AN ABSTRACT OF THE THESIS OF

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Title: PLANNING A RENOVATION OF THE UNDERGROUND DISTRIBUTION SYSTEM FOR THE CITY OF MECCA IN SAUDI ARABIA

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The present thesis is about the electric power distribution system for the city of Mecca, in Saudi Arabia. The distribution system of Mecca started suddenly, grew haphazardly and developed quickly with a load factor as high as 38%. Lack of planning, records and training plus insufficient experience of management evolved a highly muddled distribution system in the most important city of the world. Non-acceptance and appreciation of new ideas, and a negative attitude for research and development convinced the management that the situation is impossible. The present thesis is an attempt to explain that the situation is not impossible to improve, --the entire power distribution system of the city can be renovated. A patient consideration of the new technical concepts can be helpful. Spending money and

resources on a constructive program is an investment which pays dividends. Economizing by discarding the worth of the need, may create drastic problems which may be very difficult to handle in the future and cost much more by lost revenues, goodwill and stability of the organization.

Planning in town electrification and peering into the future is like touching a nerve center in a body. Every town and city has its own specific demands. The specified requirements of different towns should be separately considered, properly analyzed, thoroughly checked and the planning should also take into account the future, -- which will be brighter electrically, as well. Mecca, which is uniquely Holy, is also unique as far as electrification is concerned. Its pilgrimmage with an influx of a million people every year for a few days, and then their mass transfer from one distribution district to another presents a unique situation. To meet such a situation the distribution system should have been well planned, thoroughly engineered and kept highly flexible. On the other hand the system is deteriorating very fast due to several reasons--two of which are fast development of the load and the false economy by the power company.

Although the Mecca distribution system is in great disorder, the pressures and the prevailing philosophies to renovate it under the present circumstances make it highly challenging, yet it is not an impossible project. A little extra thoroughness now, can avoid a lot of future grief. The only effective way to avoid future operating problems lie in the consistent exercise of persistence in giving careful attention to details even though some of them may seem quite unimportant to the uninitiated.

It is imperative that a clear understanding of the distribution systems and modern practices be developed, before a renovation program can be undertaken. To cope with this requirement, the author has discussed this topic explicitly for occasional reference to help the practicing engineer. A thorough knowledge of distribution materials and equipment is equally vital to help in the selection for the possible changes, and a workable reference has also been compiled to assist the engineer and the management in this process. Principles of protection and broad guidelines for selection of protection equipment are also included to help the operating engineer realize the philosophies associated with this job. However, the area of protection is specialized and often complex and it is neither safe nor fair to the operating engineer to expect him to do it as a side line--as such details are avoided.

The renovation project may be carried out by the existing staff whose knowledge and experience can be used to advantage. However, as new concepts and materials will be introduced a thorough training of the technical staff is suggested. Programs for splicers training, fire fighting, safety precautions, record preparation and maintenance are described and ways are explained to make the job comprehensive and attractive to workers.

Training and continued education are also suggested for the engineers. A lot depends on how the engineer tackles his technical and administrative problems. A knowledge of human factors in engineering and technology, and modern management tools are also necessary for the engineer for efficient decision making. A utility engineer must be well equipped with the modern engineering developments and have a broad spectrum of knowledge and training. To help the engineer to understand his duties in rendering his services to the organization, duties and capacities of different engineers are discussed. This may also help the organization to appreciate and realize the engineering services, and make better selections of personnel in the future.

For the successful operation of a fast expanding utility much can be gained by a thorough analysis and control of the problems which are at hand and which may be confronted in the near future. These problems are discussed clearly and recommendations for improvements are made. Renovation is a process of constant struggle and achievement. Perserverence in thinking and constant struggle for betterment are the gateway to improvement. And, a change of attitude in itself is a great achievement.

Planning a Renovation of the Underground Distribution System for the City of Mecca in Saudi Arabia

by

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To

JANI, GAUHAR and JAUHAR

in

recognition, appreciation of and in reverence
for their
love, patience and courage

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LIST OF ABBREVIATIONS

A	Ampere
a-c	Alternating current (adjective)
a. c.	Alternating current (noun)
A/C	Air conditioner
ACSR	Aluminum cable steel reinforced
AD	After death
AH	After Hijrah
a. m.	Anti Meridian
Awg	American wire gauge
BICC	British insulated callenders cables
C	Degrees centigrade
CPM	Critical path method
cps	Cycles per second
CT	Current transformer
DB	Distribution box (Siemens)
d-c	Direct current (adjective)
d. c.	Direct current (noun)
D/C	Desert cooler
DE	Double entry
deg	Degree
DF	Diversity factor

F	Degree fahrenheit
ft	Foot
GM	Grand Mosque
HO	Head office
hp	Horse power
HT	High tension
hr	Hour
in.	Inch
kg	Killogram
kv	Kilovolt
kva	Kilovolt ampere
kw	Killowatt
kwhr	Killowatt-hour
lb	Pound
LDB	BICC lower distribution box
LF	Load factor
LPF	Light, plug, fan
LT	Low tension
MC	Meter connection
MD	Maximum demand
mm	Millimeter
mva	Megavolt-ampere
OCB	Oil circuit breaker

O/H Overhead

PERT Program evaluation and review technique

PH Power house

Ph Phase

PILCDSTA & S Paper insulated lead covered double steel tape armored and served cable

p.m. Post Meridian

PP & L Pacific Power and Light Company

psi Pounds per square inch

PT Potential transformer

PVC Polyvinyl chloride

SE Single entry

sq Square

SR Saudi Riyal

S/S Sub-station

TTY Teletype

TV Television

U/G Underground

VIR Vulcanized india rubber

PLANNING A RENOVATION OF THE UNDERGROUND DISTRIBUTION SYSTEM FOR THE CITY OF MECCA IN SAUDI ARABIA

I. INTRODUCTION

What is Renovation

Renovation means to renew, to restore to life, vigor or activity etc. Herein we will be concerned with the renovation of the distribution system of Mecca, Saudi Arabia as a whole, and would skip the local renovation of the individual parts which we may consider as repairs or replacement.

Why Renovation

It may be well questioned, why renovation at all? Why not discard the existing system completely and have everything restarted from the beginning? The answer is, it is a good suggestion but very expensive, impractical and off-time. As the term renovation implies our purpose is to achieve an improved and workable distribution system with minimum expenses.

As we desire to have a minimum of outage and salvage we will try to make use of the existing resources and manpower in such a way as to have the least number of complaints from consumers, and owners.

Where and When Renovation

In fact renovation is necessary for the entire city, but certain parts of the city should be immediately renovated. It is not difficult to make an areawise priority list so the job can be started as soon as possible to save future disappointments.

Organization and Purpose of this Thesis

We have given an outline of Mecca, its distribution and its associated problems in the Appendix. It will be worth for our reader to go through this outline so that he may get familiarized in broad perspective with the problem that we would try to solve in this thesis.

In the chapters that follow we will discuss the technical and philosophical aspects of distribution systems and modern practices along with the recommendations for possible improvements for Mecca distribution. This thesis is intended to serve as a reference guide for the practicing engineer and, as a peep through for the newly recruited engineer in the Mecca distribution.

2. DISTRIBUTION SYSTEMS AND MODERN PRACTICES

Introduction

The now almost universally employed a-c system of distribution was developed largely as the result of the work of L. Gaulard and J. D. Gibbs, who in 1882 designed a crude alternating-current system using induction coil as transformers. The primary coils at first were connected in series for high-voltage transmission. Satisfactory performance could not be obtained because the reactance of the transformers was not taken into account, but they were able to distribute electric energy at a voltage considerably higher than that required for lighting, and to demonstrate the economies attending its use. The system was introduced into the United States in 1885 by George Westinghouse. An experimental installation went into service at Great Barrington, Mass., early in 1886. The first large scale commercial installation was made at Buffalo, N. Y., the same year (7).

There are several considerable advantages to be gained by the use of high, voltage direct current transmission. If we consider overhead lines or single-core cables, which alone are used with extra high voltage so that the maximum voltage to earth is the criterion, the ratio of copper in the d. c., 2 wire system with earthed midpoint and the three-phase, 3 wire system is

$$\frac{(0.25)}{(0.5/\cos^2\phi)} = 0.5\cos^2\phi.$$

Thus if the power factor is 0.85, the d-c system requires only 0.36 as much copper as the a-c system. Furthermore in a-c systems the charging currents contribute to a continuous loss even when there is no load, whilst the d-c system will have losses only when the load is on. It is held that the losses due to the charging current are a determining factor in the economics of long distance transmission.

Furthermore the transmission of a. c. for great distances is attended with instability, i. e., a synchronous machine will not be pulled back into phase if it departs from its correct position; and it is necessary to inject reactive power at intervals of about 100 miles to limit the reactive drop which is the cause of instability. D. C. transmission is not affected by instability and the lines may have any length.

Insulation difficulties are much greater with a. c. than with d. c., and the adoption of d. c. will raise the permissible transmission voltage without extra cost or trouble. Thus the current-carrying capacity of buried cables used for very high voltages (100 kv and above) is determined partly by thermal instability due to the rise of the power factor of the dielectric with temperature. As there are no appreciable dielectric losses with d.c. the current-carrying capacity can be increased considerably.

Until recently there was no adequate method of transforming electrical energy from low voltage a. c. or d. c. to high voltage d. c., and from the latter to the former. The only method of utilizing high voltage d. c. was the Thury method. In this system series-wound generators are connected in series, the current is kept constant and the power is varied by varying the voltage of transmission. This is done by varying the speed of the generators or by inserting more generators into the circuit. The Thury system between Moutiers and Lyons,[1] 112 miles apart, has a constant line current of 75 amperes and a maximum voltage of 60, 000 volts, so that the maximum output is 4500 kw. The generators have to be insulated from earth for the maximum voltage.

Power is taken from the circuit by motor-generators, the motors being series-wound and connected in series with the main circuit. The generators driven by them can give d.c. or a.c. at any desired voltage. The motors have to be insulated from earth for the maximum voltage, and are short-circuited when they are not required (27).

The main disadvantages of the Thury system are the facts that the line losses are constant at all loads so that the efficiency at low loads is very poor, and an increase of power of the system necessitates fresh insulation of the line for higher voltage since the current

[1]In France.

is constant.

There are now available various rectifiers, the mercury vapor and atmospheric arc types, which can handle 30,000 kw at 400 kv. Energy can be transformed from a. c. to d. c. and from d. c. to a. c. with a very high efficiency and at a reasonable cost (25).

Henceforth we will discuss a-c systems only in this chapter and in the chapters that follow.

Feeders and Distributors

The power distribution function basically includes all of the facilities and services associated with the delivery to consumers, of power made available at some central generating or receiving station.

For convenience it has become customary on occasion to refer to various components of the distribution system as transmission, subtransmission, primary distribution and secondary distribution facilities, although each contributes its part to the over-all distribution function. With the passage of time and accompanying increases in load density, together with advances in the art, circuits having voltages originally considered so high as to be suitable only for transmitting scheduled blocks of power from one place to another, have long since been used extensively as distribution circuits, for power delivery to consumers whose momentarily changing demands also determine the loads on the circuit (7).

In general, in an a-c system there will be a change of voltage at each point where the subdivision takes place, this change being effected at a substation, and it therefore follows that there may be several working voltages in the same system. For obvious reasons it has been necessary to standardize voltages. The standard voltages in U.K. and British Commonwealth[2] countries are:

1. Generating voltages: 6600, 11,000 and up to 33,000 volts.
2. High-voltage transmission: 275,000, 132,000, 66,000 down to 11,000 volts.
3. High-voltage distribution: 11,000 to 6600 volts.
4. Low-voltage distribution: 400 volts between phases, 230 to neutral.

The distribution system, i.e., not including the transmission lines can be sub-divided into feeders, distributors, and service mains. The feeders are the conductors which connect the substations, or in some cases the generating stations, to the areas served by these stations. The distributors are characterized by the numerous tappings which are taken from them for the supply to consumers, and the service mains are the connecting links between distributors and consumers terminal. The essential difference between feeders and distributors is thus that, whereas the current loading of a feeder is the same along the whole of its length, a distributor has a

[2]Standard frequency of 50 cps.

distributed loading, with consequent variations of current along its length. The functions of these three types of main are illustrated in Figure 1, in which the distributor is shown as a ringmain.

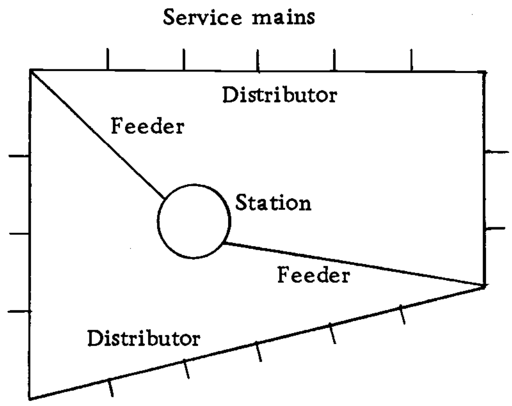

Figure 1. Elements of a distribution system.

In some cases small feeders are tee'd off from a main feeder, but this does not make any exception to the general rule that tappings are not taken from a feeder to a consumer's premises (6).

3 Ph 4 Wire System with Star Connected Secondary

The scheme is as shown in Figure 2.

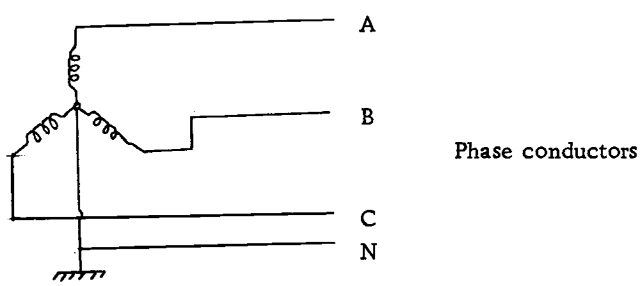

Figure 2. 3 Ph 4 wire system with star connected secondary.

