connections and earthing on earth fault current magnitude.

There are mainly two conditions for earth fault current to flow during winding to earth faults,

1. A current exists for the current to flow into and out of the winding.
2. Ampere-turns balance is maintained between the windings.

The value of winding earth fault current depends upon position of the fault on the winding, method of winding connection and method of earthing. The star point of the windings may be earthed either solidly or via a resistor. On delta side of the transformer the system is earthed through an earthing transformer. transformer provides low impedance path to the zero sequence current and high impedance to the positive and negative sequence currents.

3.2 Star Winding with Neutral Resistance Earthed

In this case the neutral point of the transformer is earthed via a resistor and the value of impedance of it, is much higher than that of winding impedance of the transformer. That means the value of transformer winding impedance is negligible compared to impedance of earthing resistor. The value of earth current is, therefore, proportional to the position of the fault in the winding. As the fault current in the primary winding of the transformer is proportional to the ratio of the short circuited secondary turns to the total turns on the primary winding, the primary fault current will be proportional to the square of the percentage of winding short circuited.

3.3 Star Winding with Neutral Solidly Earthed

In this case the earth fault current magnitude is limited solidly by the winding impedance and the fault is no longer proportional to the position of the fault. The reason for this non linearity is unbalanced flux linkage.

3.4 Three winding Transformers

3.4.1 Introduction

In addition to primary and secondary windings, the transformers may be constructed with the third winding. This winding is called tertiary winding. The normal two winding transformer can be converted into three winding transformer with an additional secondary winding having number of turns as per the requirements.

3.4.2 Why to use tertiary winding?

There are many reasons for which three winding transformers are employed. Some of the reasons are listed below.

1. If a two winding transformer has to supply an additional load which has to be insulated from the secondary windings for some reasons then three winding transformer may used with additional load carried by tertiary winding.

2. The phase compensating devices can be supplied with three winding transformer which are not operating at either primary or secondary voltage but at some different voltage.

3. The tertiary winding can be used as a voltage coil in a testing transformer.

4. Three supply systems operating at different voltages can be interconnected using three winding transformer.

5. The three winding transformer can be used to load large split winding generators.

6. The substation requirements can be met using three winding transformer which requires a voltage different from that of primary and secondary windings.

7. The tertiary winding connected in delta reduces the impedance offered to the zero sequence currents so a larger earth fault current flows for proper operation of protective equipment. For unbalanced load it limits the imbalance in voltage. It permits the flow of third harmonic current to reduce third harmonic voltage.

The third winding known as tertiary winding is generally connected in delta. Thus when any fault or short circuit occurs on the primary or secondary sides, there will be large unbalance of phase voltage which is compressed by large tertiary winding circulating current. The reactance of the tertiary winding must be such as to limit the circulating current to that which can be carried by copper in order to avoid overheating of tertiary winding under fault conditions.

3.4.3 Stabilizing Due to Tertiary Winding

For unbalanced single phase load, the star-star connection offers high reactance to flow of current. Any unbalanced load current has three components viz positive, negative and zero sequence components. The zero sequence component on the secondary side can not be balanced by primary currents as zero sequence currents can not flow in the isolated neutral of star connected primary. On the secondary side the zero sequence current sets up magnetic flux in the core. The iron path is available for this flux and the impedance offered to the zero sequence currents is very high. But the delta connected tertiary winding permits circulation of zero sequence currents in it. So impedance offered to the flow of zero sequence currents is lowered. For this purpose the tertiary winding is called stabilizing winding. This is shown in the Fig. 1.

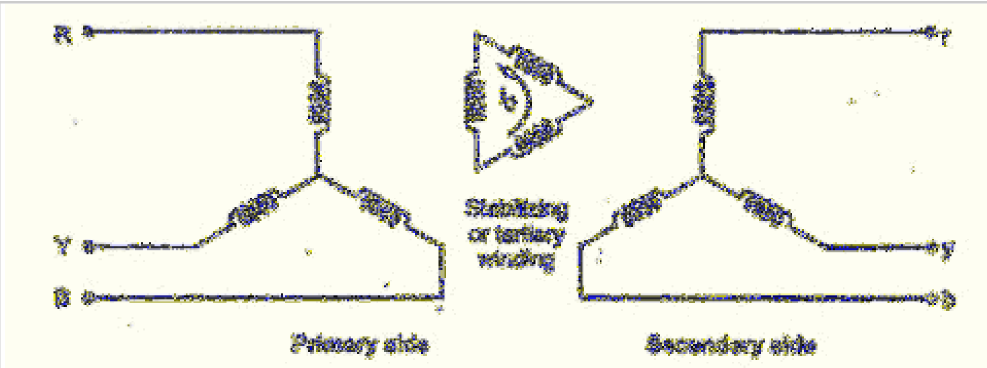


Fig. 1

3.4.5 Advantages and Disadvantages of Three Winding Transformer

The advantages of a three winding transformer are as given below

i) It can supply additional load providing insulation from secondary windings.

ii) It can act as a source of voltage at substation to meet the internal load demand of substation which is at different voltage that either of primary or secondary voltage level.

iii) The reactive power injection into the system is possible for voltage control by connecting synchronous condensers or static capacitors to the tertiary winding.

iv) A delta connected tertiary winding offers less impedance to the flow of zero sequence currents. The allows larger earth fault current to flow through protective device facilitating its proper operation.

v) It reduces voltage unbalance under unbalanced loading conditions and permits third harmonic current to flow which reduces third harmonic voltages.

vi) Three transmission lines at different voltage levels can be interconnected by using three winding transformer.

vii) The third winding of a three winding transformer, usually called tertiary winding can be used to serve purpose of measuring voltage of HV testing transformer.

The disadvantage of a three winding transformer is its construction is little complicated as compared to normal two winding transformer. A separate third winding is required to be placed which requires more copper and hence cost of three winding transformer is obviously more. The core of the transformer has to carry three windings instead of two as in case of normal two winding transformer.

CHAPTER4

4 Protection of Lines or Feeder

As the length of electrical power transmission line is generally long enough and it runs through open atmosphere, the probability of occurring fault in electrical power transmission line is much higher than that of electrical power transformers and alternators. That is why a transmission line requires much more protective schemes than a transformer and an alternator.

Protection of line should have some special features, such as-

1. During fault, the only circuit breaker closest to the fault point should be tripped.
2. If the circuit breaker closest the faulty point, fails to trip the circuit breaker just next to this breaker will trip as back up.
3. The operating time of relay associated with protection of line should be as minimum as possible in order to prevent unnecessary tripping of circuit breakers associated with other healthy parts of power system.

   These above mentioned requirements cause **protection of transmission line** much different from protection of transformer and other equipment of power systems. The main three methods of **transmission line protection** are –

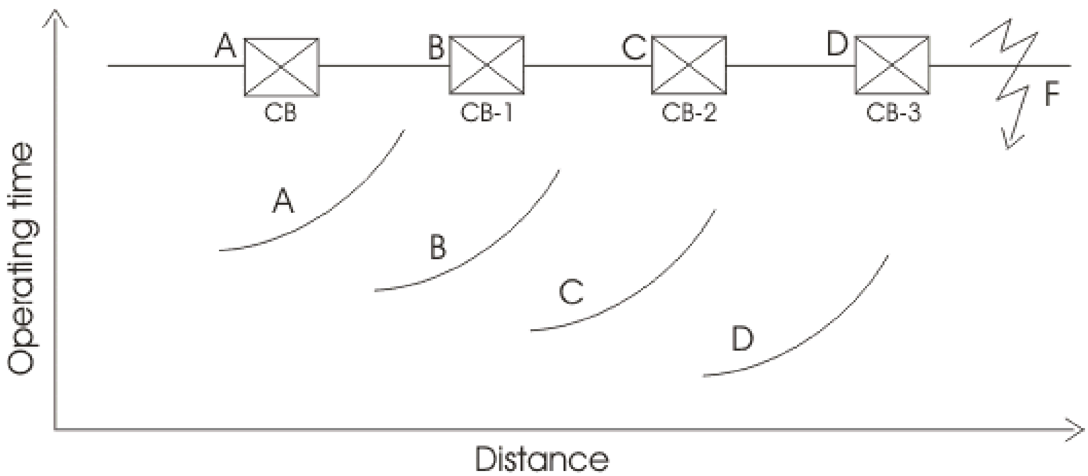
1. Time graded over current protection.
2. Differential protection.

4.1 Time Graded Over Current Protection

This may also be referred simply as over-current protection of electrical power transmission line. Let' discuss different schemes of time graded over current protection.

4.1.1 Over Current Line Protection by Inverse Relay

The drawback as we discussed just in definite time over current protection of transmission line, can easily be overcome by using inverse time relays. In inverse relay the time of operation is inversely proportional to fault current.



In the above figure, overall time setting of relay at point D is minimum and successively this time setting is increased for the relays associated with the points towards the point A.

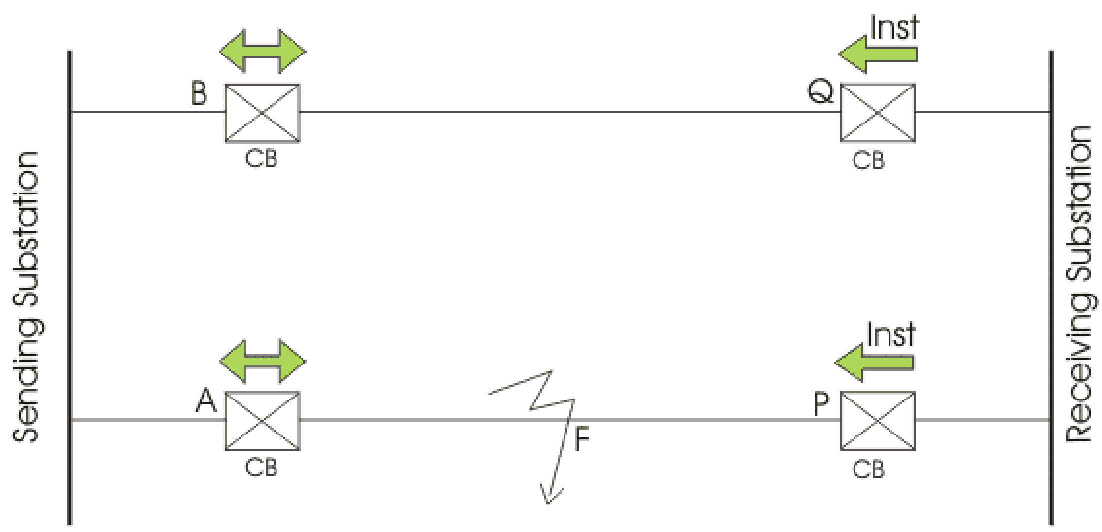
In case of any fault at point F will obviously trip CB-3 at point D. In failure of opening CB-3, CB-2 will be operated as overall time setting is higher in relay at point C.

Although, the time setting of relay nearest to the source is maximum but still it will trip in shorter period, if major fault occurs near the source, as the time of operation of relay is inversely proportional to faulty current.