The fourth wire on the secondary side is derived from the neutral point of the star-connected secondary. The single-phase loading is split up into three sections as nearly equal as possible, while any three-phase load, if existent, is connected to the three phase conductors (6).

If the single-phase load has been reasonably equally divided between the three phases, then for all practical purposes the system can be regarded as perfectly balanced. It is not necessary to install the balancing transformers and, no matter how the system extends, a continuous four-wire distributor can be laid down in the area to be served so as to be available for future new consumers. The disadvantage of the method is that there is no simple ratio between the voltages of the three-phase and the single-phase services, this ratio being 1.732 to 1. Actually, standardization[3] of voltages has largely nullified this disadvantage (6).

Since, in general, there will not be a perfect balance in the three single-phase loads there will be a current along the neutral wire. When the neutral wire is grounded, the earth connection must be thoroughly good, and the lead to it capable of carrying the maximum current which can flow at any time. This means that it should be at least one-half of the cross-sectional area of the lead or return, and

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[3]As 400/230 v or 380/220 v etc.

the metal should be copper (20).

Grounding of system neutrals at primary voltages has been almost universally practiced. However, there have always been two schools of thought regarding grounding of system neutrals at utilization voltages. There are many systems in operation with ungrounded neutrals, but few such systems are being installed today. There is therefore, a trend toward neutral grounding at the lower voltages, and it is probable that most of the new systems from now on will be of the grounded-neutral type. The advantages claimed for system neutral grounding are (12):

1. Reduced operating and maintenance expense.
2. Improved service reliability.
3. Greater safety.
4. Better system and equipment overcurrent protection.
5. Improved lighting protection.
6. Keep transient overvoltages that may appear on a system to a minimum.
7. Readily locate and isolate circuits which have been accidentally grounded.

When a wye-connected circuit and solidly--or effectively-grounded neutral is used, the following benefits are obtained in addition to dual voltage capability (13).

1. A single line-to-ground fault will cause sufficient ground current to flow to actuate standard protective relays and thereby isolate the faulted circuit, and identify the source of trouble.
2. The maximum voltage to ground[4] imposed upon any phase is limited to line-to-ground value, even when a ground occurs on one phase.

Ungrounded operation of generators and transformers will limit line-to-ground fault current to very small values. However, it has major disadvantages in that excessive overvoltages can exist on the system and locating ground faults may be difficult. Another drawback of the ungrounded system is the possibility of transient overvoltages in the event of an intermittent ground fault. Due to circuit inductance and capacitance, an intermittent ground fault can produce sufficiently high voltage to ground on the system to cause other ground faults.

If it is necessary to maintain service after the first line-to-ground fault, high resistance grounding has advantages over operating ungrounded. A grounding resistor is selected equal to or less than the ohmic value of system capacitance to ground (1/3 of X_{co}).

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[4] The earth, or the globe, made up actually of earth and lots of other things, is so enormously large that no charge of electricity which can be given to it makes any appreciable difference in its potential. Therefore the earth is taken as the base from which to measure potential; or we call its potential zero, and all other potentials are measured from that as a starting point (20).

Ground-fault relaying is used to indicate the presence of a ground.

The use of grounded-neutral systems affects power system design by requiring through study, a careful selection of a means of grounding. Selection of transformers of proper characteristics for the unit sub-stations[5] will usually be involved. In some cases lower rated lighting arresters may be used resulting in better surge protection. Ground relays are usually employed on high- and medium-voltage systems for faster relaying of faults (12).

<u>3 Ph 4 Wire with Delta-Connected Secondary</u>

This is a less commonly used method which has been devised to give a ratio of 2 to 1 between the three-phase and single-phase voltages. The circuit diagram is shown in Figure 3.

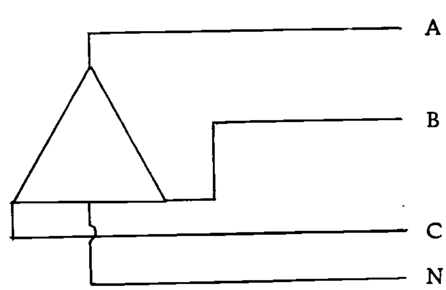

Figure 3. 3 Ph 4 wire system with delta connected secondary.

[5]See Balancer for 3 Ph 4 Wire System, ahead in this chapter.

It will be seen from the Figure 3 that the whole of the single phase load is taken by one phase only, the fourth wire being derived from a mid-point tapping on that phase. Owing to the position of the tapping the voltage of the single phase service is one-half that of the line voltage of the three-phase service. This is the only advantage of this method (6).

The obvious disadvantage is that the load is completely unbalanced, and it is therefore necessary to divide the district served into a number of sections which are quite independent so far as the secondary sides of the transformers are concerned, each section being fed by its own transformer. Also to obtain reasonable balance in the primary circuit it is desirable to have three sections, the three mid-point tappings being taken from each of the three phases in turn. Figure 4 will make it clear. It is obvious that with this system it is not possible to lay a continuous four-wire distributor through the area to be served.

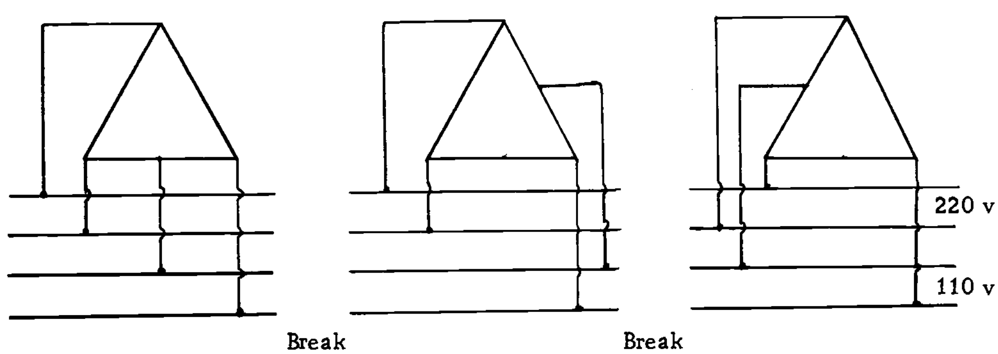

Figure 4. Subdivision of four-wire distributor fed from a delta-connected transformer.

With an ungrounded-delta secondary, a single line-to-ground fault will cause practically no ground current to flow and service continuity is maintained to this grounded apparatus. However, the ground will likely remain undetected unless a second ground fault occurs on another phase. In the first case the location of grounds can only be found by successive opening of breakers until the ground is removed or by special ground-fault-locating equipment. In the second case a complete outage will occur and the grounds must be located by successive closing of breakers (or replacement of fuses) (13).

Balancers for 3 Ph 4 Wire System

Even with the star-connected secondary it is not always possible to obtain a satisfactory balance with the three single-phase loads, and in such cases it is necessary to install balancing apparatus (6). Since any lack of balance manifests itself by a current in the neutral wire, the restoration of balance can be effected by diverting this current to the other wires. One method is to employ a three-phase 1/1 ratio transformer with interconnected star windings on the secondary side, the star point of this winding being connected to the neutral wire, as shown in Figure 5.

In addition a choke coil is included in the neutral, to ensure that out of balance current flowing from the load shall be forced to pass through the secondary windings of the balancing transformer.

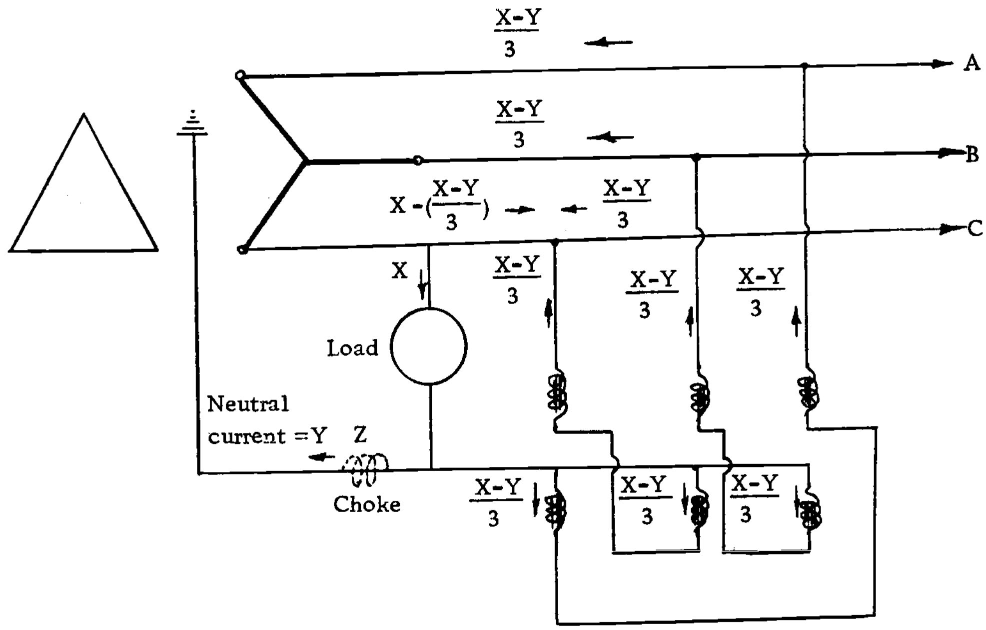

Figure 5. Connections of balancing transformer.

The balancer does not direct the whole of the out-of-balance current into the three-phase conductors, the amount of current so diverted being proportional to the inverse ratio of the impedances of the direct path for the current, via the line, load, and neutral, to the second path, line, load, balancer, neutral point, and balancer. For satisfactory results it therefore follows that the impedance of the balancer must be kept as low as possible, while the impedance of the fourth wire to the flow of out-of-balance current must be as high as possible. In some cases the required high impedance of the fourth wire has been achieved by making a break in this wire, but this has the disadvantage that even though the fourth wire may be earthed at the supply point, beyond the break there is the possibility of the line wires assuming too high a voltage with respect to earth. The best method of obtaining the high impedance is thus to include the choke coil. In the figure, the worst possible case is assumed, i. e., a load on one phase only, but the balancer gives a much improved performance from the point of view of voltage balance.

Development of Underground Systems

Distribution of electricity by underground systems was started by the early telegraphers, among them Ronalds, Wheatstone and Morse. Insulated wires buried in the ground and wires drawn into conduits were tried with varying success. Francis Ronalds, in 1816, used bare copper wires drawn into glass tubes placed in a buried wooden trough. W. F. Cooke and Charles Wheatstone, in 1837 placed insulated wires in grooves in buried timber. In 1844 S. F. B. Morse buried some miles of lead sheathed cable between Washington and Baltimore but abandoned it in favor of an overhead line. None of these early lines proved to be successful due to hygroscopic nature of the only insulations then available. The best of these was gutta-percha, but it was too prone to oxidation in the absence of adequate protection from the air.

Very little was done in the way of underground distribution from the early days of the telegraph until the advent of Edison's electric lighting, a period of nearly 40 years.

Edison planned his first installation for New York City and decided that an underground system of distribution would be necessary. This took the form of an electrically interconnected network of low voltage distribution mains supplied by feeders radiating from a centrally located d-c generating station to various feeding points in the network.

Edison designed a rigid buried system consisting of copper rods insulated with a wrapping of jute. Two or three insulated rods were drawn into iron pipes and a heavy bituminous compound forced in around them. They were laid in 20-ft sections and joined together with specially designed tube joints from which taps could be taken if desired. The Edison tube gave remarkably satisfactory performance for this class of service.

The load voltage, heavy current characteristic of d-c distribution limited the area that could be supplied from one source, if the voltage regulation were to be kept within reasonable bounds. Moreover, the high first cost and the heavy losses have made such systems uneconomical for general distribution. Therefore, they developed in limited areas of high load density, such as the business districts of the larger cities, and even in these areas, subsequent load growth has largely compelled replacement by a-c systems (7).

Overhead and Underground Systems

Overhead and underground distribution systems both perform the same basic function, although their design and operation involve quite different techniques. Both systems include various types of lateral, branch and radial circuits, some of which will operate in parallel after a fashion commonly referred to as a "network" (7).

In towns and densely populated areas overhead lines are clearly impossible. In the very early days of distribution the principles of overhead lines were employed in underground work (25).

One significant difference between open-wire and cable circuits lies in the fact that cable conductors must be covered by an insulating material throughout their entire length for the full operating voltage of the circuit, whereas open-wire circuits are insulated by air, except at terminations and at intermediate points of support. Hence, the challenges to be met by the designer of underground systems have centered largely about this problem of conductor insulation. There are also many other problems associated with corrosion, heat dissipation, safety and providing needed accessibility for maintenance or replacement. Of course it will be understood that other distribution equipment, as well as cables and their accessories, must all be designed to permit satisfactory installation and maintenance.

Since underground construction is an expensive alternative for overhead installation, it follows naturally that an underground system should be specified only in those areas where considerations of public welfare, safety, very high load density or architectural environment are unquestionably sufficient to warrant the greater cost. Consequently, very few power distribution systems are installed wholly underground. Even in areas served predominantly by aerial systems, however, it is often necessary to avoid intolerable overhead congestion by the underground installation of high-capacity feeders, particularly in the vicinity of major distribution centers.

With each passing year, therefore, systems having had little previous experience with underground construction are finding themselves confronted with the inescapable necessity of entering a new field of specialized practice in which a tremendous amount of talent and effort have brought about almost revolutionary development during the last few decades. The great strides which have been made toward developing package equipment, which can be installed with a minimum of field labor, have had little effect upon reducing the amount of extremely specialized skill and care required for the field installation of cable, joints and terminals in environments where the procedures required to avoid contamination seem almost impossible of attainment. The integrity of an underground cable system, therefore, continues to be extraordinarily dependent upon excellence of workmanship in the field installation.