4.1.2 Over Current Protection of Parallel Feeders

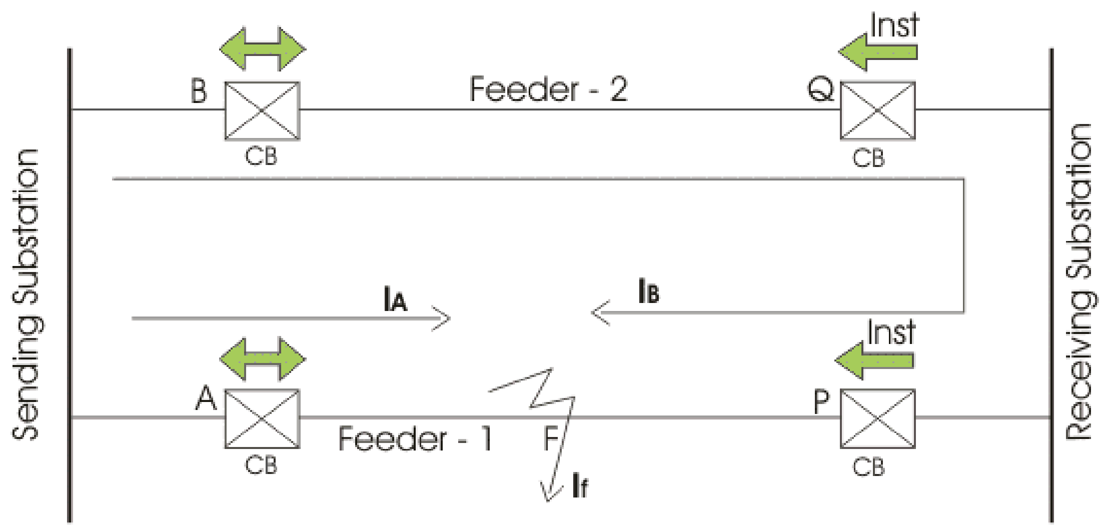
For maintaining stability of the system it is required to feed a load from source by two or more than two feeders in parallel. If fault occurs in any of the feeders, only that faulty feeder should be isolated from the system in order to maintain continuity of supply from source to load.

This requirement makes the protection of parallel feeders little bit more complex than simple non direction over current protection of line as in the case of radial feeders. The protection of parallel feeder requires to use directional relays and to grade the time setting of relay for selective tripping.



There are two feeders connected in parallel from source to load. Both of the feeders have non-directional over current relay at source end. These relays should be inverse time relay. Also both of the feeders have directional relay or reverse power relay at their load end. The reverse power relays used here should be instantaneous type. That means these relays should be operated as soon as flow of power in the feeder is reversed. The normal direction of power from source to load.

Now, suppose a fault occurs at point F, say the fault current is I_f. This fault will get two parallel paths from source, one through circuit breaker A only and other via CB-B, feeder-2, CB-Q, load bus and CB-P. This is clearly shown in figure below, where I_A and I_B are current of fault shared by feeder-1 and feeder-2 respectively.



As per Kirchhoff's current law, $I_A + I_B = I_f$.

Now, I_A is flowing through CB-A, I_B is flowing through CB-P. As the direction of flow of CB-P is reversed it will trip instantly.

But CB-Q will not trip as flow of current (power) in this circuit breaker is not reversed. As soon as CB-P is tripped, the fault current I_B stops flowing through feeder and hence there is no question of further operating of inverse time over current relay.

I_A still continues to flow even CB-P is tripped. Then because of over current, CB-A will trip. In this way the faulty feeder is isolated from system.

4.2 Busbar Protection

In early days only conventional over current relays were used for busbar protection. But it is desired that fault in any feeder or transformer connected to the busbar should not disturb busbar system. In viewing of this time setting of busbar protection relays are made lengthy. So when faults occur on busbar itself, it takes much time to isolate the bus from source which may come much damage in the bus system.

In recent days, the second zone distance protection relays on incoming feeder, with operating time of 0.3 to 0.5 seconds have been applied for busbar protection.
But this scheme has also a main disadvantage. This scheme of protection can not discriminate the faulty section of the busbar.

Now days, electrical power system deals with huge amount of power. Hence any interruption in total bus system causes big loss to the company. So it becomes essential to isolate only faulty section of busbar during bus fault.

Another drawback of second zone distance protection scheme is that, sometime the clearing time is not short enough to ensure the system stability.

To overcome the above mentioned difficulties, differential busbar protection scheme with an operating time less than 0.1 sec., is commonly applied to many SHT bus systems.

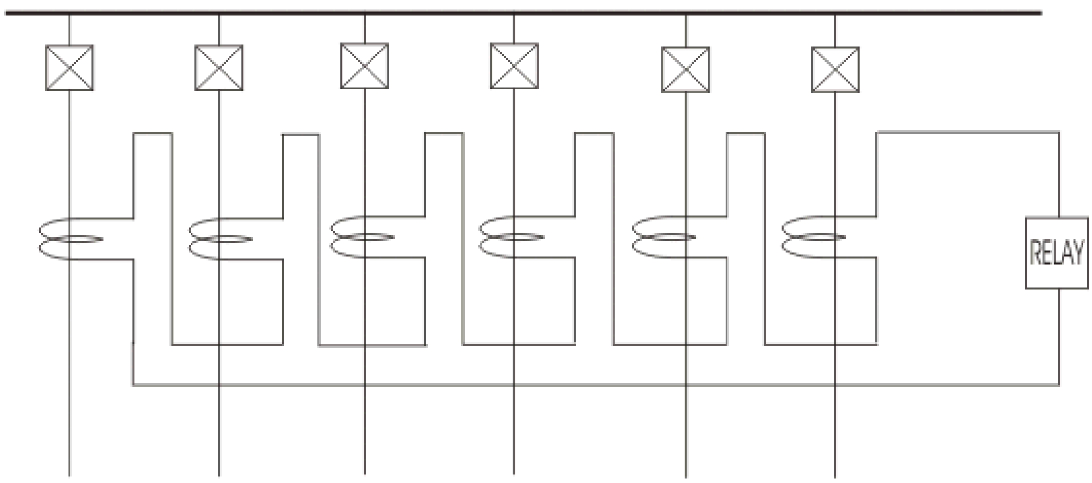
4.2.1 Voltage Differential Protection of Busbar

The current differential scheme is sensitive only when the CTs do not get saturated and maintain same current ratio, phase angle error under maximum faulty condition. This is usually not 80, particularly, in the case of an external fault on one of the feeders. The CT on the faulty feeder may be saturated by total current and consequently it will have very large errors. Due to this large error, the summation of secondary current of all CTs in a particular zone may not be zero. So there may be a high chance of tripping of all circuit breakers associated with this protection zone even in the case of an external large fault. To prevent this maloperation of current differential busbar protection, the 87 relays are provided with high pick up current and enough time delay.

The greatest troublesome cause of current transformer saturation is the transient dc component of the short circuit current.

These difficulties can be overcome by using air core CTs. This current transformer is also called linear coupler. As the core of the CT does not use iron the secondary characteristic of these CTs, is straight line.

In voltage differential busbar protection the CTs of all incoming and outgoing feeders are connected in series instead of connecting them in parallel.



The secondaries of all CTs and differential relay form a closed loop. If polarity of all CTs are properly matched, the sum of voltage across all CT secondaries is zero. Hence there would be no resultant voltage appears across the differential relay. When a buss fault occurs, sum of the all CT secondary voltage is no longer zero. Hence, there would be current circulate in the loop due to the resultant voltage. As this loop current also flows through the differential relay, the relay is operated to trip all the circuit beaker associated with protected bus zone. Except when ground fault current is severally limited by neutral impedance there is usually no selectivity problem when such a problem exists, it is solved by use of additional more sensitive relaying equipment including a supervising protective.

CHAPTER5

5 Grounding Systems

5.1 What is Grounding?

Equipment earthing or earthing is a connection done through a metal link between the body of any electrical appliance, or neutral point, as the case may be, to the deeper ground soil. The metal link is normally of MS flat, CI flat, GI wire which should be penetrated to the ground earth grid.

5.2 Necessity of Equipment Earthing/Grounding

(a)Safety of personnel

(b)Safety of equipment Prevent or at least minimize damage to equipment as a result of flow of heavy currents.

(c) Improvement of the reliability of the power system.

5.3 Classification of Earthing/Grounding

The earthing is broadly divided as

a) System earthing (Connection between part of plant in an operating system like LV neutral of a power transformer winding) and earth.

b) Equipment earthing (safety grounding) connecting bodies of equipment (like electric body, transformer tank, switchgear box, operating rods of air break switches, LV breaker body, HV breaker body, feeder breaker bodies etc) to earth.

5.4 Permissible Values of Earth Resistance

a) Power stations – 0.5 ohms

b) EHT stations – 1.0 ohms

c) 33KV SS – 2 ohms

d) DTR structures – 5 ohms

e) Tower foot resistance – 10 ohms

5.5 What are the Basics for arriving at Permissible Earth Resistances?

As per IE rules one has to have a definite base for that as per IE rules one has to keep touch potential less than

a) Recommended safe value 523 volts

b) I_{fault} = maximum current in fault conditions,

$$resistance = \frac{Touch\ voltage}{I_{fault}} = \frac{V_{touch}}{I_{fault}}$$

c) Maximum fault current is 100 KVA the current in 100 KVA is about 100 A; where percentage impedance is 4%

$$\frac{100X100}{4} = 2500\ A\ Say\ 2000\ A\ Max$$

d) For a substation of 100 KVA transformer

$$R = \frac{V_{touch}}{I_{fault}} = \frac{523}{2000} = 0.26\ ohms$$

0.26 ohms being quite low, quality work is to be done during construction, to obtain such a value of earthing system, and the expenditure for that will be very high. Hence the electrical inspectors are insisting about 1.0 ohm. This seems justifying for the urban areas. This value may be 2 ohms in case of rural areas, which is recommended by most of the authorities.

e) The earth electrode resistance value also carries importance in view of full protection by lightning arrestors against lightning.

The earth electrode resistance value in that case is given by the formula

$$R = \frac{\text{Flash over voltage of 11 KV}}{\text{Lightning Discharge Current}}$$

Flash over voltage of 11KV = 75 KV

Lightning arrestor Displacement = 40 KA.

$$\text{The earth electrode resistance } R = \frac{75\ KV}{40\ KA} = 1.9\ \Omega$$

5.6 Type of Earthing/Grounding

5.6.1 Plate Type Earthing/Grounding

In this, cast Iron plate of size 600 mm X 600 mm X 6.3 mm thick plate is being used as earth plate. This is being connected with Hot dip GI main earth strip of size 50mm X 6mm thick X 2.5 meter long by means of nut, bolts & washers of required size. The main earth strip is connected with hot dip GI strip of size 40mm X 3mm of required length as per the site location up to the equipment earth / neutral connection. The earth plate is back filled & covered with earthing material (mixture of charcoal & salt) by 150mm from all six sides. The remaining pit is back filled with excavated earth. Along with earth plate, rigid PVC pipe of 2.5 meter long is also provided in the earth pit for watering purpose for to keep the earthing resistance within specific limit.

5.6.2 Pipe Type Earthing/Grounding

In this hot dip GI pipe of size 40mm dia X 2.5 meter is being used for equipment earthing. This pipe is perforated at each interval of 100mm and is tapered at lower end. A clamped is welded with this pipe at 100mm below the top for making connection with hot dip GI strip of size 40mm X 3mm of required length as per the site location up to the equipment earth / neutral connection. On its open end funnel is being fitted for watering purpose. The earth pipe is placed inside 2700 mm depth pit. A 600mm dia “farma“of GI sheet or cement pipe in two halves is placed around the pipe. Then the angular space between this “farma” and earth pipe is back filled with alternate layer of 300mm height with salt and charcoal. The remaining space outside “farma” will be backfilled by excavated earth. The “farma” is gradually lifted up as the backfilling up progresses. Thus the pit is being filled up to the 300mm below the ground level. This remaining portion is covered by constructing a small chamber of brick so that top open end of pipe and connection with main earth pipe will be accessible for attending when necessary. The chamber is closed by wooden / stone cover. Water is poured into the pipe through its open end funnel to keep the earthing resistance within specific limit.

Other types of earthing: When the capabilities of certain equipment are limited, they may not with stand certain fault currents then the following types of earthing are resorted to limit the fault current.

(a) Resistance earthing
(b) Reactance earthing
(c) Peterson coil earthing.
(d) Earthing through grounding transformer.

5.7 Grounding Grids

The low ground resistance in case of high voltage substations can be obtained with the use of interconnected ground grids. In a typical grounding grid system, a number of interconnected bare solid copper conductors are buried at a depth of 0.3 to 0.6 m and spaced in a grid pattern. It provides common earth for all devices and metallic structures in the substation.

At each of the junction point, the conductors are bonded together. This system is usually supported by a number of vertical rods about 3 m long at some joints.

If a is cross-sectional area of copper, in circular miles, t is the fault duration in seconds, T_m is the maximum allowable temperature and T_a is the ambient temperature then the size of grid conductors required which prevents fusing under the fault current is given as,

$$a = I\sqrt{\frac{76t}{\ln\left[\frac{234+T_m}{234+T_a}\right]}}$$

If the grid depth is less than 0.25 m then the earthing resistance of the grid is given by,

$$R = \frac{\rho}{4}\sqrt{\frac{\pi}{a}} + \frac{\rho}{L}$$

Here R = Grid resistance in ohms

a = Ground area occupied by grid in m^2

L = Total length of buried conductors in m

But when the grid depth is greater than 0.25 m then earthing resistance is given by,

$$R = \rho\left[\frac{1}{L} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right]$$

The effective grounding of the equipment is possible through the grid. Also the voltage gradient at the surface of the earth can be controlled at safe value for human contacts with the addition of ground rods; the ground resistance further reduces when soil resistivity in the upper layer is more than the soil underneath.

5.8 Grounding Transformer

If a neutral point is required or not available in case of delta connections and bus bar points, a zig-zag transformer is used. Earthed transformer are used for providing the neutral pint for such cases. It is a core-type transformer having three limbs built-up in the same manner as that of a power transformer. Each limb accommodates two equally-spaced windings and the way they are connected is shown in the Fig. 1. It will be seen that the current in the two halves of the winding on each limb acts in opposite directions. These currents do not allow undeserving harmonics to prevail in the circuit, and thereby, the stresses on the insulation of the transformer are considerably reduced.

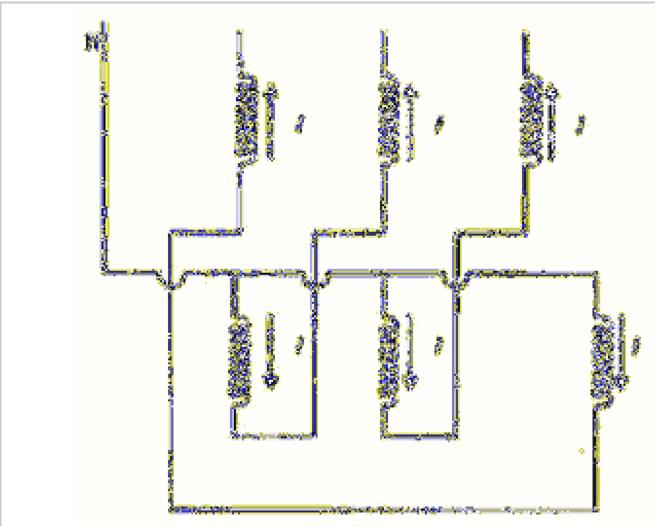


Fig. 1 Representation of an earthing transformer

The impedance of the earthing transformers is quite low, and therefore, the fault current will be quite high. The magnitude of the fault current is limited by inserting resistance either in the neutral circuit as shown in Fig. 2 or in the windings of the earthing transformer. Components of various currents flowing under the conditions are also shown therein.

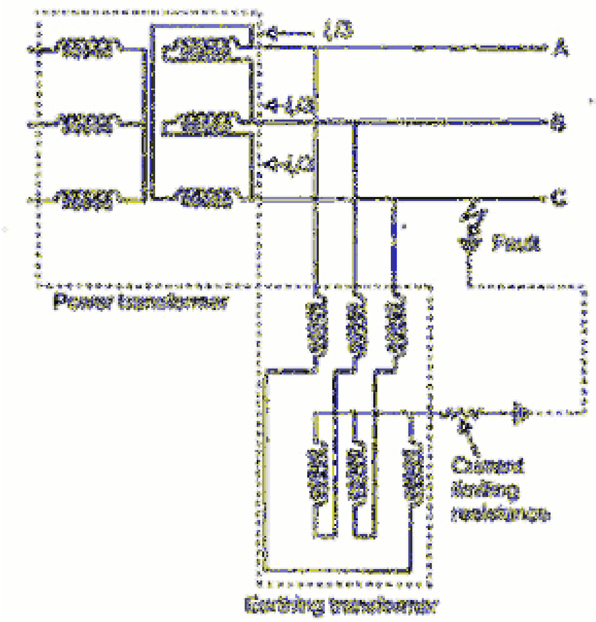


Fig. 2 Insertion of resistance in the neutral circuit

The terminals of the earthing transformers are soldered to the power transformer for obtaining a solid connection between them. The capacity of the earthing transformer is denoted by the fault current it is capable of handling. Under normal operating conditions, it is only iron losses that are continuously present; copper losses are present only when the fault occurs. These copper losses are present only for short periods due to the short duration of fault (in the order of a few seconds).

CHAPTER6

6 Lighting Arrester and Surge Arrester

That is why all electrical equipment and insulators of power system must be protected against electrical surges. The method of protecting system from surge is normally referred as surge protection. The main equipment commonly used for this purpose is **lightning arrester** or **surge arrester**.

There are two types of surges one comes externally from atmosphere such as atmospheric lightning. Second type is originated from electrical system itself, such as switching surges.

When an electrically charged cloud comes nearby an electrical transmission line, the cloud induces electrical charges in the line. When the charged cloud is suddenly discharged, through lightning, the induced charged in the transmission line is no longer confined static. It starts travelling and originate dynamic transient over voltage.

This transient overvoltage travels towards both load and source side, on the transmission line because of distributed line inductance and stray capacitance. This surge voltage travels with speed of light. At the end of the transmission line, as the surge impedance changes, the surge voltage wave reflected back. This forward and backward travelling of surge voltage wave continues until the energy of the surge or impulse is attenuated by line resistance.

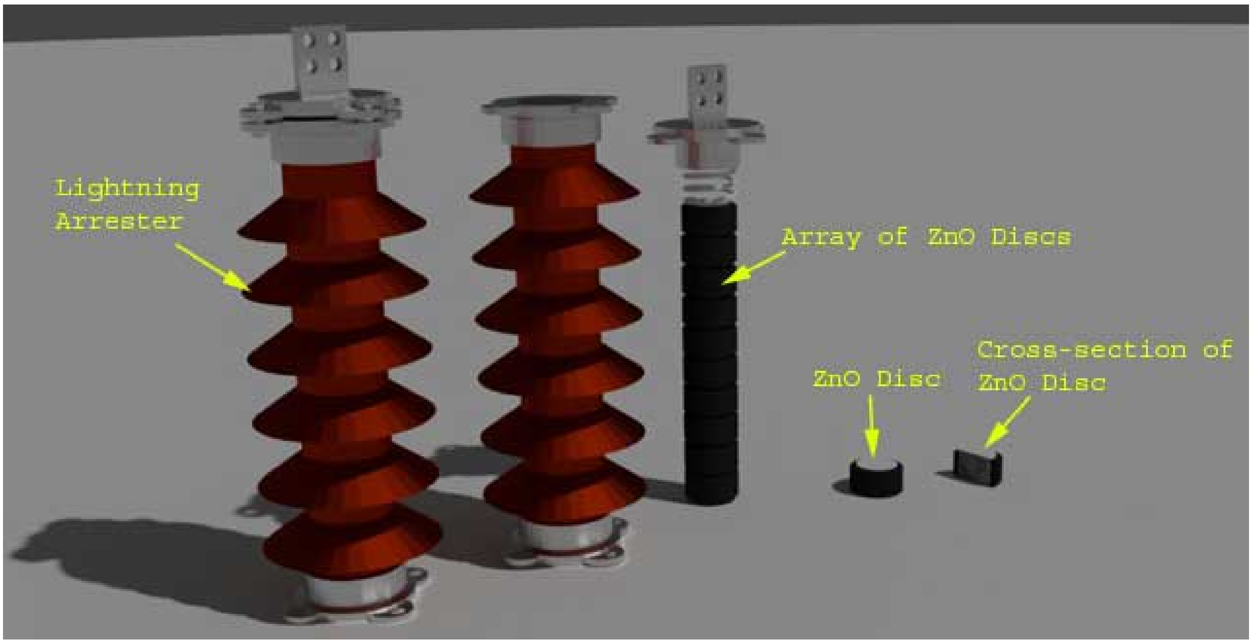
This phenomenon causes voltage stress on the transmission system many times greater than normal rated voltage of the system. Hence, surge protection scheme must be provided to the electrical power transmission system to make reliable and healthy system. **Lightning arrester** is one of the main components to protect the system from surge.

As we said earlier, that the electrical surge also can be generated from the system itself. Actually during switching operation there may be a chance of current chopping. If during normal operation, if electrical isolator is opened on load. Sudden open circuit is occurred in the system.
In addition to these, the basic arc-quenching techniques of SF_6 circuit breaker and vacuum circuit breaker may give rise to current chopping and multiple re-ignition sometimes.

As we know that sudden current chopping give rise to the di/dt. [di/dt = rate of change of current with respect to time]. As the electrical load is generally inductive, there is a transient voltage, expressed by L(di/dt) where L is the inductance of load of system. This voltage is induced across the opening contacts, and travels towards load and reflects in similar manner of lightning impulse. Lightning arrestor or surge arrester are provided at the end of the transmission line to withstand the surge voltage.

Generally oil field electrical power transformer, electrical switchgear, cables, electrical transmission lines, distribution lines are quite capable for withstanding these switching impulse voltages, as their insulation level is quite high to withstand these over voltages. But, generator, electric motor, dry type transformers and electric arc furnaces etc. cannot withstand large switching impulse voltages. As essentially this types of equipment do not have very high level of insulation. To protect this equipment from surges, lightning arrester is must.
In electrical sub-station, arresters are mainly used at the entrance of any feeders and also they are used at both rides of electrical power transformers as transformer is also considered as inductive load and very costly equipment.