General Considerations for Underground Systems (7)

The cost of underground construction is nearly always greater than the cost of the equivalent overhead construction. For this reason underground lines have been restricted almost entirely to localities where considerations other than lowest cost are of primary importance. The use of underground conductors will depend upon the relative importance of one or more of the following considerations:

1. The density of the load in the district to be served.
2. Availability and cost of overhead rights-of-way.
3. Presence of physical obstructions which are impractical to by-pass with overhead construction.
4. The importance of the line and the advisability of taking extraordinary precautions to insure it against mechanical injury.
5. The appearance of the streets.
6. Public laws, rules and regulations.
7. Proximity to air ports and other considerations of overhead clearances.
8. Construction and maintenance cost.

The circumstances surrounding a particular problem will determine which of these considerations will be involved in arriving at a decision whether to use underground construction. Each has its own particular considerations concerned with whether or not it shall be underground. For example, the reasons for an underground lighting system would be different than for an underground transmission line. All factors can be grouped into three general categories:

1. Those involving technical and economic consideration,
2. Those involving service reliability and other characteristics of underground construction, and
3. Those in which special considerations of public interest outweigh technical and economic consideration.

We will discuss all the above three in short details.

a) Technical and Economic Considerations: A primary responsibility of the transmission and distribution engineer is to evaluate the cost of all proposed construction and to specify the most economical type of construction compatible with the location and the type of service for which it is required.

The importance of a firm stand on this fundamental principle cannot be too greatly emphasized. The extensive use of underground construction merely to satisfy public pressures in areas which could be adequately and much more economically served by overhead must inevitably result in substantial rate increases. Installation of costly complete underground systems may often be avoided or deferred by less costly partial underground systems in combination with overhead line rebuilds or rear lot construction.

The first cost of an underground system is high in comparison to that of a conventional open-wire overhead system of equivalent carrying capacity. The ratio of underground to overhead costs varies widely, depending on voltage, number of circuits involved, whether private right-of-way is obtainable, the standard of service continuity which is required and whether equipment such as transformers, protective and sectionalizing equipment are included in the project. Examples are common where local conditions and the character of the system involved would raise this ratio to ten or more. Since the cost of electricity to the ultimate consumer bears a relation to plant investment and operating costs, it is highly important that the utilities, the various regulating authorities and the general public understand that any public utility, whether privately or publicly owned, is under obligation to serve its customers in that manner which will supply satisfactory service at minimum cost. The transmission and distribution of electrical energy accounts for substantially more than one-half of its total cost to the ultimate consumer; consequently, decisions by a utility or municipal regulation which result in an underground system where overhead construction would have been practicable and more economical must demonstrate inherent advantages sufficient to justify its increased cost.

Most of the reasons for the higher cost are perhaps obvious. Underground cables have reduced carrying capacity per unit of cross-section due to the thermal limitations imposed by the conductor insulation and soil conditions. Manholes and duct lines or steel pipes, transformer vaults, transformers and other associated equipment suitable for underground service, together with the more detailed engineering, design and plant record work involved in underground systems, also contribute to the increased cost.

In designing an underground system, the fact must not be overlooked that, since underground cables have quite definite maximum current-carrying capacities as dictated by the thermal characteristics of their insulation they consequently do not have the ability to handle extreme overloads safely during operating emergencies which is a characteristic of open wire conductors. The cable portion of the underground system must therefore be designed with a suitable excess carrying capacity over that normally required in order to meet all expected emergency situations without exceeding permissible cable operating temperatures.

The annual maintenance and operating expense associated with an underground system is usually more than for any overhead system of equivalent capacity. While outages on the underground system are relatively infrequent, repairs are costly both in material and time. Specialized personnel are involved for all but the simplest cable splicing operations; sizable crews and heavy equipment are required for removing and installing cable. The time involved in locating and repairing faults in underground circuits is long in comparison to that usually associated with overhead systems, especially when the higher voltage cables are involved. This element of long outage time associated with cable failures is a disadvantage inherent in underground systems which requires substantial additional capital investment in sectionalizing and tie facilities and excess cable capacity or networking on distribution circuits. Spare cables or other forms of backup must usually be provided for transmission and subtransmission circuits. Careful analysis is required to establish a proper balance between system cost and assured continuity of service.

The time involved in the location and repair of cable fault varies widely with the voltage rating of the cable, type of construction and location of the fault. The lower voltage distribution cables installed in duct lines can frequently be repaired in a fraction of a day, even when it is necessary to replace the complete duct section of cable. Jointing time and fault location will extend this outage time to a day or more for the higher voltage duct-type and buried cables. Experience to date with pipe-type cable indicates that the outage time to locate and make repairs may be in the order of a week under normal conditions.

Conventional duct lines of conduit in concrete and properly coated steel pipes last for decades unless subject to damage by careless excavation, drilling, broken water mains or other similar external hazards. Lead-covered cables installed in properly designed duct lines and operated within their ratings can be expected to perform satisfactorily for 30 to 40 years or longer unless sheath corrosion occurs. Similar life can be expected for the high-voltage pipe-type cables. The newer designs of nonleaded cables may well have almost as long a life. The life of the various items of associated apparatus, such as transformers, fuses, sectionalizing devices and junction boxes, varies widely with the severity of corrosive conditions. Under normal manhole conditions, if care is exercised in the selection of materials and protective coatings, life approaching that of the cables may be realized. In those cases where equipment is periodically immersed through the action of tidewater, a materially higher rate of depreciation must be expected.

Cost considerations tend to direct the choice of the type of installation to overhead construction. Local conditions must, however, be given careful consideration and sometimes are such as to modify the choice. In many localities underground construction may be more desirable than overhead and in extreme cases may even be necessary. High cost of right-of-way or longer overhead routes may substantially diminish or even in rare instances eliminate the cost differential between overhead and underground.

Underground construction is often necessary for high load-density urban areas where lack of space and building congestion greatly restrict the possible installation of pole lines. Underground construction makes it possible to route any reasonable number of circuits of any desired operating voltage through public ways and often provides the solution for the installation of supply lines in certain localities.

The increasing cost and difficulty of acquiring private right-of-way to generating stations may necessitate use of public ways for underground transmission and subtransmission circuits from the station to the nearest point or points to which it is possible or economic to acquire rights-of-way suitable for overhead lines. The same requirement for subtransmission circuits, with the added complication of a multiplicity of distribution circuits, may be encountered in the vicinity of major distribution sub-stations, in which case it may also be necessary to place the distribution circuits underground for a sufficient distance to permit them to spread out into several different routes on which they can be accommodated as open-wire lines.

Many types of obstructions which conflict with the installation of open-wire lines may be by-passed by the use of duct-lay cable and pipe-type cable are accepted methods of carrying circuits past approach zones to airports, through tunnels and across those types of bridges where open-wire lines cannot be considered and alternative routes are either unavailable or uneconomically long. Both submarine and pipe-type cable furnish the solutions for crossing large bodies of water under the same conditions or where excessively high crossing structures for open wires could be required.

b) Service Reliability and Other Advantages: From the standpoint of continuity of service, the relative immunity of underground systems to many of the hazards which are the most frequent causes of interruption on open-wire circuits is a consideration of the greatest importance in favoring the use of underground construction. In those installations where the highest practicable degree of service reliability is required, an underground system will offer protection from outages due to storms, high winds, tree interference, lightning, traffic accidents, fires and the more common form of vandalism. Properly installed and operated metal-sheathed underground cable is generally susceptible to only two major external hazards, i.e.,

1. Mechanical damage
2. Corrosion.

Only the highest grade of overhead construction compares favorably in service reliability with that of a well-designed cable system. However, cable systems are subject to interruptions of much longer duration for repair and maintenance. This requires that provision be made for such longer circuit interruptions in the system design.

The analysis of operation of underground cables in the 7.5 kv and higher voltage brackets in a group of the larger electric utilities disclose that mechanical damage and corrosion are responsible for over 60 percent of the cable failures in these systems and that less than 15 percent can be attributed to inherent insulation failures. Conduit and manhole systems properly designed to provide adequate cable offset or the use of alloy lead sheaths or both can minimize this type of failure.

The relatively complete isolation between circuits which is achieved in a properly designed duct and manhole system greatly reduces the likelihood of circuit trouble being communicated from one circuit to another or for more than one circuit to be affected by external interference at the same time. Underground circuits occupying the same route can therefore be depended upon for mutual backup to a considerably greater extent than may be practicable where open-wire circuits are involved.

The relatively low incremental cost of installing spare ducts at the time of constructing an underground duct line and the ability to install additional cables from time to time without interference to or from existing operating circuits permit economical and convenient provision for future load growth and system expansion.

c) Special Considerations of Public Interest: Local ordinances, agreements, etc., governing the type of construction suitable to the different types of districts served by the utility should be known to and observed by the designers. Such regulations are designed in the public interest, usually with the close co-operation of the utility. However, the arbitrary extension of such regulations to all types of areas is not necessarily in the public interest. They restrict the utility engineers in their choice of the most economical and most suitable type of construction compatible with the area to be supplied and result in higher costs to consumers and, in some cases, a poorer grade of service.

Every effort should be made to cooperate with law-making bodies contemplating such legislation by fully informing them of its possible effect on rates paid by the consumer and service reliability and by showing how much more effective improvement per dollar invested can be accomplished by steps involving improvements in overhead construction less drastic than complete underground construction.

It is obviously a responsibility of the utility engineers to plan their work on public roads so as to cause as little inconvenience as possible to the free movement of traffic. When major street surfacing or highway projects are proposed, it is in the best interests of all for the utility engineer to cooperate with the local authorities, study their plant in the street under consideration and, if new construction is required in the next few years, to complete it before new pavement is laid. This may avoid the necessity of reopening the street soon after the improvements have been completed, thus minimizing the inconvenience to the public due to the blocking of traffic lanes. Construction costs may be reduced by such practice, although a study of the present-worth economics is necessary to determine the facts.

Requirements restrictive of overhead crossing as well as pole lines along vehicular expressways introduce a serious problem to the utilities affected. Due to the nature of these thoroughfares, they frequently cut completely across the operating territory of a system and the requirements may compel the installation of short sections of underground in many otherwise overhead circuits irrespective of operating voltage or whether they are on private right-of-way or public streets.

Difficulty in acquiring the property and rights to construct distribution substations in residential areas frequently arises from public antipathy to the concentration of supply and distribution circuits involved. Cases arise where it becomes expedient to use underground exists for these circuits in order that the utility plant be in keeping with its surroundings, even though overhead construction would be practicable from both the legal and physical standpoint.

Situations occasionally arise where it is good judgment to avoid overhead lines in certain areas where they might be permitted legally but would be objectionable to the public to the extent of injuring public relations and even promoting agitation for underground ordinances which might be more inclusive in their scope and consequently more burdensome to the utility and its customers. The flight approach zones to airports occasionally offer a problem in this category. In situations such as this where the expenditures involved can not be attributed to any requirement of the utility, it is fair and equitable that the costs involved should be borne by the benefiting party.

Cases have arisen where legislation was proposed and seriously considered which would have required entire urban and suburban area electric facilities to be placed underground. These proposals have been initiated as the outcome of extensive and long-time service outages resulting from unprecedented storms. While there was general agreement that a totally underground system would not have suffered the interruptions which were experienced, the proposals were abandoned when the impracticability of using only underground construction throughout such area was demonstrated.

There are frequent requests that the distribution and services associated with large, new housing developments be entirely underground. There has been a trend in such situations for the additional cost above overhead construction to be borne by the developer or the developer may pay the entire cost with the utility accepting ownership and assuming obligation for future maintenance. A study of the cost frequently results in installation of an overhead system.

Henceforth we will discuss only the underground systems.

Basic Choices

There are three basic choices or determinations to be made in the planning of transmission, sub-transmission and distribution systems. They are:

1. Voltage
2. Size of units (substations, circuits, etc.)
3. System patterns.

These are inter-related in a complex way. They may conveniently be discussed separately but actually modification of one has some effect on the others.

All choices have in view the basic goal of good voltage and good continuity of service to the consumer at minimum capital and operating cost. Underground systems differ substantially from overhead systems in that their reactances and resistances are usually much lower. Consequently, voltage drop is usually less than it is in overhead systems. However, it should be considered and may on occasion become important.

Thermal considerations are generally of primary importance in underground system design. This fact imposes a severe economic limitation because, if the voltage is doubled for a given conductor size, the permissible kva rating does not quite double. The overhead system can usually, but not always, benefit in direct proportion to the voltage. As load density increases in a given area, the thermal limitations of underground cables may require a greater increase in line capacity than would be the case if the area were supplied by open wire lines.

Underground systems are generally, but not always, free from the disturbances of nature and public interference. This advantage is offset to a considerable extent by the much greater time it takes to locate and repair a cable fault. This is further aggravated by the greater cost of duplicating feeders or running branches or taps to adjacent feeders for use in emergency.

It is inherent in the nature of an underground system to require a somewhat longer range of planning for the future on account of the public inconvenience and expense involved in digging trenches and installing conduit, manholes and transformer or other equipment vaults. This longer time interval augments the higher construction cost by reason of carrying charges over the longer period of time it takes to become loaded to capacity.

We will discuss now, only the choice of pattern in detail.

Choice of Pattern

Radial, loop and network are three general categories of patterns for system connections or diagrams. We will discuss each separately.

Radial Systems

The radial pattern is the simplest and is usually the lowest cost alternative.