In modern era, gap less ZnO or zinc oxide surge arresters are mainly used for surge protection. Let us discuss zinc oxide type gap less arresters.



6.1 Construction of Zinc Oxide Lightning Arrester

This type of arrester comprises of numbers of solid zinc oxide disc. These discs are arranged one by one to form a cylindrical stack. The number of zinc oxide discs used per lightning arrester depends upon the voltage rating of the system. This stack is kept inside a cylindrical housing of polymer or porcelain. Then the stack is placed inside the housing and highly pressed by heavy spring load attached to end cap at top. The equipment connection terminal for line is projected from top cap and connection terminal for earth is projected from the bottom cap.

6.2 Working Principle of Zinc Oxide Lightning Arrester

The normal operation is defined as condition when no surge is presented and the surge arrester is subjected to normal system voltage only.

The zinc oxide has highly non-uniform current voltage (I – V) characteristics. This typical I-V characteristic makes zinc oxide very suitable for designing gap less zinc oxide lightning arrester for surge protection. The non linear resistance of the block is an inherent bulk property and consists of mainly zinc oxide (90 to 95%) with relatively small amounts of several additives of other metal oxide (5 to 10%) like alumina, antimony tri-oxide, bismuth oxide, cobalt oxide, zirconium etc. On a macroscopic scale the additives are almost homogeneously distributed throughout the arrester blocks. But the micro structures of the metal oxide block represent a network of series and parallel arrangements of highly doped zinc oxide (ZnO) grains separated by inter granular junctions. The non linear behavior is the super imposition of non linear characteristics of individual junctions. The current carrying capacity of the surge arrester block is proportional to the total cross-section of the block.

The non linear resistance characteristics of ZnO block can be expressed as,

$$\frac{I}{I_r} = \left(\frac{V}{V_r}\right)^x$$

Where, I_r and V_r are the reference current and voltage respectively of the lightning arrester or surge arrester block. The value of x is 30 to 40 in case of metal oxide block. For normal system, the voltage and current increase. For normal system, the voltage and current increases linearly, i.e. for increasing system voltage at this range, current is increased in linear proportionate. The current at this region of characteristics is in range of micro ampere. But beyond a certain voltage level, leakage current voltage level, leakage current starts increasing very rapidly it is of KA range. The voltage beyond which the current through the LA becomes such high, is referred as reference voltage and the current at reference voltage is known as reference current. Sudden draining of huge current through lightning arrester just beyond reference voltage level, prevents the system from transient over voltage stress. The voltage-current relation in a metal oxide block highly depends upon temperature. Metal oxide block has negative temperature co-efficient. That means with increase in temperature, resistance of the surge arrester decreases hence for some system voltage, the leakage current through the instrument increases with increase in temperature.

As we know that, there would be a continuous leakage current through the LA. This leakage current generates heat. This generated heat should be dissipated properly otherwise the temperature of the LA may rise which further increases the leakage current. Because of this the proper thermal design of surge arrester housing plays an important role. There is a critical temperature depending upon the voltage rating of the metal oxide block beyond which joule heat generated in the block which joule heat generated in the block cannot be dissipated at required rate and which finally leads to thermal runaway of lightning arrester.

Now we can understand that, the working principle of LA or surge arrester used for surge protection fully depends upon non linear V-I characteristics of metal oxide (ZnO) blocks inside the insulator housing of the arrester.

CHAPTER 7

7 SAFETY CONSIDERATIONS:

The philosophy employed in the safety design of a Westinghouse PWR is described as "defense in depth." Defense in depth ensures that a plant is designed, fabricated, constructed, and operated not only to be safe during normal operation but to account safely for the possibility of a spectrum of accidents. The plant has sophisticated safety systems and devices to guard against human error, equipment failures, and malfunctions taking into account such natural phenomena as Earthquakes, tornadoes, and floods.

7.1 FIRST LEVEL OF DEFENSE

The first level of defense addresses prevention of accidents through the design of the plant, including quality assurance, redundancy, separation, testing, and inspection. The plant is designed and built to operate as intended with a high degree of reliability. An example of how this first level of defense is applied is the design of the reactor coolant system (RCS) pressure boundary. This same philosophy is utilized in the design of all safety-related systems, components, and structures. The components that comprise the RCS pressure boundary are required to be designed, fabricated, erected, and maintained to quality standards that reflect the importance of the safety function to be performed.

The quality standards provide that the facility will be able to withstand, without loss of capability to protect the public, any additional forces that might be imposed by natural phenomena such as earthquakes, tornadoes, flooding conditions, winds, ice, or other local site factors.

The RCS pressure boundary is designed as Seismic Category 1 to provide a design margin to ensure the capability to perform its function under the conditions of the largest potential ground motion or other severe natural phenomena at the site.

The RCS pressure boundary is capable of accommodating, without exceeding stress limits, the static and dynamic loads Imposed as a result of anticipated operational occurrences and design basis accidents.

Credible transients which could cause pressure surges have been conservatively designed for by reactor protection system trips and by incorporation of relief and safety valves. In addition to these considerations, reduction of the probability of a rapidly propagating-type failure is accomplished through provisions for control over service temperature and irradiation effects.

Close control and inspection over the selection of RCS pressure boundary materials and the fabrication of RCS pressure boundary components are exercised. Provisions are made for inspections, testing, and surveillance of critical areas of the pressure boundary to assess the structural and leak tight integrity during its service lifetime.

Materials and components of the RCS are subjected to thorough nondestructive inspection prior to operation and a pre-operational hydro test is performed at 1.25 times design pressure. Provisions have been made for periodically inspecting, in situ, all areas of relatively high service factors.

A reactor vessel material surveillance program is employed utilizing test samples which are placed in the reactor vessel and irradiated for designated periods of time, removed, and examined to determine changes in material properties. Also, RCS water chemistry control protects against corrosion which otherwise might reduce structural integrity during service lifetime. For pipes of the size, thickness, and material used in the RCS, detectable leakage will occur before a major rupture of the pipe. The RCS pressure boundary is conservatively designed to accommodate the system pressures and temperatures attained under all expected modes of plant operation, including anticipated transients and abnormal loading conditions, such as seismic conditions, and to maintain the stresses within appropriate stress limits. The RCS pressure boundary is protected from overpressure by means of pressure-relieving devices

7.2 SECOND LEVEL OF DEFENSE

Despite the care taken at the first level of defense, it is prudently anticipated that some failures or operating errors could occur during the life of a plant with the potential for safety concern. Accordingly, a second level of defense is provided by means of reliable protections systems, designed to assure that expected occurrences and off-normal conditions will be detected and either arrested or accommodated safely.

The requirements for these protection systems are based on a consideration of a spectrum of events that could lead to off-normal operations. Extensive testing programs are carried out to verify that the protective systems will function adequately.

An example of a second level of defense system is the reactor protection system. The reactor protection system is activated by redundant and Independent instrument channels which translate their respective signals into redundant logic channels to automatically initiate a protective action. Conservative design practices, adequate safety margins, inspect ability, and redundant detection and actuating equipment are incorporated in protection systems to assure effectiveness and reliability.

In addition, these systems are designed to be monitored and tested routinely to assure that they will operate reliably if and when required.

The reactor protection system is designed to a high degree of reliability and testability to prevent or suppress conditions that could result in exceeding acceptable fuel limits. Protection and operational reliability is achieved by providing redundant instrument channels for each protective function.

These redundant channels are electrically isolated and physically separated from one another. The basic reactor operating design defines an allowable operating region of power, reactor coolant pressure, and reactor coolant temperature conditions. If the reactor protection system receives signals which are indicative of an approach to operating conditions outside of the allowable operating region, the system actuates alarms, prevents control rod withdrawal, initiates load cutback, and/or opens the reactor trip breakers.

The reactor protection system is designed to withstand the effects of the Design Basis Earthquake. Typical protection system equipment is subjected to type tests under simulated seismic accelerations to demonstrate its ability to perform its functions. Should a failure occur, the reactor protection system is designed to fail safe. To meet this requirement, each reactor trip channel is designed on the "de-energize to operate" principle; a loss of instrument power to that channel causes the system to go into its trip mode. To assure that the reactor protection system continues to function properly, the plant Technical Specifications require periodic surveillance, testing, and recalibration of each channel.

7.3 THIRD LEVEL OF DEFENSE

The third level of defense is designed to add further margin by postulating, for design purposes, the occurrence of extremely unlikely circumstances. A hypothetical accident is assumed to occur and to progress beyond that which would be expected and which could occur only in the event of failures in both the first and second levels of defense. This scenario is studied in detail, with a deliberate compounding of combinations and sequences of events to make the safeguards performance objectives more demanding.

From an analysis of these Postulated events, a third level of features and equipment is designed and incorporated into the plant to safely control such an unlikely event and to protect the public health and safety.

For example, the emergency core cooling system (ECCS)* is provided to mitigate the consequences of a loss-of-coolant accident (LOCA) even though the first level of defense makes such an occurrence highly unlikely. The ECCS is designed to comply with U.S. NRC General Design Criteria. The many conservative steps required by these requirements ensures the ECCS a very high probability of successful operations, if and when required. The primary function of the

ECCS is to deliver emergency core cooling in the event that the primary coolant system is accidentally depressurized (i.e., a LOCA).

The ECCS limits the fuel cladding temperature below the level allowed by U.S. NRC Regulations so that the core will remain intact and in place, with its essential heat transfer geometry preserved. This protection is afforded for all pipe break sizes up to and including a postulated circumferential rupture and separation of a reactor coolant pipe. The ECCS employs a passive system of accumulators, in addition to independent high pressure and low-pressure pumping systems.

The passive system of accumulators does not require any external signals or source of power for its operation. An accumulator is connected to each of the cold leg pipes of the reactor coolant system and provides for the short-term cooling requirements for a large pipe break by injecting borated water when RCS pressure falls below accumulator pressure.

Two independent high pressure pumping systems, each capable of providing the required cooling, are provided for small break protection and to maintain water inventory after the accumulators have discharged following a large break LOCA. Two independent low-pressure pumping systems are provided, each capable of fulfilling long-term cooling requirements. The ECCS is designed with sufficient redundancy and diversity of components such that the failure of any single active component does not prevent the ECCS from fulfilling its mission. For example, the cooling capability of the ECCS would be sufficient to maintain the fuel cladding temperatures below allowable limits even if the failure of any single active component occurred during a major LOCA. Also, no operator action is required to maintain the ECCS capability in the event of a single failure in the system.

To meet other criteria, additional conservative actions have been taken concerning the ECCS. The ECCS and its components have been designed, fabricated, constructed, tested, and inspected under a strict and detailed Quality Assurance Program commensurate with the importance of its safety function.

The ECCS is designed to applicable codes to provide safety margins to protect against dynamic effects. The ECCS equipment has also been designed and fabricated so that it will function without failure under the worst conditions of post-accident temperature, pressure, radiation, and humidity conditions for the length of time required.

It also requires that a reliable power supply be provided for ECCS operation. This power supply is provided through independent connections to the system grid and a redundant source of emergency power from independent diesel generators installed on site. Sufficient power for operation of the ECCS is provided even with the failure of a single active component, including a diesel generator in each of these separate and independent power systems.

The ECCS is subjected to a thorough inspection and testing program conforming to U.S. NRC requirements. ECCS components are tested both in the manufacturer's shop and after installation to demonstrate performance and reliability.

The ECCS design permits periodic testing of active components for operability and required functional performance as required by Technical Specifications. The ECCS delivery capability can be tested periodically by recirculation of water to the refueling water storage tank.

CHAPTER 8

8 PWR nuclear Power Plant Station Black Out

8.1 Passive Safety System for Station Black Out

- AC power is not required for safe shutdown
- Core cooling provided for long-term safe shutdown state:
  72 hours without operator action
- Pressurized water Reactor is designed so that core stays inside of the reactor vessel During a severe accidents
- After 72 hours with some operator actions to transfer water, core cooling and containment cooling are maintained indefinitely
- PWR spent fuel pool cooling system is capable of providing cooling for spent reactor fuel indefinitely, with minimal need for operator action
- Diagram of passive safety system of PWR Reactor is shown in fig. A

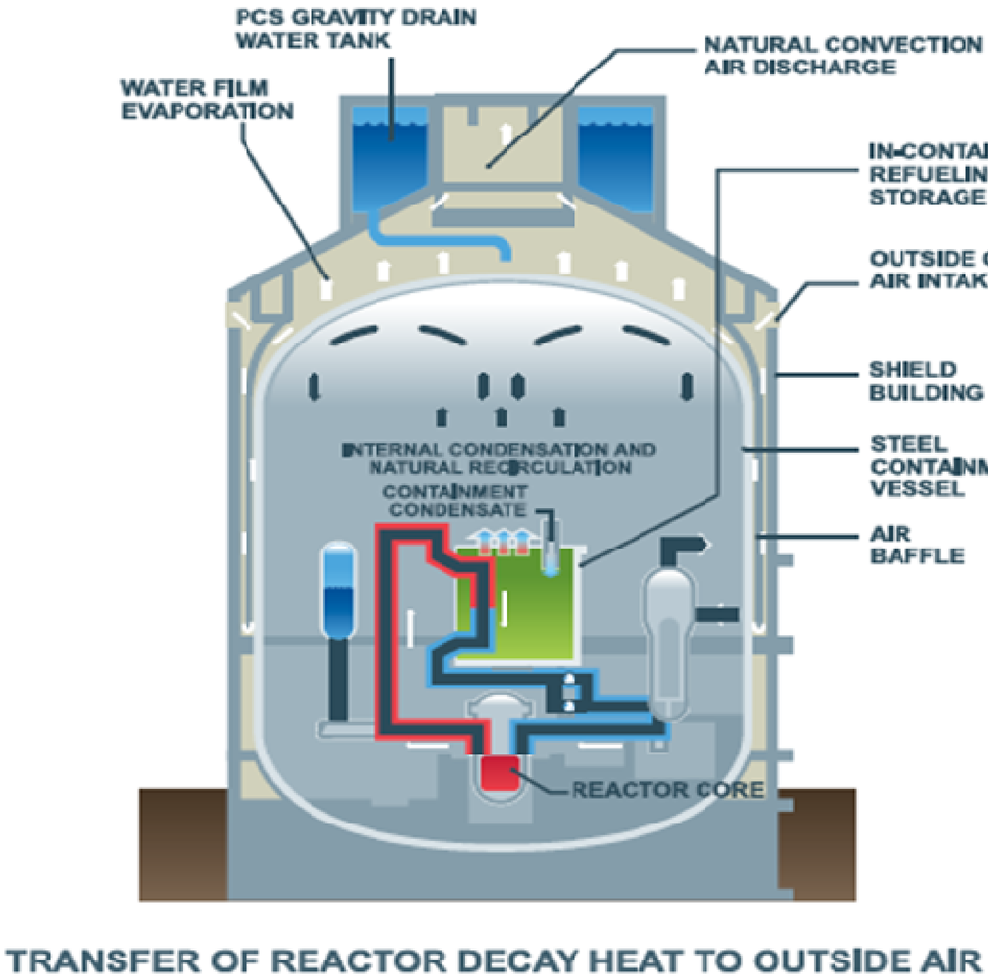
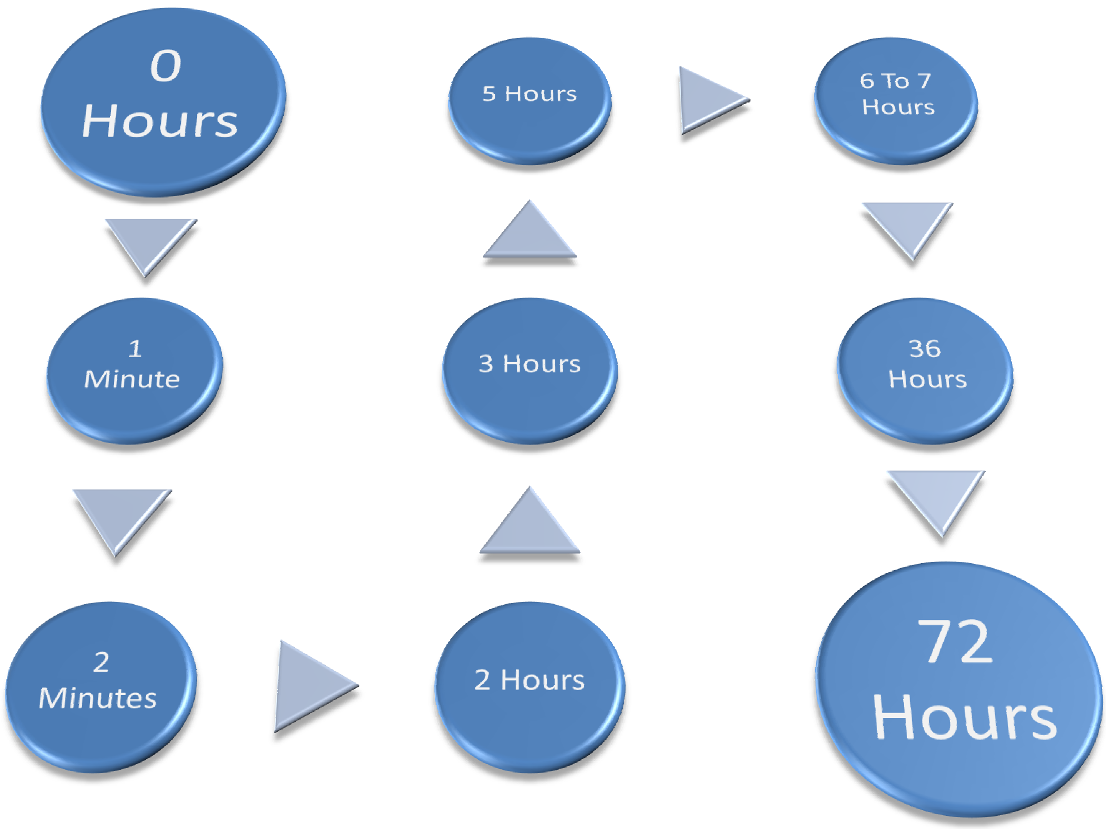

PCS GRAVITY DRAIN WATER TANK
NATURAL CONVECTION AIR DISCHARGE
WATER FILM EVAPORATION
IN-CONTAINMENT REFUELING WATER STORAGE TANK
OUTSIDE COOLING AIR INTAKE
SHIELD BUILDING
STEEL CONTAINMENT VESSEL
AIR BAFFLE
INTERNAL CONDENSATION AND NATURAL RECIRCULATION
CONTAINMENT CONDENSATE
REACTOR CORE
TRANSFER OF REACTOR DECAY HEAT TO OUTSIDE AIR

Fig. A

8.2 Timeline for Station Blackout



8.2.1 Initially at zero time station blackout occurs:

Loss of offsite power occurs at the same time standby diesel generator fails to start, resulting in station blackout

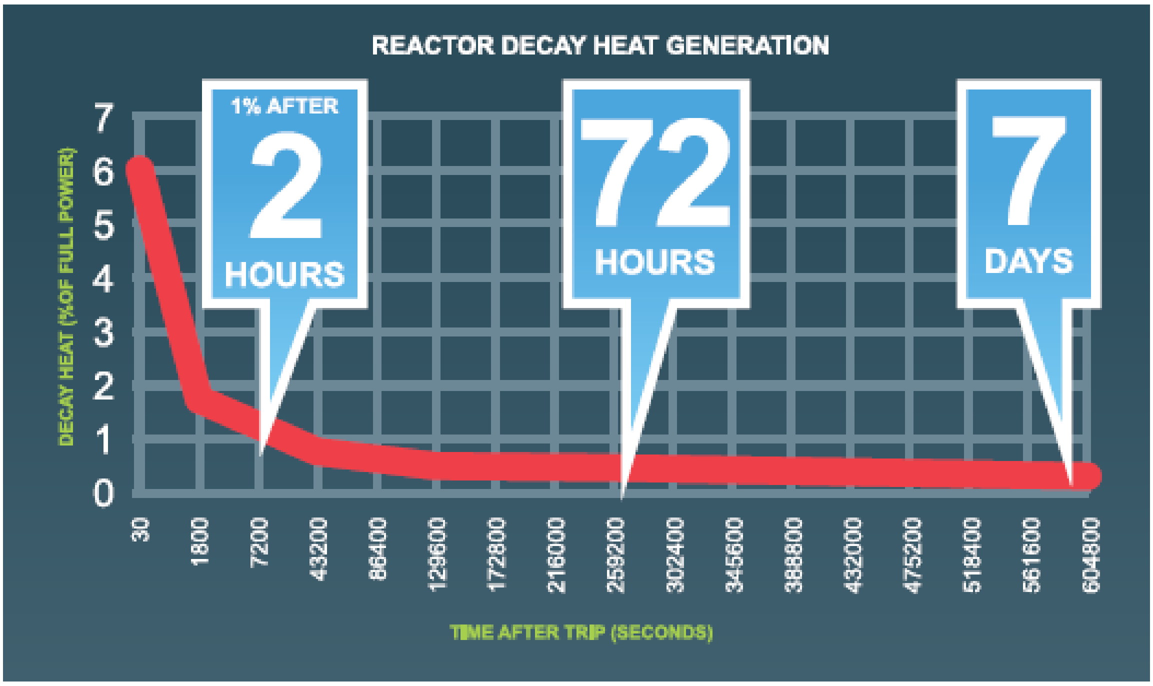


Fig.B

8.2.2 1 Minute:

Control rods are inserted in reactor core, terminating the fission process and shutting down the reactor.