The essential feature of radial circuits is that they are supplied from one end only and do not connect to each other at the load end or in the load area. It is capable of many variations. It may be just a single circuit to a single load, or a single circuit along a street supplying loads distributed along it, or it may cover an area with few or many mains, branches or laterals as shown in Figure 6.

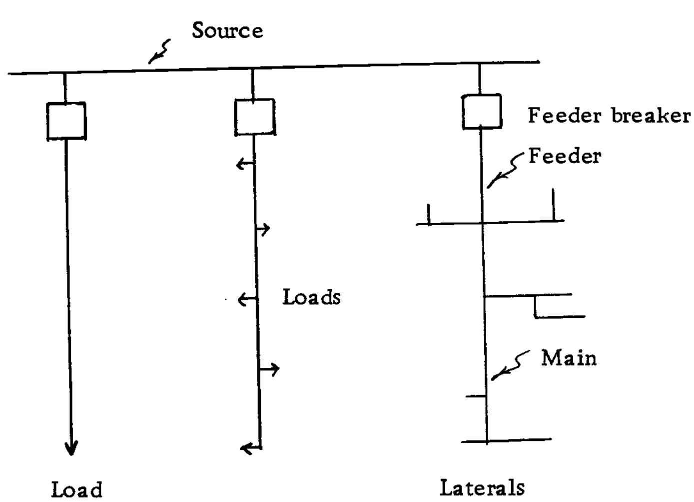

Figure 6. Radial type circuit.

Its chief disadvantage is the long time involved in interruption to service on the occasion of a cable or joint failure.

Several provisions are made to reduce the outage time and the magnitude of the load interrupted. Switches, circuit breakers or fuses may be used to reduce magnitude and time of outage on radial circuit. Such an arrangement is shown in Figure 7.

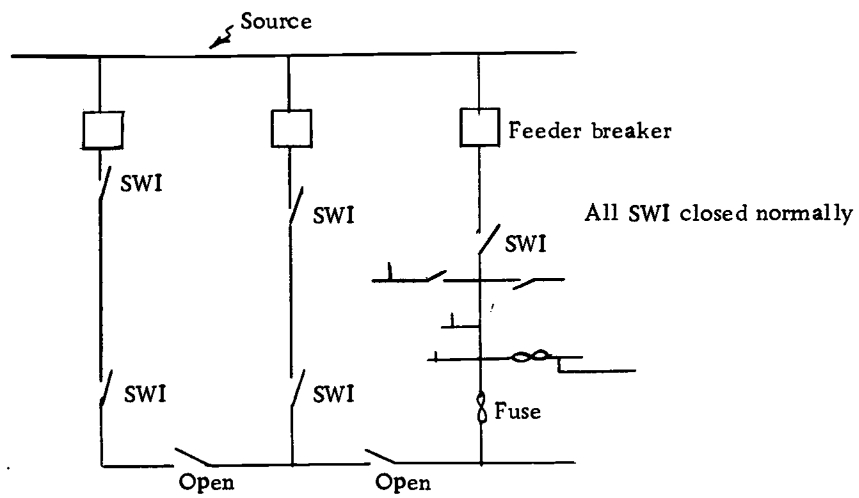

Figure 7. Use of switches, circuit breakers and fuses on radial circuits.

A further improvement in service can be made to individual loads, large or important enough to justify the added cost, by means of taps to two adjacent circuits. One switch is provided in each tap at the load or consumer. One of the switches is normally closed and the other is normally open. Upon the occurrence of an outage the load is transferred to the unfaulted circuit. This arrangement is shown in Figure 8.

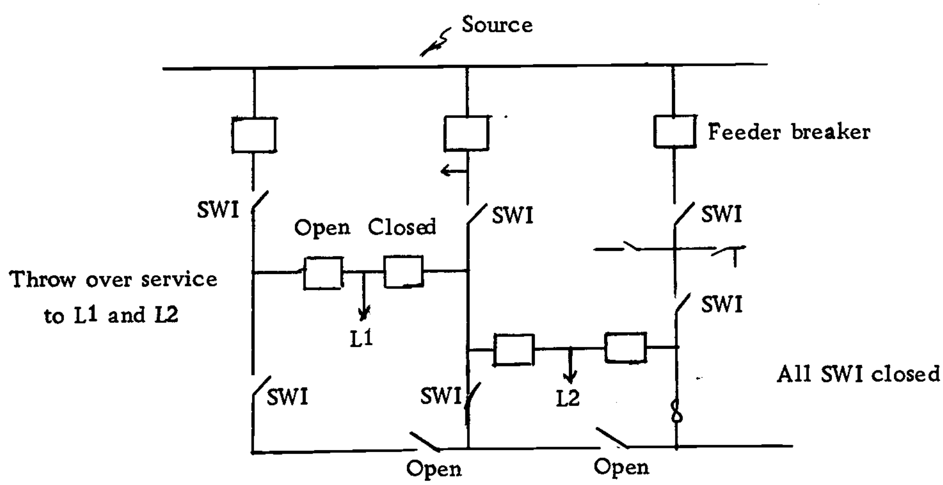

Figure 8. Throw over service to radial fed loads.

All transfer or throw-over schemes must allow enough thermal capacity in the circuits for the expected duration of outage. All can be used at any voltage level but the cost and space required for any of these means increase appreciably with increasing voltage. For this reason it becomes more important to abandon the simple radial system at medium-to-high-voltage levels in view of the greater load, length and area covered by high voltage circuits.

Loop Systems

The ring or loop system is one of the oldest and most popular patterns for the supplying of substations or large individual loads. Its advantages are:

1) Increased security of service.

2) Reduction in the stand by plant.

3) Economy obtained by dividing the total load in such a way as to reduce the total capital cost and running costs to a minimum.

Loop system is essentially a single circuit run successively to two or more individual loads which then returns to its source. It may be sectionalized by switches or circuit breakers located in its incoming and outgoing lines at each individual load, as shown in Figure 9.

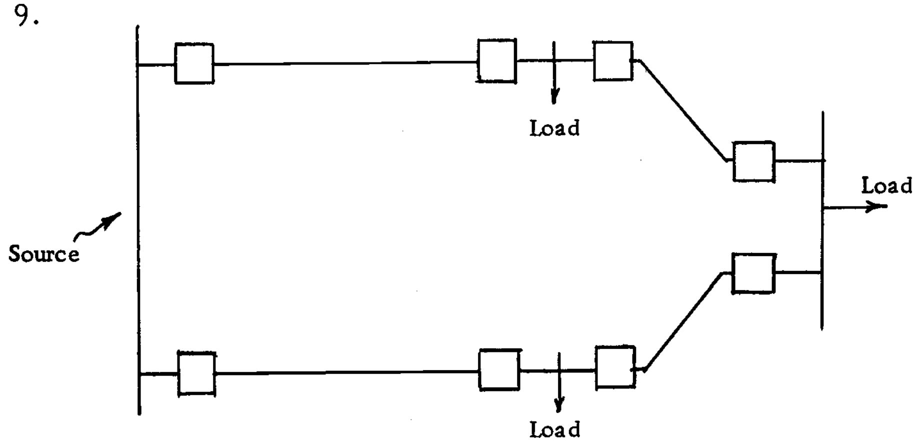

Figure 9. Loop circuit by connecting the ends of two simple radial circuits.

The switches or circuit breakers may be manually operated, controlled by pilot wire supervisory systems or automatically operated.

A fault on either of the cables between the sub-station and the first load imposes the total load current on the remaining cable. The emergency current is thus 100 percent greater than the normal current. Special emergency ratings will help to reduce to some extent the cable cost. The loop has the advantage that it can reach several loads and given uninterrupted service upon the occurrence of a single cable fault by use of suitable relays and circuit breakers.

Further growth in load within the area covered by the loop can be economically provided for by reinforcing the loop. This is a simple process of running additional feeders to particular points and feeding into the loop as indicated by the anticipated load distribution in the area.

Figure 10 shows two such reinforcements for two new substations and greater loads at the initial sub-stations or consumers.

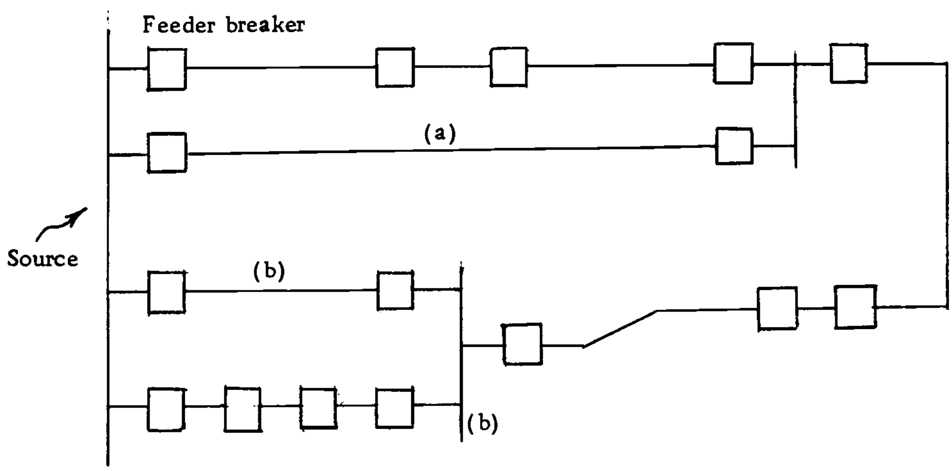

Figure 10. Reinforcing a loop circuit by two feeders.

The average loading per circuit was 50 percent in Figure 9 which, neglecting effect of cable impedances and unequal load distribution, increases to 67 percent with reinforcement (a) and 75 percent with reinforcement (b). A fifth reinforcement will raise this to 80 percent, indicating a diminishing economic benefit with attendant complications discouraging a continuation of the reinforcement process. It would be better to break the loop up into two loops at the time of the fifth reinforcement. Figure 11 shows an arragement for the sixth reinforcement.

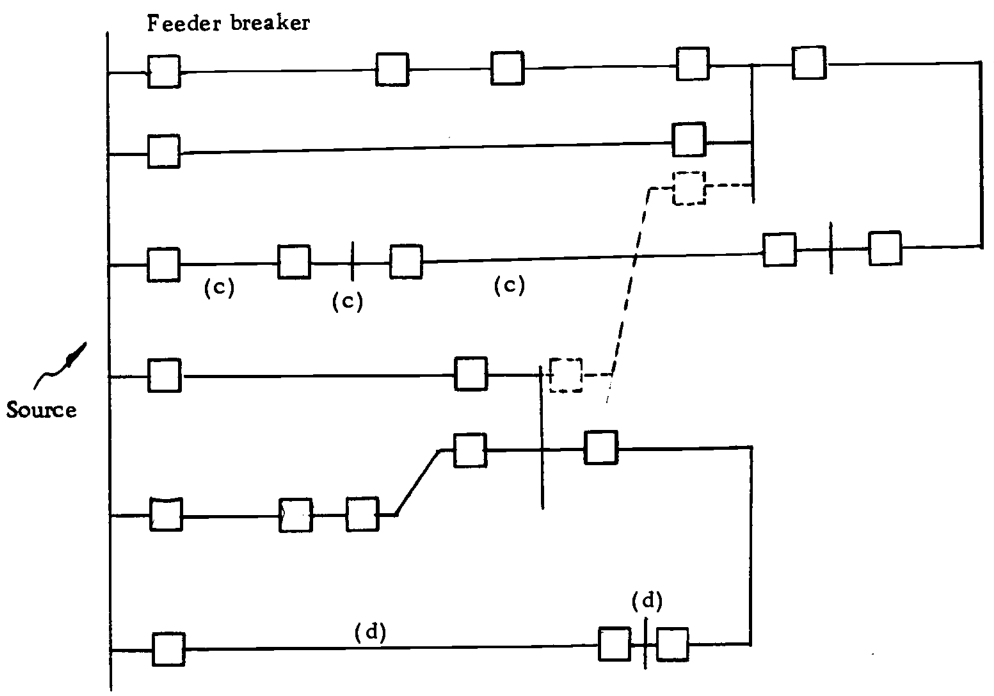

Figure 11. Two reinforced circuits with emergency tie line.

The two reinforced loops should be operated separately to conserve simplicity and reduce short circuit duties. The lines between loops normally operated open can be used effectively to improve average loading by being closed during emergencies or other conditions that require a cable removal.

The reinforced-loop concept can be employed to build up load area systems to great magnitudes depending on the voltage level employed. For example, on the basis of emergency rating Figure 10 could carry:

13.8	kv	30,000 kva
34.5	kv	75,000 kva
69	kv	150,000 to 300,000 kva
138	kv	600,000 kva
230	kv	1,200,000 kva

depending on the type of cable and its maximum loadings.[6]

As indicated in Figure 11 the system development could be carried on indefinitely. Cable impedance and load distribution may force lower average loadings in practice than those indicated here. Such reinforced loops do however, present difficult relaying problems with ordinary overload-reverse power relays but are practical with modern pilot wire or distance type relays. Too many substations in series become impractical with overload-reverse power relay systems and pilot wire may have to be used if it becomes necessary to have many stations in series. Care must be taken to consider this factor with one of the circuits out for any reason in a reinforced-loop system.

It is obvious that these individual reinforced loops also have several feeders that could be used to feed sub-stations that do not need

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[6]We will discuss this issue a little bit later.

high-tension buses or switchgear as indicated in Figure 12.