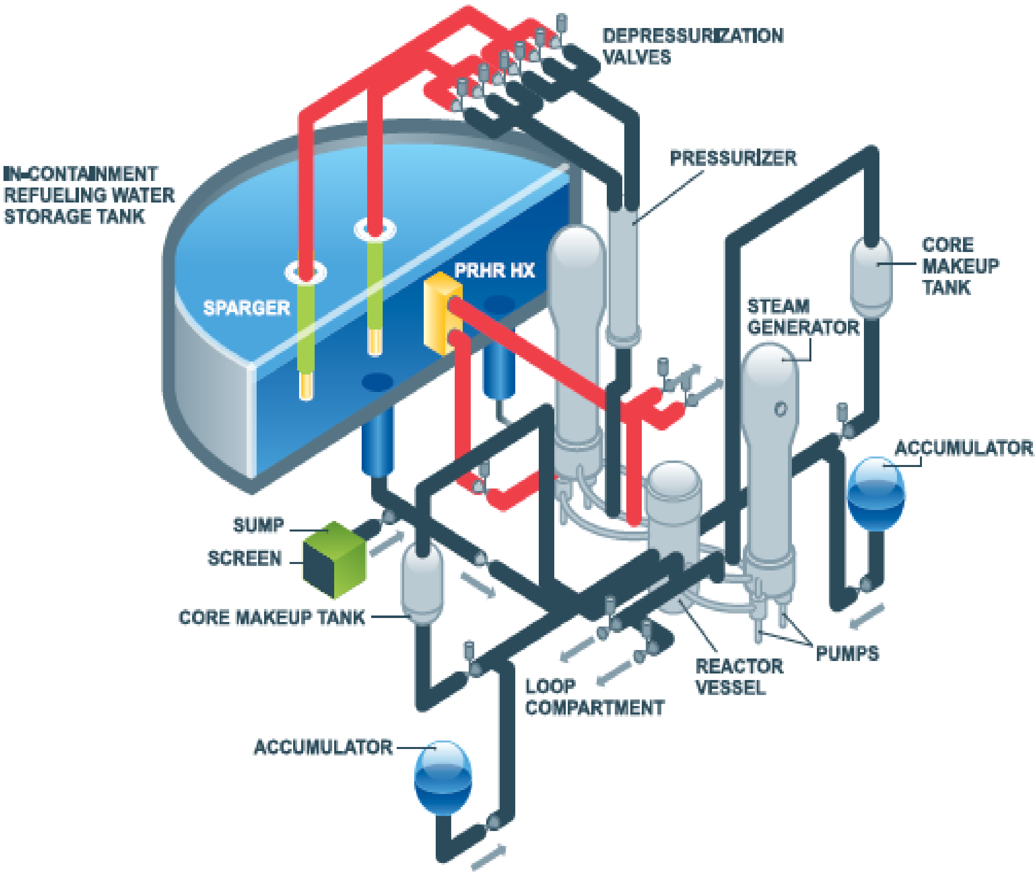
Reactor core continues to provide decay heat that needs to be removed by cooling.
Active pumping of cooling water through the spent fuel stops due to loss of power.

The used fuel in spent fuel pool continues to transfer decay heat to the pool of water, causing the water to heat up

8.2.3 2 Minutes:

The steam generator water level decreases and activates the Passive Core Cooling System.

Natural circulation flow started automatically because density difference between the cold reactor coolant in the passive heat exchanger and hot fuel in the reactor core.



3D VERSION OF PXS AND REACTOR COOLANT SYSTEM

Fig.C

8.2.3 2 Hours:

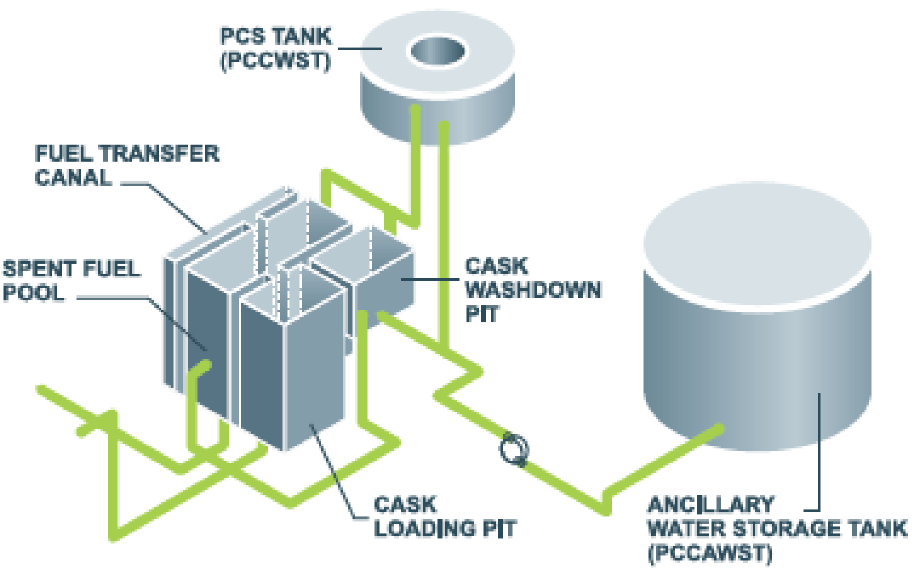
Reactor decay heat has decreased to one percent of full power.

8.2.4 3 Hours:

The cooling water in spent fuel begins to boil.

Decay heat from spent fuel is transferred from the water to the steam.

Any Evaporated water is replaced from supply located in the adjacent cask washdown pit which is gravity-fed to spent fuel pool.



SPENT FUEL POOL WATER SOURCES FOR 7 DAYS

Fig.D

8.2.5 **5 Hours**:

The passive heat exchanger has transferred enough decay from the reactor to the in-containment tank that the water inside the in-containment tank begins to boil.
Steam produced inside of containment vessel.

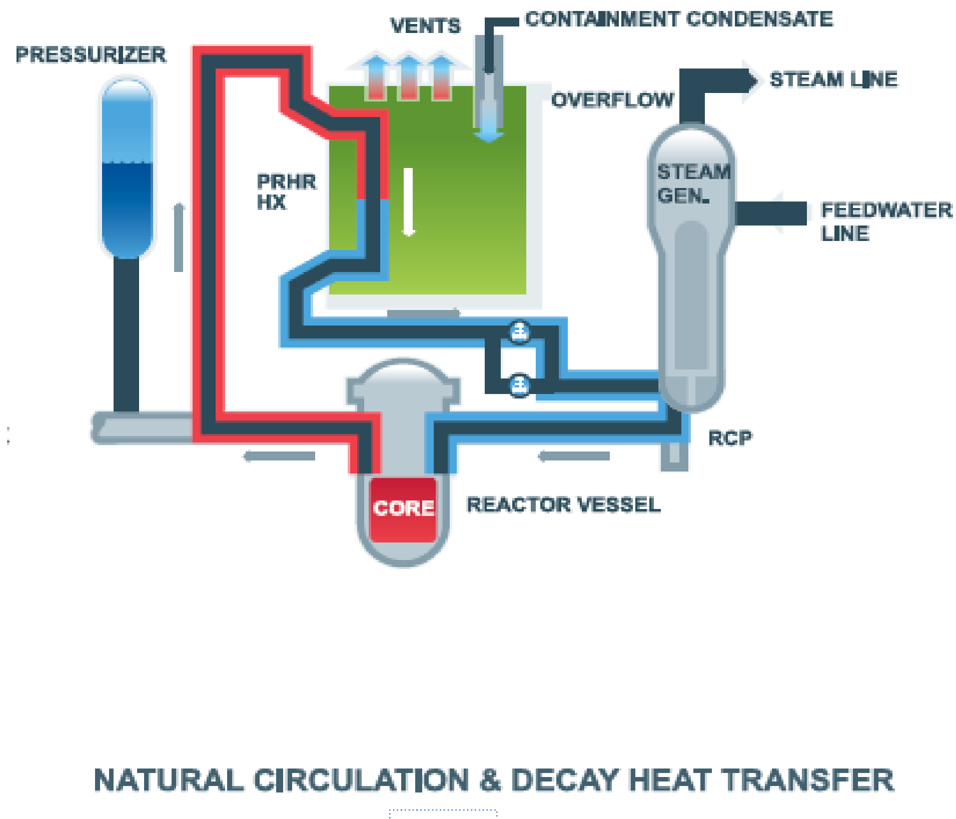


Fig.E

8.2.6 6 Hours:

The instrumentation monitoring system detects the need for containment cooling and open valves to start cooling water flow

Water in the containment cooling tank, located on the roof of shield building, automatically drains through gravity and cools the top and sides of the steel containment vessel.

8.2.7 6 to hours:

The steam generated by in-containment tank transfers the decay heat to the steel of the containment vessel through condensation of the steam.

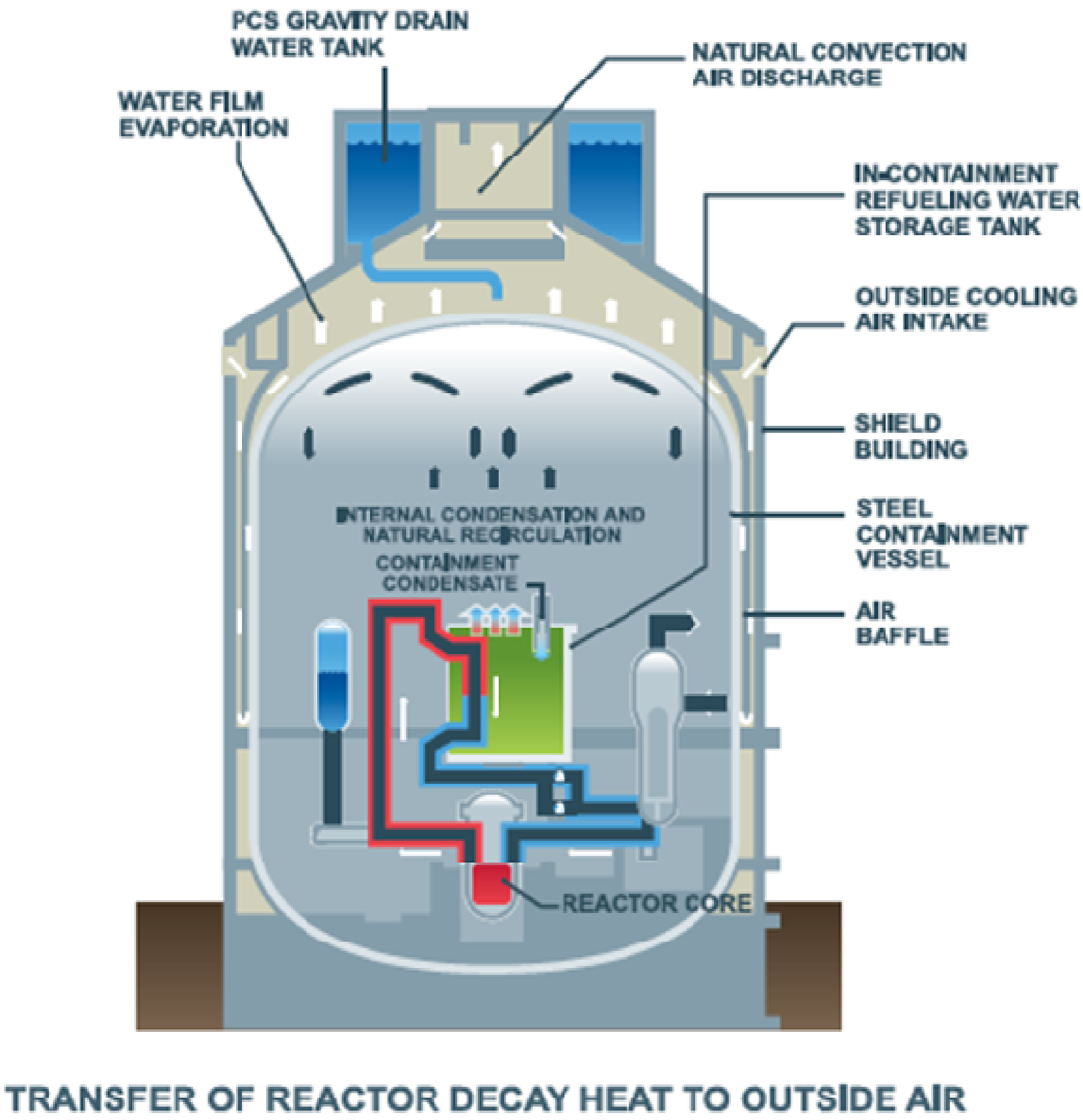
The water cooling the steel containment vessel removes decay heat through evaporation

Natural convection airflow passing through the shield building promotes the water coolin of containment.

8.2.8 >7 hours:

As the steam from the in-containment tank transfer decay heat to the steel containment vessel, steam condense back to water and is redirected back to in-containment tank for continued use in removing decay heat from the reactor core.

This cooling cycle continued indefinitely.


PCS GRAVITY DRAIN WATER TANK
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CONTAINMENT CONDENSATE
AIR BAFFLE
REACTOR CORE
TRANSFER OF REACTOR DECAY HEAT TO OUTSIDE AIR

Fig.F

8.2.9 36 Hours (Safe Shutdown Condition):

The reactor has reached safe shutdown condition without operator action and without use of active AC power sources, using passive cooling.

Reactor decay heat generation one half of one percent of full power.

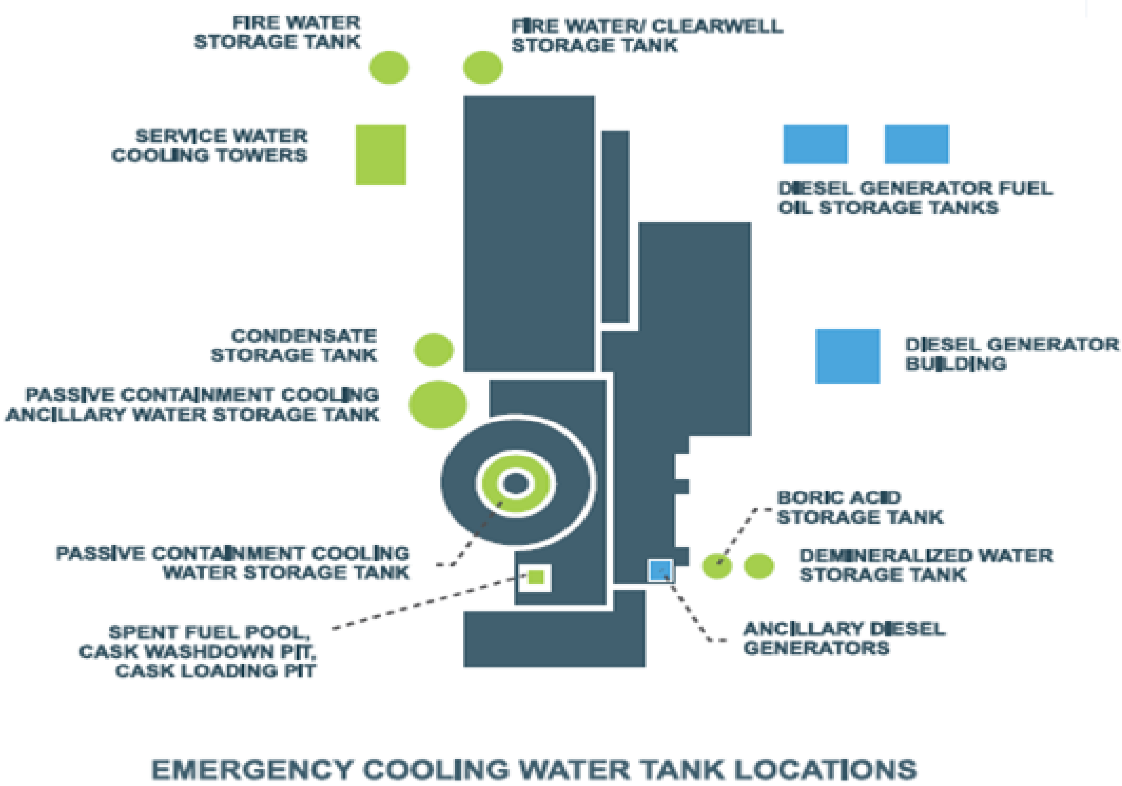


Fig.G

8.2.10 72 Hours:

The operator starts the ancillary diesel generators to provide power for post accident monitoring, water making pumps and main control room lightning.

Water makeup pumps are used to transfer water from ancillary water storage tank to passive containment cooling water storage tank to maintain water cooling of containment. These pumps also transfer water from ancillary storage tank to the spent fuel pool to continue its cooling of the spent fuel.

8.2.11 7 Days:

Diesel fuel is replenished in the ancillary generators if power is not restored to the site, To maintain ancillary functions.

Water from other available sources, including on site tank sea water, or other off site water supplies is transferred to either ancillary storage water tank or safety related makeup water flanged connection in the yard.

Portable equipment could be used to continue cooling of the containment vessel and the spent fuel.

Operator can continue transfer water to maintain containment and spent fuel cooling indefinitely.

Reactor decay heat is slightly more than one third of one percent of full power.

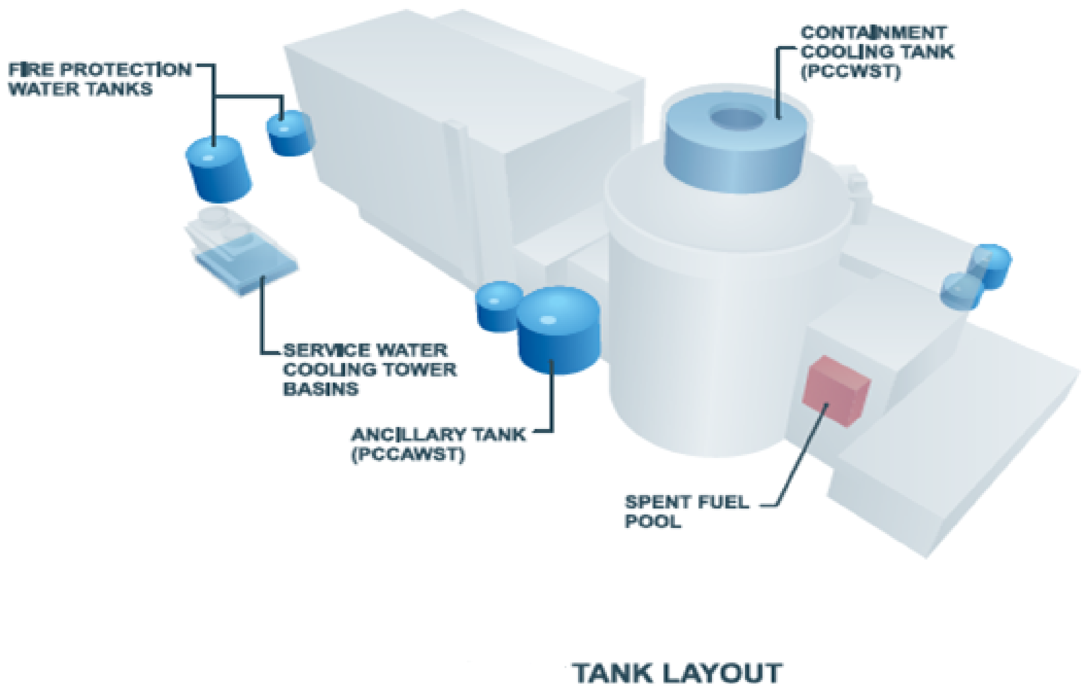


Fig. H

CHAPTER 9

9 Fault Calculations

9.1 Symmetrical fault calculation on main Generator

9.1.2
Main generator

1370 MVA, Output voltage = 2400 V to 26000V

Frequency = 50Hz, p.f. = 0.9, Speed= 1500 rpm

Generator is connected to 11.68KV bus , p.u reactance = 0.1 (Assumed)

Taking S_{Base} = 1400 MVA

$Z_{p.u.}$ =0.1pu

For,
1370 → 8 pu
1400→ 8.17 pu

Fault MVA = $\frac{Base\ MVA}{Zp.u.}$
= 1400/ 8.17
= 171.35 MVA

$\sqrt{3}\ V_L I_{SC}$ =171.35 MVA

$I_{SC} = \frac{171.35}{\sqrt{3}\times 11.8}$

$I_{SC} = 8.3842$ K

$= I_F$

9.1.3

An 11.8KV bus bar is fed from three synchronous generators having the following ratings and reactances :

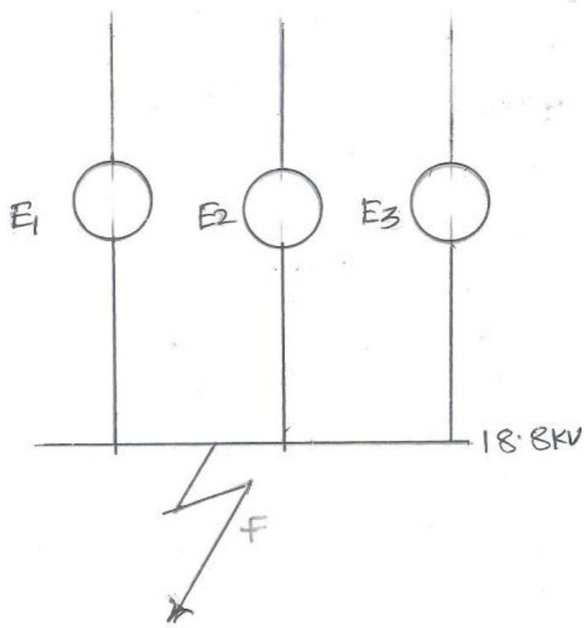
- 20 MVA,X_1' =0.08 PU
- 60 MVA,X_2' =0.1PU
- 20 MVA,X_3' =0.09PU

A three phase symmetrical fault occurs on the bus bar. Resistance may be neglected. The voltage base is 11.8KV & VA base is 60 MVA.

Find:

1. Fault MVA
2. Fault current

SOLUTION:



V_{BASE} = 18 KV

S_{BASE} = 60 MVA

1. FAULT MVA

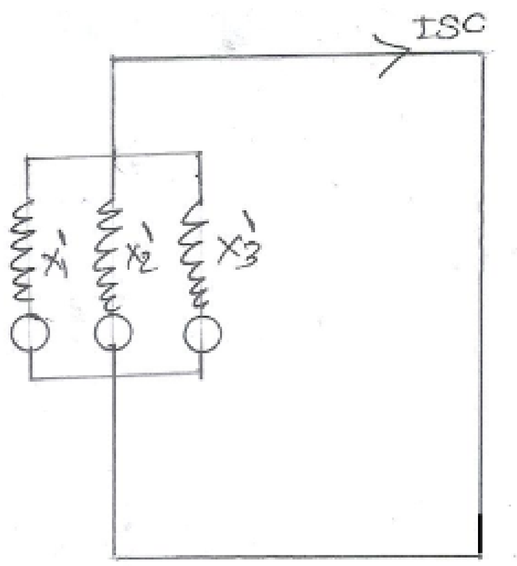
   FAULT MVA= (base MVA / Z_{PU})

Z_{PU} for generator 1 is 0.08PU.