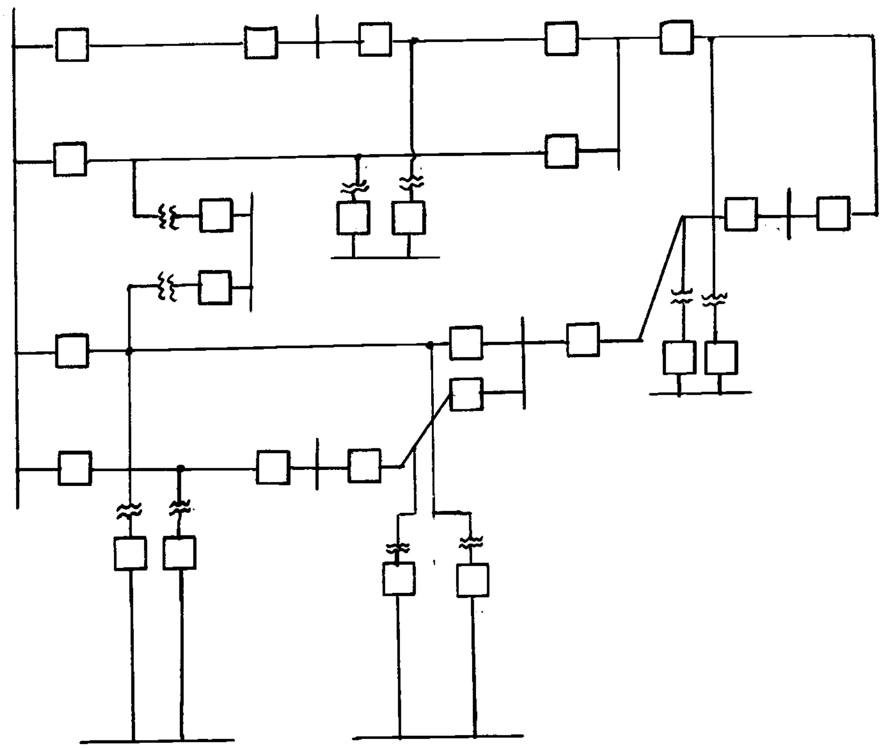

Figure 12. Reinforced loop for multi transformer bank that do not require high voltage switchgear.

Obviously, attention needs to be given to loading, load division and relay problems as more loads are tapped to these lines. Figure 12 is merely illustrative of possibilities.

Network Systems (7)

Network systems are conveniently discussed under three voltage classifications. These are secondary, primary and sub-transmission. We will discuss each separately.

a) Secondary Network System: The secondary network system is essentially a grid system like its predecessor, the d. c. Edison network system. A typical network system is shown in Figure 13.

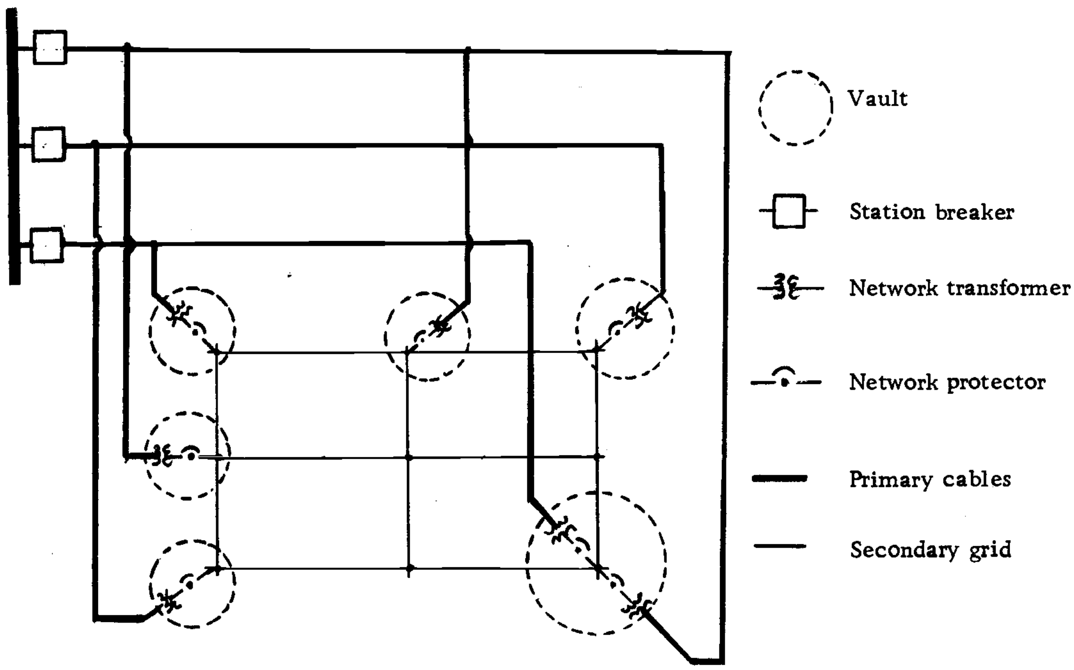

Figure 13. A typical network system.

The economy of this system is apparent when compared with an alternative system capable of giving equally satisfactory service. Loop or radial systems with automatic throw over could not provide the same degree of continuity of service without a greatly increased investment requirement. Much of the savings that made this system as universal was accounted for by its ability to use the generated voltages of 11-14 kv and save a transformation.

The secondary mains are single-conductor cables that depend for fault clearance on self-clearing characteristics of low voltage cables, or reduced copper sections called "limiters."

These features provide a higher order of service than obtainable with other systems commonly used to supply large and small distributed loads. Figure 14 shows how large individual loads are supplied with the same equipment as used in street vaults. Such individual vaults may or may not be in the network area and may or may not be interconnected to the network through low-voltage ties if they are in the area.

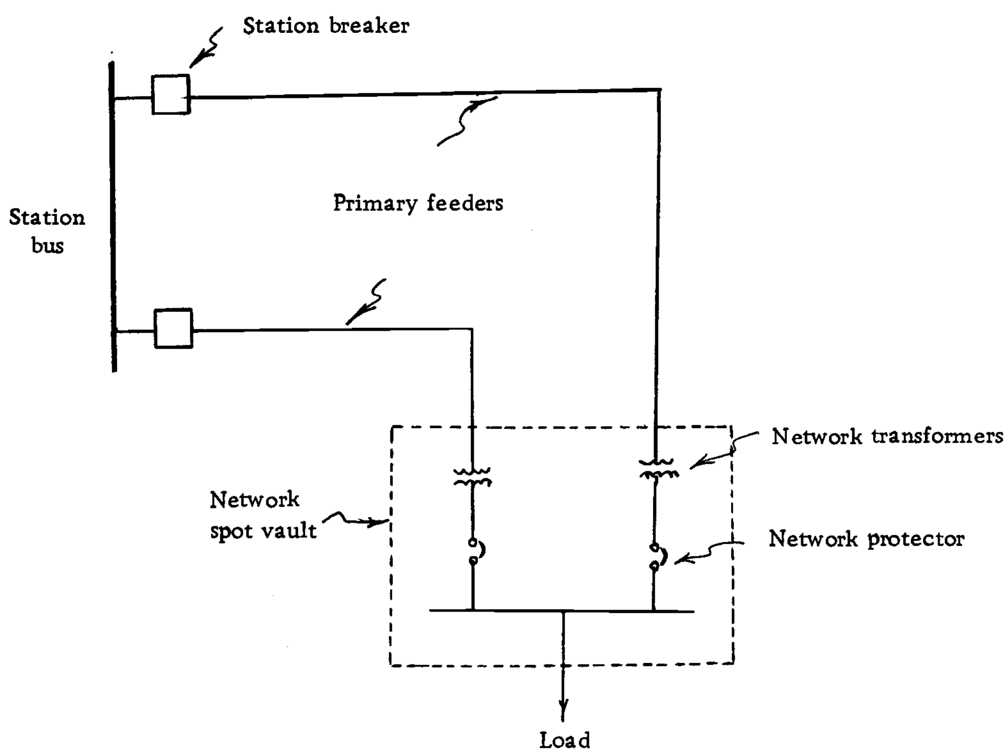

Figure 14. A typical spot network for large individual load.

Interposing additional transformers of like size between existing transformers on existing secondary mains provides economically for the first stage of reinforcement of a network. The second stage is handled by increasing the standard transformer size and installing additional secondary mains in parallel with the original mains. During both the first and second stages large spot loads are accommodated from multiple-unit vaults essentially self-sustaining but tied in with the street mains for what measure of mutual support is available.

The plurality of feeders and transformers feeding a common set of low-voltage mains gives many operating advantages in the event of primary cable or transformer faults. Primary repairs and extensions are normally made during regular working hours by taking the affected circuit out of service while the loads are carried by the remaining circuits supplying the network. Transformer repairs, replacements and additions are handled similarly. Secondary mains are normally maintained and reinforced without de-energizing.

The size of secondary network systems is usually limited by the ability to energize at one time all or a sufficient number of primary feeders in a case of a complete netowrk shutdown. With a higher primary voltage, the network size can be greater because the same number of cables carry much more load.

b) Primary Network System: Primary network systems are similar to secondary networks in that they have a plurality of feeders but differ in that the primary mains are not self-clearing like secondary mains and therefore require circuit breakers on each end of the mains. They have similar advantages of uniformity of sizes for cable mains and transformer sub-stations and the omission of high-voltage buses with switchgear. The plurality of feeders also gives similar operating advantages. Their economy comes about by being able to substitute substations for primary feeders of equal or larger rating at the feed point of a set of mains where the primary feeder from a distant substation would otherwise terminate. This feature must save enough in 4 kv feeders to pay for the extra mileage of the 12- to 34.5 kv subtransmission supply plus extra substation costs. In as much as secondary networks are applicable in most underground areas, primary networks are rarely used in such areas.

c) Sub-transmission Network System: Sub-transmission network systems are unlike either secondary network or primary network systems. They are usually the result of a continual expansion of earlier loop systems, particularly where they were started at generator voltage level of 12 to 14 kv. The necessity for low-impedance ties between generating stations is likely to result in interconnections between them that are essentially network ties in character. Higher voltage levels, such as 69 to 138 kv, in these underground areas are, however, likely to result in some kind of reinforced loop or a backbone linear type of system consisting of several parallel lines. It is evident that reinforced loops illustrated in Figure 9 through 12 are network systems in miniature and serve equally well for any voltage level as sub-transmission networks while possessing load carrying abilities of the loop system.

Modified Loop and Radial Systems

Figure 15 shows a loop system with one higher voltage circuit breaker at each substation.

A cable failure is cleared by the operation of two of these breakers and two transformer low voltage breakers.

Figure 16 shows a radial type of high voltage supplying the same sub-station but with an extra length of line which is required to give the duplicate feed provided by the loop with circuit breakers. This trading of line for circuit breakers may be uneconomical at light density because of the long length of line to be added. At high density, however, the lines may become short enough to trade cables for circuit breakers, particularly if very high short-circuit duties are involved or sub-station space is expensive or restricted.

There are many other modifications, but these two serve to indicate the points of difference and dependence on certain features related to load density for their economic justification.

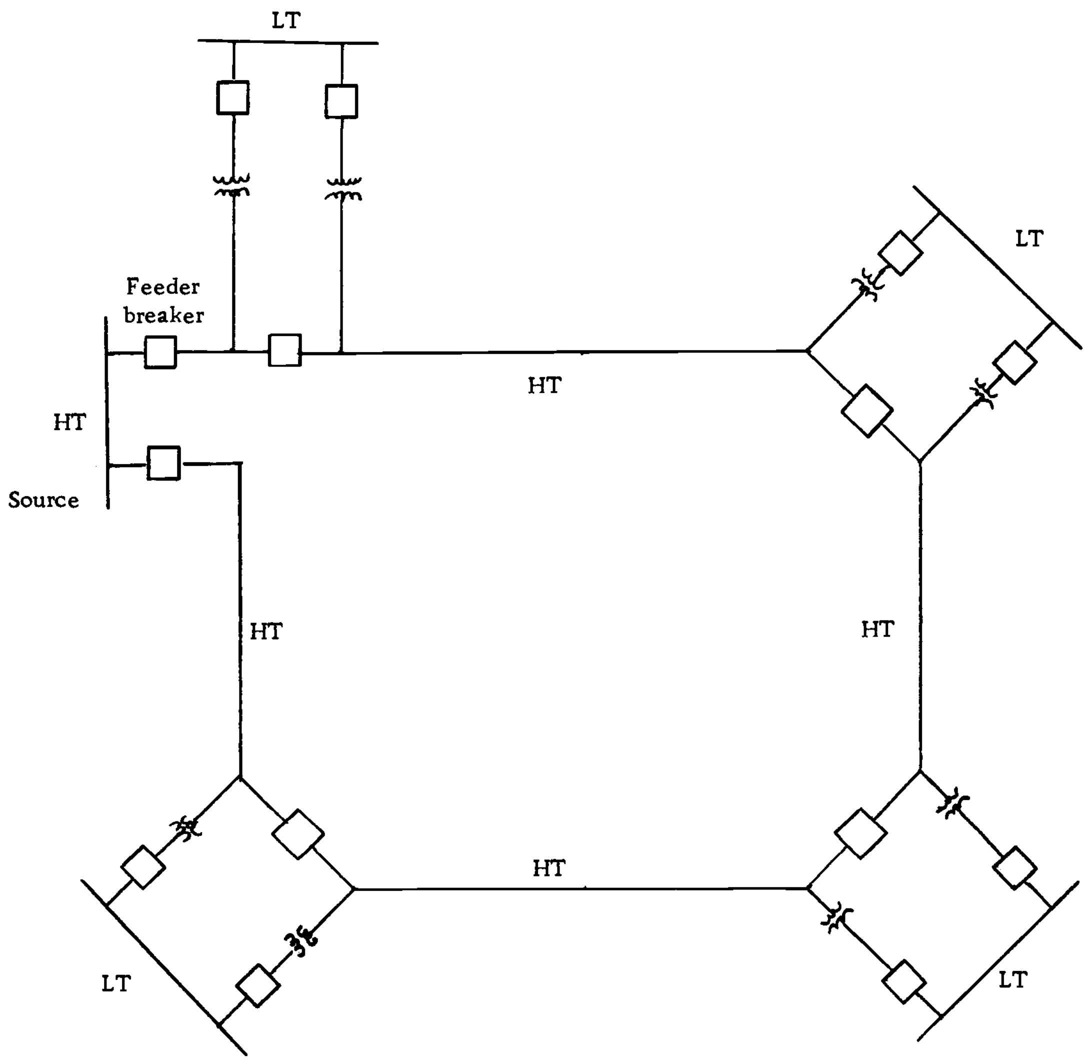

Figure 15. Loop system for subtransmission, using circuit breaker for throw over.