Z_{PU} for generator of 60 MVA is: (60*0.08/20) = 0.24PU.

Z_{PU} for generator 2 is 0.1PU.

Z_{PU} for generator 3 is: (60*0.09/20) = 0.27PU.



Therefore, $Z_{EQ} = 1/ (Z_1^{-1}+Z_2^{-1}+Z_3^{-1})$

$= 1/ (0.24^{-1}+0.1^{-1}+0.27^{-1})$

= 0.056PU.

Their fore, FAULT MVA= (60 MVA/0.056)

= 1071.42 MVA.

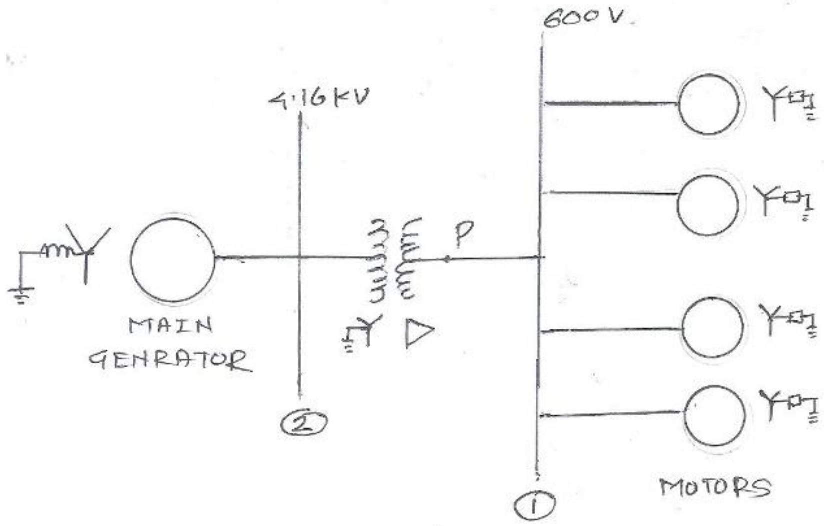
2. FAULT CURENT

   FAULT CURENT = (fault MVA / √3* base KV)

   I_{SC} = (1071.42 / √3* 11.8K)

   I_{SC} = 52.42KA.

9.2 Unsymmetrical Fault Calculation



- Group of identical synchronous motors is connected through a Transformers.
- Motors are rated 600V operate at 89.5% efficiency at full load and unity power factor and rated voltage .
- The sum of the output rating is 4476 KW (6000HP). The reactance in per unit of each motor based on its input kilovolt ampere rating are X_d'' $=X_1= 0.20$, $X_2= 0.2$, $X_0= 0.04$, each motor is grounded through reactance of 0.02 per unit.
- Motors are connected to the 4.16 KV bus through a transformer bank composed of three single phase units each of which is rated 2400/ 600V , 2500KVa . The 600V windings are in Δ connected and 2400 in Y connection . Leakage reactance of each transformer is 10%= 0.1 pu
- Generator rated 7500 KVA. 416 KV, with reactance $X_d''=X_2= 0.1$ pu, $X_0= 0.05$ pu and $X_n= 0.05$ pu

FAULT Condition

Each of initial motors is supplying an equal share of a total load 3730 KW(5000HP) and is operating at rated voltage 85 % of power factor log and 88% efficiency when single line to ground Fault occurs on the low voltage side of the transformer bank

Assuming group of motors as a single unit
The rating of the equivalent generator as base 7500KVA, 4.16 KV os system Bus
Since,
$\sqrt{3}$ x2400 = 4.16KV & 3x2500= 7500 KVA (For 3 phase transformer)
3 phase rating of Transformer is 7500KVA , 4160 Y/Δ
Therefore Base for motor circuit is 7500 KVA , 600V,
Therefore KVA rating of single motor can be given by

KVA of 1st motor = $\frac{}{\eta\% \times p.f}$

= 4476/ (0.895x 1)

= 5000 KVA

Reactances of motor are given as
$X_d'' = X_1 = 0.20$, $X_0 = 0.04$

For 7500 KVA p.u reactance will be

$X_d'' = X_1 = X_2$ = (0.2x7500)/ 5000 = 0.3 p.u
X_0 = (0.04x7500)/ 5000= 0.06 p.u

In zero Sequence network the reactance between neutral ang ground of equivalent motor is
$X_n = 0.02$

For 5000 KVA → $3X_n$ = 3 x 0.02

Taking base as 7500 KVA then

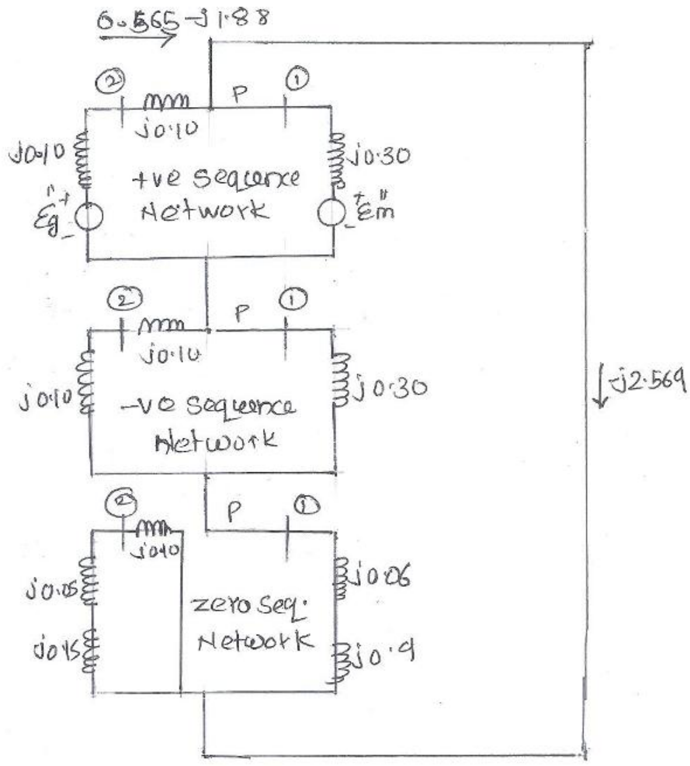
$3X_n$ = 3x 0.02x (7500/5000) = 0.09 p.u.

For equivalent generator the reactance from neutral to ground

X_n = 0.05

$3X_n$= 3 x 0.05 = 0.15

Sequence networks



SERIES CONNECTION OF SEQUENCE NETWORK

Motors are operated at rated voltage equal to the base voltage of the motor, the prefault voltage of phase 'a' at the fault bus 1, we assume

V_f=1 p.u

Base current for motor circuit is

$\sqrt{3}\ V_pI_p$= 7500KVA

I_p = 7500K/($\sqrt{3}$x600)

$\approx$ 7217 A

I_{base} = 7217 A

Now motor current during fault is

During fault in KW = 3730 KW

KVA rating will be = 3730K/ (0.88x 0.85)

Current will be =$\sqrt{3}\, V_p I_p$= KVA

I = 3730/(√3 x 600 x 0.88 x 0.85)

I ≈ 4798 A

Current drawn by the motor through line ‘a’ before fault occurs is I/I_{base}

=4798/(7217 < $\cos^{-1}$0.85)

≈ 0.665< -31.8°

I_{pf}= 0.5646-j0.350 p.u

→ If prefault current is neglected, E_g'' & E_m'' are equal to 1<0° p.u

Thevenin impedances for each of sequence network as follows

For positive sequence

$$Z_1^{(1)} = \frac{j(0.1+0.1) \text{x } j\,0.3}{j(0.1+0.1)+j\,0.3}$$

≈ j 0.12 p.u

For negative sequence

$$Z_{11}^{(2)} = \frac{j(0.1+0.1) \text{x } j\,0.3}{j(0.1+0.1)+j\,0.3}$$

≈ j 0.12 p.u

For Zero sequence network

$Z_{11}^{(0)}$= j 0.06 +j0.09

=j 0.15

Fault current in the series connection of the sequence network is

$$I_{fa}' = \frac{1}{0.12+\;0.12+\;0.15}$$

= 1 / j0.39 = -j2.56

$I_{fa}^{1} = I_{fa}^{2} = I_{fa}^{0} = -j2.56$

Current in fault = 3 I_{fa}^{0} = -j7.692

In the positive sequence network the portion of $I_{fa}^{(1)}$ flowing toward P from the transformer is found cy current division

$= \frac{-2.564 \times 0.3}{0.5}$ = -j 1.538 p.u

Portion of I_{fa} flowing through motor toward P

$= \frac{-2.564 \times 0.2}{0.5}$ = -j 1.026p.u

Similarly in case of motor as reactance's are same $I_{fa}^{(2)}$ from transformer to p is –j1.538 and $I_{fa}^{(2)}$ from motor to P is –j 1.026 and in negative sequence network current is shown in figure , which is –j2.54 toward P

To P from transformer in p.u

$$\therefore \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ -j1.538 \\ -j1.538 \end{bmatrix}$$

$$= \begin{bmatrix} (0 - j1.538 - j1.538) \\ (0 + a^2(-j1.538) + a(-j1.538)) \\ (0 + a(-j1.538) + a^2(-j1.538)) \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} -j3.076 \\ -j1.538 \\ j1.538 \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} -j2.56 \\ -j1.026 \\ -j1.026 \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} -j4.616 \\ -j1.538 \\ -j1.538 \end{bmatrix}$$

As transformer winding Y(grounded)-Δ connected

$I_a^{(1)}= I_a^{(1)} < 30^\circ$ and $I_a^{(2)}= I_a^{(2)} < -30^\circ$

$I_a^{(1)}= -j1.538 < 30^\circ = 0.769- j1.332$

$I_a^{(2)} = -j1.538 <-30^\circ= -0.769-j1.332$

From fig $I_a^{(0)}$ =0 in the zero sequence network. Since, there are no zero sequence on high voltage side of transformer

$I_a= I_a^{(1)}+ I_a^{(2)}$

$= -j2.664$ p.u

$I_B^{(1)}= a^2 I_a^{(1)})=(1<240^\circ)$

$=-1.538$

$I_B^{(2)}= a I_A^{(2)}= 1.538$

$I_B= -1.538+1.538 = 0$

$I_c^{(1)}= a I_a^{(1)}= (1< 120)(1.538< -60^\circ)$

$= 0.769+j1.332$

$I_C^{(2)}= a^2 I_a^{(2)}$

$= -0.769+j1.332$

$I_C = j 2.664$

Now by calculating base currents on the two sides of the transformer , we can convert the above per unit currents to amperes

Base current for motor circuit is calculated previously and its vlue is 7217 A

Base current for high voltage side is

$$= \frac{7500}{\sqrt{3} \times 4160}$$

= 1041 A

Fault current is –j7.692

Current in fault $= I_{Base} \times I_{pu}$

$= 7217 \times 7.692$

$3I_{Fa}^{0}$ = 55,500 A

Bibliography

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- **US N.R.C. PWR nuclear power plant design control document/guide.**

- **Westinghouse electrical PWR guide.**

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