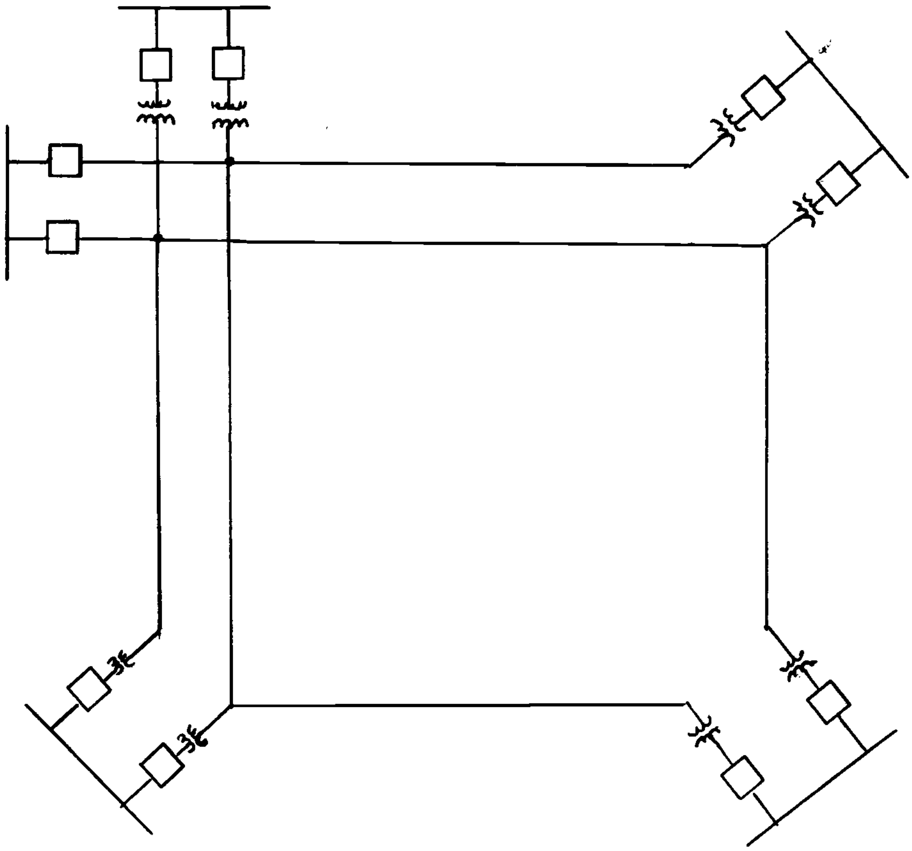

Figure 16. Loop system for sub-transmission using additional feeder in place of circuit breakers.

Choice of System

The preferred type of sub-transmission and distribution facilities for serving additional customers or new developments is dependent to a large degree on the existing systems available in the area, adequacy of existing sources and lines and the type of buildings, ground and streets associated with such developments. For average residential areas and light commercial and industrial districts, overhead lines provide reliable service at reasonable cost and provide a high degree of flexibility for future expansion to meet growing demands for electric service. Large blocks of load or areas of high load density require special consideration, and in view of the greater revenue in such cases, underground distribution lines, although considerably more expensive, may be justified on the basis of reasonable return on the larger investment. In areas normally supplied by overhead lines, underground service, possibly of a simplified type, may be sufficiently attractive to customers that they may elect to bear all or some portion of the cost to obtain the desired type of installation.

The need for underground lines in a particular area is dictated by local conditions or municipal requirements. The choice of type of system is dependent largely upon the class of service to customers in relation to cost. Underground installations are preferred by electric utilities in high load-density areas and along the routes of important electric lines where the number of circuits would, if installed overhead, result in undesirable congestion. In some cases, the underground lines may be more economical depending on the number of circuits to be installed. Underground lines may, in fact, be the only practical means of supplying large blocks of load in certain areas.

Each of the ring, loop and network systems has distinctive characteristics and require special engineering treatment. It should be noted also that functional differences as well as relative importance, and amount of load served, will determine design requirements.

Design Objective (7)

If a dependable system is to result, its component parts, such as transformers, cables, accessories and connections, must be reliable and adequately protected from operational hazards inherent in underground installations. These hazards include tree roots, lightning, corona discharge and leakage current, entrance of moisture, freezing, corrosion, damage from digging, and attack by animals, insects and microbiological organism. The design will be influenced by the number and degree of various hazards present.

The quality of service with respect to continuity and voltage should be equal at least to that provided by the usual overhead system. The installation should make maximum practicable use of overhead system components, particularly transformers and switching equipment, in the interest of low cost, simplification and adaptability to operation by the normal operating personnel, whose training and experience often centers around overhead system practices.

Features which may be included to provide convenience and flexibility of operation are:

1. System capable of keeping up with load growth without

replacement of cables.

2. Service restored without digging, preferably by an overhead trouble man, through some of the following:
   a. Convenient locations to connect temporary portable cables to by-pass faulty sections;
   b. Primary tie and sectionalizing points;
   c. Secondary tie and sectionalizing point; and
   d. Transformers easily replaced.

The cost should be minimum consistent with the foregoing considerations. In evaluating the comparative cost of underground and overhead facilities, proper weight should be given to certain operational advantages of the underground system. Ordinarily, underground installations are not subjected to major damage and prolonged outages from severe storms to which overhead lines are susceptible. Continuity of service to sections of underground distribution which are supplied from overhead lines may still be related to overhead line hazards, but, generally speaking, they avoid the extraordinary costs and manpower requirements associated with problems of service restoration and repair over wide areas and under emergency conditions. It must be remembered, however, that when failure does occur in underground cables, the time required to locate and repair a fault may be considerably greater than in the case of most kinds of damage to overhead lines. Tree-trimming costs, which often are important items of installation and maintenance expense on overhead lines are avoided through use of underground distribution.

3. DISTRIBUTION MATERIALS AND EQUIPMENT

Introduction

If a dependable distribution system is to result, its component parts, such as cables, transformers, circuit breakers, accessories and connections, must be reliable and adequately protected from operational hazards inherent in underground installations. We give now an account of the component parts and installation procedures as broad guidelines for selection.

Cable Conductors, Insulations and Mechanical Protection

After it has determined that a cable system is necessary for a particular application it must be decided what type of insulation, conductor, sheath material and sheath covering should be specified and whether an installation in ducts, buried directly in the ground, or on poles would most satisfactorily and economically meet the service requirements. The amount of power to be transmitted and the distance involved will influence the choice of voltage and the type and size of the conductors to use. The area through which the cable passes will largely determine the type of cable system and the sheath covering to use.

1) Conductors: The load to be carried by the cable influences

to a large extent the type and shape of conductor. The principal factors to be considered in the selection of conductors are:

1. Materials
2. Flexibility
3. Shape
4. Size.

The conductor shapes in general use are round, sector, annular and segmental. The shape of the conductors determines the size and influences the current-carrying capacity and has some effect on flexibility. The selection of conductor material for insulated conductors principally is one of economics, taking into consideration:

1. Availability
2. Initial cost
3. Operating costs
4. Salvage value
5. Conductance per area of ductway
6. Jointing and terminating facility
7. Oxidizing tendency
8. Coefficients of expansion
9. Thermal (burnoff) characteristics
10. Internal chemical reaction between conductor and insulation.

Because of its high conductivity, ready workability and ease of handling, annealed copper (tinned or lead-alloy coated when used with rubber insulation) generally is used for insulated wires and cables. Medium hard-drawn copper may be used to advantage for special installations; for example, rubber- or varnished-cambric-insulated, vertical-riser cable in a sky-scraper or mine, terminated with a special unit for suspension by the conductor.

Aluminum has gained in use recently, because of its availability but principally in service drop and secondary distribution cables and, to a lesser extent, for use in low-voltage building wires and cables. There is no objection to its use in underground insulated wires and cables, provided it is properly engineered and satisfactory provision has been made for joining and terminating.

When greater flexibility than that of solid wire is desired for a given conductor cross-sectional area, a number of wires are stranded together to give the desired conductor size. The larger the number of component wires, the greater is the flexibility, other things equal. Naturally, the cost of a given conductor size increases with the number of strands used due to additional drawing and stranding operations. In some cases a choice of two or three degrees of flexibility is offered. Unfortunately, there is no simple method for determining the degree of flexibility of a stranded cable. Accordingly, the specification of proper stranding is largely one of judgment and experience.

The conductor size primarily is determined by two considerations:

1. Voltage drop

2. Current carrying capacity.

Voltage drop is calculated by conventional methods and usually is a limiting factor only for small conductors and utilization voltages. Current-carrying capacity is dependent upon the permissible operating temperature of the insulation and the installation conditions.

2) Insulations: The three most common materials used as insulation for power and control cables are Rubber (Natural and Synthetic) compounds, Varnished cambric and Impregnated Paper with the Polyvinyl Chloride and Polyethylene gaining recognition as suitable for low voltage service. Which one of these materials is best suited for a specific cable depends upon many factors, such as operating voltage, current load, ambient temperature, type of installation (i. e., aerial, underground ducts, direct earth burial, submarine, etc.), type of outer coverings, cable first cost, installation cost, skill of available workmen and cost of accessories. To these must be added the safe maximum operating temperature for the insulating materials, the essential electrical properties and the rate of deterioration, physically and electrically, which may determine the service life of the completed cable (7). We will discuss different materials separately, now.

a) Rubber (Thermosetting) Compounds: The word "rubber" includes natural and synthetic rubbers. Rubber compounds are "thermosetting," i. e., they require vulcanization to attain the necessary electrical and physical properties essential for electrical insulation. The two principal types of synthetic rubbers used in electrical insulation are Buna S (GR-S) and Butyl (GR-I) with occasional use of Neoprene (GR-M) and Buna N (GR-A). Each type has its own special property that makes it particularly adaptable for specific insulation demands such as heat resistance, superaging, low moisture absorption, ozone resistance, oil resistance, flame resistance, etc.

Table 1 shows some of the comparative inherent properties of the synthetic and natural rubbers (7).

Rubber compounds used for electrical insulation may contain as little as 20 percent or as high as 90 percent rubber. The balance of the compound consists of suitable organic or inorganic materials which facilitate manufacture and develop desirable properties not possessed by the rubber alone. The ultimate physical and/or electrical properties of the vulcanized rubber compound depends largely on these "other materials." One rubber technologist list 185 vulcanizing materials, 87 protective materials, 349 processing materials, 120 reinforcing materials, 159 loading materials, 91 coloring materials and 193 miscellaneous materials--a total of over 1100 "other materials" that may be used in rubber insulating compounds.

Because of this wide variety of materials that is available, a rubber insulating compound may be tailored for the ultimate service

Table 1. Comparative properties--synthetic and natural rubbers.

Type	Buna S (GR-S)	Buna N (GR-A)	Butyl (GR-I)	Neoprene (GR-M)	Natural
Base or source (see notes)	(1)	(2)	(3)	(4)	(5)
Specific gravity	0.94	1.00	0.91	1.25	0.93
Aging--Sunlight	Fair	Poor	Excellent	Excellent	Poor
Oxidation	Good	Fair	Very good	Very good	Good
Heat	Fair	Good	Excellent	Very good	Fair
Resistance to compression	Fair	Good	Fair	Fair	Good
Oil resistance	Poor	Excellent	Poor	Good	Poor
Moisture resistance	Good	Poor	Good	Poor	Poor to good
Flame resistance	Poor	Poor	Poor	Good	Poor

(1) Copolymer of butadiene and styrene
(2) Copolymer of butadiene and acrylonitrile
(3) Copolymer of isobutylene and isoperene
(4) Polymerized chloroprene
(5) Hevea brasiliensis trees.

conditions--low dielectric constant for communication cables, low power factor and ozone resistance for the high-voltage cables, heat resistance for high temperature service, sunlight resistance where exposed, and flame resistance where fire is a hazard.

b) Varnished Cambric: Varnished cambric is a closely woven cotton cloth, both sides of which have been coated with several layers of insulating varnish. Tapes of varnished cambric are wrapped helically around each conductor. Between the layers a viscous, moisture-repelling, nondrying slipper compound is used. The electrical properties of this compound are compatible with those of the cambric itself. Its viscosity at operating temperature retards migration but does not hinder the slipping of the tapes one upon the other when the cable is bent. Varnished cambric insulation has moderately high dielectric and impulse strength, is ozone, corona and oil resistant. Cables insulated with varnished cambric have a tendency toward high dielectric loss, high power factor and low ionization level. This is generally accredited to the fact that the wall of insulation is made up of tapes with resultant voids and entrapped air which are conducive to these objectionable features in a high voltage cable insulation.

Because it is not harmed by mineral oil, varnished cambric insulation is used extensively in transformers, oil switches or any other electrical equipment where the insulation is exposed to oil. Varnished cambric insulation is used on cables ranging from 600 to 23,000 v.

c) Impregnated Paper: Impregnated paper is the most common form of insulation for cables used for bulk transmission and distribution of power, particularly for operating voltages of 13.8 kv and above where low dielectric loss, low power factor and low ionization are important factors in determining the cable life.

Impregnated paper insulation consists of multiple layers of paper tapes, each tape from 2.5 to 7.5 mils in thickness wrapped helically around the conductor to be insulated. The total wall of paper tapes is then vacuum dried and impregnated with an insulating compound. The quality of the impregnated paper insulation depends not only on the properties and characteristics of the paper and impregnating oil used but even more on the mechanical application of the paper tapes to the conductor, the thoroughness of the vacuum drying and the control of the saturating and cooling cycle during impregnation.

Originally, most of the paper used was of the Manila-rope fiber type which was erratic in its physical properties and not always susceptible to adequate oil impregnation. Increased knowledge of the chemical treatment of wood to obtain pure cellulose, of the adjustment of fiber content, the control of air resistance and the availability of long fiber stock, has resulted in the almost universal use of wood pulp paper in present-day cables.

The impregnating compound generally is a pure mineral oil or oil blended to obtain higher viscosity. Impregnated paper insulation has extremely good electrical properties, such as high dielectric strength--both impulse and at power frequencies, low power factor and dielectric loss, and excellent electrical stability over a wide range of operating temperatures. Because of these properties, the thickness of impregnated paper insulation generally is considerably less than for rubber or varnished cambric insulations for the same working voltages.

Impregnated paper insulation is very susceptible to deterioration due to water and hence must always be protected by a metallic sheath or other absolutely impervious covering if used where exposed to moisture.

d) Polyvinyl Chloride (PVC) and Polyethylene (Thermoplastics): Polyvinyl chloride (PVC), when compounded, is the thermoplastic most commonly used for low-voltage power and control wires and cables. Its electrical characteristics, principally its power factor and dielectric loss, limit its use to low voltages--600 v or less for general purpose wiring and 5000 v or less for series lighting circuits.

PVC is highly resistant to moisture, ozone, most chemicals and oils within operating temperature limits, flame resistant, and can be supplied in a variety of colors. It does not require outer protective coverings and is easily spliced or terminated.

Polyethylene is a thermoplastic quite different chemically and structurally from PVC and has quite different electrical and physical properties. Polyethylene undoubtedly has the best electrical properties of any of the so-called solid homogeneous dielectrics.

The low power factor and dielectric loss, high dielectric and impulse strength, and stability of electrical properties over a wide range of temperature and voltage stress, all inherent in polyethylene as a material, make it interesting as insulation for high-voltage wires and cables. It is a material that is very susceptible to environmental conditions above 70 C and has a critically sharp softening point at about 110 C.

Polyethylene is the most stable electrically of any of the solid dielectrics when exposed to or immersed in water, and also the best of these insulations for operation on d-c negative. For this reason it is finding a wide usage in control and communication cables. Newer polyethylene compounds are being developed which, it would appear, will have improved characteristics.

"Thermoplastic" compounds differ from "rubber" compounds in that they do not require vulcanization to attain the essential physical and electrical properties for electric insulation. Table 2 shows some of the applications for the most common insulating materials (7).

For working pressure above 33 kv, cables are styled "super voltage" and are subject to specifications issued by purchasing authorities or their consultants. All "oil filled" and "gas-pressure" cables come under this heading (6).

3) Mechanical Protection: Since all the insulating materials used in the construction of cables are mechanically weak, some form of protection against mechanical injury is necessary (6). The protective coverings over the insulation on electrical wires and cables may be of several kinds or types; namely, fibrous, rubber and rubber-like (thermosetting), thermoplastic, and metallic. These coverings must meet certain requirements, such as flexibility, moisture proofness or moisture resistance to a high degree, ease of application, long life, in some cases good electrical properties and mechanical properties, so as to prevent damage to the cable during installation as well as while in operation.

For power supply with cables laid direct in the ground, this usually takes the form of an armouring of steel tape wound on in two layers so that the upper layer covers the joint in the lower layer. For surface installations this is very satisfactory, but it is very inflexible, and therefore not suited to installations where the bending of the cable

Table 2. Application of commercially available insulations.

Insulating material	Type	Maximum operating temperature deg C	Usual operating voltage range volts	Outstanding characteristics	Common applications
Rubber	R	60	Up to 600	Low cost	Residential and industrial building Wiring--not exposed to moisture
	RW	60	Up to 2000	Moisture resistant	Industrial wiring when exposed to moisture
	RH	75	Up to 2000	Heat resistant	Important commercial and industrial wiring and control cables where not exposed to moisture. Installation at high ambient temperature.
	RH-RW	60 wet 75 dry	Up to 2000	Moisture resistant for 60 C Heat resistant for 75 C	Where exposed to heat up to 75 C or moisture up to 60 C
	RHW	75	Up to 2000	Moisture and heat resistant for 75 C	Where exposed to heat and/or moisture up to 75 C
	RU	60	Up to 600	Can be applied in thin walls	Communication, signal, supervisory control cables
	Ozone resistant Oil base	75	2001-15, 000	Ozone resistant Good dielectric strength	High-voltage cables, station control and auxiliary power
	Butyl	80	2001-15, 000	Ozone resistant Moisture resistant	High-voltage cables
	Neoprene	60	Up to 600	Oil resistant Flame resistant	Industrial wiring where exposed to oil
Varnished cambric	--	85 at 600 V to 70 at 17, 000V	Up to 17, 000	Ozone resistant Oil resistant Moderately high dielectric strength	Generator, transformer and oil switch head Indoor cables for power plants
Impregnated paper	Solid type	70 to 85	Up to 69, 000	Low first cost	In underground ducts for transmission and distribution systems
	Gas filled	70 to 85	15, 000-138, 000	Low dielectric losses. Good stability	
	Oil filled	70 to 81	15, 000-230, 000	High impulse and dielectric strength	

Table 2. (Continued)

Insulating material	Type	Maximum operating temperature deg C	Usual operating voltage range volts	Outstanding characteristics	Common applications
Thermo-plastics	PVC	60	Up to 600 Street lighting to 5000	Excellent physical properties Low cost. Oil resistant. Flame resistant. Moisture resistant	Building wire--control and signal cables, low voltage only (600V)
	Polyethylene	75	Up to 5000	Excellent physical properties Excellent electrical properties Exceedingly high moisture resistance	Supervisory and station control cables Communication and signal cables Street lighting cables

cannot be avoided, e. g., in mines; also, owing to their lack of longitudinal strength, steel-tape armored cables are not considered suitable for installation on supports above ground. In addition there is a regulation to the effect that the armoring of a colliery cable shall have an electrical conductivity of at least 50 percent that of the largest conductor enclosed within the armoring. This prohibits the use of steel tape owing to its very small lay; and it is therefore necessary to use an armoring of steel wire. For very small cables a single layer of such wire is suitable, but for large cables a double layer is preferable, in spite of the fact that the necessary conductivity can be obtained by a single layer of larger-sized wire. This is because the double wire armoring renders the cable easier to handle and gives greater flexibility for the same conductivity. Double wire armoring is used chiefly for cables run vertically as in the mine shaft. The cable may be held in heavy cleats every few yards, or suspended from the upper end by means of a cone clamp which grips the armor wires. With regard to ordinary main cables an aluminum sheathing has been recently introduced. This does not need armoring, and is usually finished with watertight protection such as rubber sandwich or a covering of PVC.

Cable Joints and Terminations

Typical splicer's tools and equipment can be found in any manufacturer's manual. The providing of proper tools and equipment will insure a better quality of workmanship and increase the over-all efficiency and safety of the splicing operations.

The designs of joints and terminations are based primarily on two types of dielectric stresses or voltage gradients:

1. Radial gradients
2. Axial or longitudinal gradients.

The longitudinal gradients are probably of greatest concern to all who design joints and terminations. They should be very carefully considered, since the type of insulation which can be applied in the field generally does not produce a homogenous dielectric strength in all planes. The permissible longitudinal gradient in a given design can obviously be affected by the type of material used, method of application, skill of the splicer, maximum operating temperatures, possibility of compound migration, or the application of a positive gas- or oil-pressure medium.

Abrupt changes in section of insulation in joints and terminations must be avoided if the voltage gradients are to be kept to a minimum. The shaping of built-up insulation to form stress relief cones and the stepping of insulation are the means of controlling the gradients in various sections of the joints and terminations. The shape of the built-up type of insulation can be designed to control both longitudinal and radial gradients to suit the particular joint or terminations.

Mathematical formulas are available for calculating the shape of a particular design to keep the various gradients within desired limits. These calculations result in curved surfaces of the log-log type. This degree of accuracy is generally not necessary in joints and terminations rated up to 69 kv.

Joints and terminations designs can be made which will keep the material and space requirements to a minimum. However, these restrictions may require extreme care in installations and high working stresses which may not be practical for the general working conditions and type of splicing skill available. The most desirable design is one in which simplicity and ease of construction are combined with adequate allowance for considerable variation in splicing skill. Adequate space should be allotted for proper forming of the cable conductors in the joint or pot head to prevent damage to the insulation. The designs should facilitate simple and reliable joining of the cable conductors in joints and the cable to connector in potheads to prevent thermal damage of the insulation because of high-resistance connections.

Insulations having high dielectric losses should be avoided unless such materials are used at a relatively low stress, since such losses in a mass of solid insulation tend to produce local heating with corresponding higher losses and more heating until serious deterioration takes place. The use of these materials may be desirable because of other properties and they can be employed safely if the voltage gradients are low and the losses are kept within safe limits.

The designs should be made to reduce the possibility of void formation in the insulation during installation or subsequent filling and operating conditions. This is especially important in the designs for higher voltages. Where there is the possibility of trapping air due to the design of special mounting positions, provisions should be made for evacuating the joint or pothead to remove occluded gases. Adequate facilities for flushing and filling should always be provided, including filling under vacuum in the case of the higher-voltage designs. The physical design should be adequate to withstand all the mechanical stresses which can be anticipated in service. The external materials used should be able to resist deterioration by the elements and corrosive atmosphere. The materials employed in the designs should be proven and of the highest quality and, in the case of gaskets, should have low cold flow, long life and high oil resistance.

The ideal cable joint is one which embodies all the electrical and mechanical characteristics of the cable. To prevent overheating, the conductor ends must be joined by a connector which provides conductivity equivalent to that of the conductor.

Special-type joints in the secondary voltage class are the prefabricated multiple branch joints variously designated as crabs, moles and multitops. Joints in heat-covered paper-insulated cables are covered with a lead sleeve wiped to the cable sheath and filled with compound. It should be noted that untinned copper is subject to corrosion when it is exposed to the sulphur present in a rubber insulation.

In case of lead covered cables, the joint sleeve should be pressure tested with nitrogen gas to assure that the wipes are not porous, as moisture will cause failure.

As the voltage at which the joint must operate increases, the design stress must increase to avoid joints of prohibitive size. The design of the joint then becomes more complicated with a greater number of steps in the factory insulation, sometimes of varying widths and heights.

When designing a cable joint, the objective is to produce a joint as strong electrically as the cable in which it will be installed. Determination of the safe values of stress for the various insulations used in joints must of necessity precede intelligent designing of a cable joint or termination. When insulating materials with different permittivities and dielectric strengths are used in the same joint, care must be exercised to avoid over-stressing the weaker materials. Abrupt changes in joint profile will distort the dielectric field and may cause dangerously high radial and longitudinal stresses.

Table 3 shows the maximum radial and longitudinal stresses permitted in the insulating materials used in the construction of joints. It is recommended that, in practice, radial and longitudinal

Table 3. Stresses in hand applied cable joint insulation.

Material	Recommended Maximum Radial Stresses, Volts per mil	Recommended Average Maximum Longitudinal Stresses, Volts per mil		Recommended Maximum Average Stresses Along Creepage Path, Volts per mil
		At Shoulder of Connector	Elsewhere in Joint	
Varnished cambric	50	12	6	3
Impregnated crepe paper	60	12	6	3
Rubber	45	12	6	2

stresses be kept below these values.

In case of joining rubber and paper insulated cables great care should be taken to save the oil from the paper insulation from affecting the rubber insulation. Sealing the paper insulation is particularly difficult with these conductor cables. Oil from the paper insulation can travel through the connector and damage the rubber insulation. A barrier must, therefore, be provided in the center, even with soldered connectors.

The thicker insulation walls of higher-voltage cables hold more cable oil. Because of differences in elevation and temperature the oil migrate uniformly along the cable causing the pressure differentials. These pressure differences may cause swollen or collapsed joint casings and split cable sheaths. The severity of trouble from this source depends upon the thickness of the cable insulation, the prevalence of longitudinal channels in the cable through which the oil may migrate and the amplitude of frequency of the temperature cycles.

Materials used in constructing joints[7] and terminations should be of the highest quality obtainable. The differential in cost between average and optimum grades is negligible in comparison with the over-all cost of installation. The importance of obtaining the best in

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[7]As connectors, Crab Joints and Limiters, insulating materials, filling materials, joint sleeves, solder, shielding tape, accessories such as nitrogen gas feeding equipment, reservoirs, etc.

reliability and performance can hardly be evaluated.

Splicer's tools and equipment are geared to the needs of the individual company. The need of each company is different and depends on a number of factors such as;

1. Climate
2. Type of system, direct buried, duct etc.
3. Selection of pattern
4. Selection of voltage.

However, it should be noted that the handles and metal parts of many of the tools are insulated. These may be purchased from the manufacturer fully insulated or they may be insulated in the shop with rubber or varnished cloth tapes. When insulated tools are used, tested rubber gloves should be worn.

Cable Installation

The manner in which cable is installed greatly influences not only the immediate cost of the installation but also the operational reliability and service continuity of the cable system.[8] Accordingly, close attention to the problems involved in installation will prove rewarding.

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[8] 12 kv cable installed in Portland in 1901 is still in good condition for use. (Courtesy of Al J. Cardelli, Pacific Power and Light Co., Portland, Oregon.)

The cost of transporting cable reels to and from a job site can be both considerable and repetitive. The tendency toward longer cable sections results in larger and heavier reels. Cable reels weighing 4 to 6 tons are not unusual, and in instances of steel-armored cable the size and weight of reel will be considerably greater. Economical handling requires the right kind of hauling and handling equipment.

The amount of cable in stock and the handling between the storage yard and the job location are important items in the total cost of cable installation. The total stock should be kept as low as possible, but enough lengths must be available for choice in selection to avoid waste and for scheduling of the work without delays. The control, secondary and lower-voltage cables up to 12 kv can be ordered in long stock length of 1200, 1500, 2500 or 5000 ft, depending on size and weight, and the requirements fitted into this stock. Practically no waste and no accumulation of short lengths will occur with this method when enough attention is given to the assignments.

The long lengths can be sent to the field where the cable will be cut as the required amounts are installed at assigned locations. Another method is to set up the reels with the long lengths in a cable shop where the required lengths are cut as the cable is rereeled. The second reel is then sent to the job location with the correct amount of cable. While this requires some extra handling in the shop, a saving is made as the shop crew is smaller than the pulling gang which will be involved in the cutting, sealing and lugging operations at the job site. The lagging also is removed from the factory reel in the shop and is not installed on the reels sent to the field. This saves the time otherwise required for the pulling gang to remove and to reinstall or bundle the lags. The saving in time by the elimination of the several operations of cutting and sealing the cable, of installing a pulling lug on the cable left on the reel and in handling the lags will often result in the installation of an additional length of cable for the working period.

In most cases, cable reels are hauled considerable distances from the factory to the places where they will be used. Because of the possibility of damage, the cable should be inspected as soon as possible after its receipt. If the reels have been knocked loose from the blocking, rough handling is indicated and the carrier's representative should be brought to the location to view it before the conditions of receipts are changed. If the lagging on a reel is broken, enough should be removed to determine whether or not the cable has been damaged. If there is damage, the manufacturer's representative should be informed immediately. The new cable should also be inspected by the men in the pulling crew as it is being installed. They should watch for cracks, gouges, flat spot, scratches or other defects or injuries to the lead sheath. When wooden reels are used there may be no nails on the inside of the flange that would damage the cable if they were not removed before unreeling.

The number of men in a pulling gang will vary greatly because of local conditions. Where a large part of the gang's time is spent in traveling, the number of men should be relatively small. On the other hand, when the time occupied in pulling is proportionately great and the pulls are within a small area, the number of men in the gang can be increased economically. Where there are enough service installations, a small gang can be organized for this purpose only. One method is to have a driver with a small truck, equipped with necessary pulling tools, meet a two-man crew at the service location. The two men assist the driver to install the service cable and remain on the job to make the connection while the driver takes the truck to another location, where he is assisted by another service connecting crew of two men. Crews that travel long distances will have 4 to 6 men. Heavier pulling will require 9 to 13 men including the foreman and truck driver. The men are assigned to the several operations of rigging, winch operation, reel set-up, cable feeding, cable inspection, application of lubricant[9] and other tasks.

Time and saving devices adopted in the last few years have made it possible to reduce the number of men on the pulling gang.

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[9] For duct systems.

Mechanical equipment has been provided for both ends. The two-unit combination of truck and trailer, or tractor and semitrailer speeds up the work by having a complete unit located at each manhole. The work at these two locations can thus proceed in parallel rather than in series. Winches are provided at each end. At one manhole a winch is connected to the galvanized iron wire which was left in the duct by the rodding[10] gang to pull in the wire-rope pulling line. At the other end the winch on the truck is immediately available to pull the cable as soon as the wire rope can be connected to it. Electric reel movers powered by storage batteries, used at one manhole, also make it possible to move the reel into place with a smaller number of men. The most economical gang size and organization can best be determined by experience under the existing conditions. However, operating a gang with too few men can be as inefficient as having too many men. The productive capacity of a pulling gang depends to a large degree on the ability of the foreman to keep every man busy. He must assign each man to particular tasks and plan ahead to keep the job progressing.

As previously mentioned, cable installation practices vary widely, from the least costly direct-burial methods to the more expensive practice of cable in conventional conduit systems. The usual

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[10]For duct systems.

application for direct burial is in locations where the cable can be so placed that there is small probability of it being damaged or disturbed by local digging operations, and where it will be reasonably accessible for repair and maintenance. Satisfactory installation requires depth below the frost line. Depth of 30 to 36 in. are usual with 36 in. or more being favored for greater protection from digging and other underground operations, especially those associated with other utilities, such as sewer, water, gas, etc. It is important to bed the cable in soil which is free from hard objects like stones, clods of hard earth, etc. Soil may be screened to accomplish this result. Layers of sand above and below the cable may be used for this purpose.

When more than one primary cable is laid in the same trench, the cables may be laid side by side without any special effort to maintain separation. Where it may be necessary to work on one primary cable in the same trench with others which are alive, it is considered good practice to provide definite separation of 6 in. or more. If ducts are used, the cables which it is desired to keep separated are placed in separate ducts. Primary and secondary cables in the same trench may be separated by being laid on opposite sides, or with the secondary placed directly above the primary, separated by 6 in. or more. The latter arrangement is advantageous in that the secondary cables are somewhat of a safeguard for the primary cables in case of excavation and the secondary cables can be uncovered for making service connection without risk of digging into the primary cables.

In many cases extra protection against digging is provided by some covering, such as treated planks 1 to 2 in. thick, concrete slabs or half-round tile. The use of such protective covering is a matter of judgment and opinion as to whether the reduced risk of cable damage is enough to justify the extra cost (7).

Where mechanical equipment is used for digging trenches, a depth of 36 to 42 in. is practical without undue cost. Trenches are narrow, usually just wide enough to provide room to lay the cable. Mechanical equipment which digs the trench, lays the cable and backfills, all in one operation, is now available for jobs of the type and size which would make such equipment economical.

With most direct-burial installations there will usually be certain special locations, such as under driveways, streets or specially landscaped areas, where the use of steel pipe or duct is advisable. In some cases, the pipe is pushed through without a trench being opened.

Buried duct, laid directly in the ground without concrete envelope, is favored by some for general use. This is advantageous where it may be necessary to replace cable without digging, for inaccessible locations or to avoid future disturbance of the landscape. Also, the duct provides some degree of protection for the cable. The duct may be continuous between two terminal points, such as two transformers locations, in which case the cable can be pulled in and out without digging. In other cases, small pits may be used at certain locations for pulling and making joints or for connections. These pits are backfilled with earth after the cable installation is complete. Then, for repair or replacement of the cable, it is necessary to uncover the joint and the duct ends in the pit. Handholes or shallow boxes for pulling and splicing are used sometimes when buried duct is installed without concrete encasement.

Conduit and manhole systems are used also for residential area distribution, usually in close conformity with conventional underground distribution practice. However, in cases where disturbance by installation of other underground facilities or by street and property improvements is unlikely, the concrete encasement may be omitted from the duct.

When low cost is an objective, choice of design with respect to the use of duct, or cable without duct, depends on the utility's point of view regarding operating requirements and quality of service in relation to costs. It is important to evaluate how the simplification will affect operating, maintenance and service restoration practices, especially over the long-term life of the installation. Adaptability of design, for handling increases in load and capacity additions must be considered. An important factor in many decisions to use duct in preference to directly buried cables has been the greater ease with which the cable can be replaced when required by unforseen load growth or other system developments.

It is essential for long life and uninterrupted operation that cables and joints be properly arranged and supported in manholes, and for this reason, the arrangement or training of the cable and the position of the cable supports should be planned before the manholes are built. Also, because of the direct and appreciable influence of manhole dimensions and cable training on cable life, the relationships involved should be carefully reviewed before any new cable is installed in existent manholes. It is advisable to install cable racks and supports before cable is pulled into the ducts in order to minimize the possibility of injury to the cables between the time of installation and the time of jointing.

The location of cables in manholes is determined to a large degree by the ducts they occupy. The cables should always be fanned out from the duct mouth so as not to cross other ducts or cables. This makes possible better access to all ducts for cable replacement and easier inspection of the cable at the duct mouth. When the bottom ducts are used, the splices should be made low on the side walls, but if higher ducts are used first, the cable should be supported in such a way as to leave a splicing area for the cables from other ducts. In distribution manholes it is best to place the higher voltage cable in the lower and outside ducts, which are less affected by heat from excavations along the line.

When training the cable, as discussed above, there must be due regard for the minimum safe bending radius of the cable, as well as for the cable movement problem Also influencing the training is the problem of sufficient straight cable near the splice for the joint casing or joint casing half during the splicing operation. The safe bending radius depends on several factors, the more important being the type of insulation and the size of the cable. Common practice is to allow at least 6 in. of straight cable out of the duct before starting the offset bend in the manhole. For long sections of large-diameter cable this may be increased to 8 or 10 in. In well designed manholes there should be sufficient room to do this without restoring to a smaller bending radius than recommended in Table 4.[11] This practice helps to mitigate two problems. Movement of the cable into the manhole due to load cycling will result in lateral movement of the splice and, unless there is room for a compensating increase in the length of the offset bend, this in turn will reduce the radius of curvature. Also, there is sometimes a tendency for newly trained cable to straighten out and if the offset bend wire originally began too near the duct mouth, this would cause the bend to spread into the duct. Subsequent cable movement could then result in sheath damage at the

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[11] Recommended by Insulated Power Cable Engineers Association.

resultant bearing point at the duct edge.

Table 4 enlists the maximum bending radii recommended for different types of cables.

In some instances the profile of a line will be such that there will be appreciable differences in elevation between the two ends of a given duct section. In such cases, whether due to vibration caused by heavy traffic or to the alternate expansion and contraction of the cable incidental to daily load cycles and failure of the cable to contract uphill by the same amount it has expended downhill, there will usually be a net downhill movement or creepage of the cable. As this will continue until sufficient restraining force to stop it is developed, damage to the cable sheath is likely unless some provision is made to exert the necessary restraining force in a safe manner.

Proper installation of cable in manholes will include measures calculated to preserve the cable during anticipated trouble conditions and provide protection for personnel who may be present in the manhole at the time a fault occurs. The conditions against which the cable should be protected include arcing, the flow of fault currents, electrolytic corrosion and mechanical abrasion of the sheath due to movement of the cable.

Underground cables in exposed areas may be subjected to lightning surge voltages travelling through the surrounding earth independent of surges for overhead lines. Grounded metallic cable

Table 4. Recommended minimum bending radii (7).

Rubber and Thermoplastic Cable without Metallic Shielding or Armor

a. Power Cable--Conduit or Duct Installation

Thickness of Conductor Insulation, 64th of an Inch	Minimum Bending Radius as a Multiple of Over-all Diameter	
	Less Than 500,000 Cir Mils	500,000 Cir Mils and Over
up to 8	3	4
9 to 12	4	5
13 to 20	5	6
21 and over	6	6

b. Rubber-Sheathed Portable Cable

Type of Cable	Minimum Bending Radius as a Multiple of Over-all Diameter
Single conductor, and multi-conductor over 5 kv	8
Multi-conductor 5 kv and under	6

Rubber and thermoplastic cable with metallic shielding or armor bending radii shall be not less than 12 times the over-all diameter of the completed cable.

Varnished Cambric Cable

a. Single-Conductor and Shielded or Nonshielded-Nonbelted Cables*

Conductor Insulation Thickness, 64th of an Inch	Outside Diameter of Cable, Inches		
	0-0.750	0.751-1.500	Over 1.500
	Minimum Bending Radius as Multiple of Cable Diameter		
10 and less	5	6	7
11 and 20	6	$6\frac{1}{2}$	7
over 20	$6\frac{1}{2}$	7	7

(continued)

Table 4. Continued.

b. Multiple-Conductor Belted Cables

Outside Diameter Inches	Minimum Bending Radius as Multiple of Cable Diameter
1.000 and less	5
1.001 to 1.500	6
Over 1.500	7

Paper Cable

Cable Over-all Diameter, Inches	Total Conductor Area MCM	Minimum Bending Radius as Multiple of Cable Diameter	
		20 kv and less	Above 20 kv
Up to 1.00	---	8	--
Above 1.00	1500 and less	8	10
Above 1.00	Above 1500	10	12

Armored Cable--All Types

The minimum bending radius is 12 times the over-all diameter.

Pole and Bracket Cable for Street Lighting

Minimum radius of bend $1\frac{1}{2}$ in. with maximum bend of 180 deg.

*Flat twin cables are bent on the minor axis only and the minor diameter is used in computing the bending radius.

sheathing or covering and lightning arresters at the cable ends are helpful for protection against such surges.

The depth at which the cable is to be installed should be governed by load conditions, i. e., obstructions, frost line and possible future digging operations. Protection against damage by insects or rodents may be necessary. Cable crossings adjacent to sanitary sewers or chemical discharges should be avoided to eliminate corrosion of the armor wires or lead sheaths. Asphalt covering over the armor wire will provide some protection, but will not be sufficient under severe conditions. Similar circumstances exist near wharfs and docks since a considerable amount of refuse material will pollute the soil surrounding the cable. Dumping of material and construction and maintenance work may also endanger the cable.

Fire proofing or arc proofing of electric cables installed in manholes, vaults, tunnels and other locations has become a very general and recognized practice among the electric utilities. The purpose of fire proofing is to limit cable damage, resulting from cable faults, to the cable actually in trouble. Fire proofing is necessary only where there is probability of damage to one or more cables due to failure of another.

In some instances, cable fireproofing is not considered necessary due to the physical separation between cables, isolation by barriers or other construction, high speed relay protection of the cables or the class of service of the cable under consideration. With adequate modern relay protection of the cables, reduction of fireproofing thickness is possible and recommended where practicable.

The useful life of modern paper and lead cable is essentially equal to the life of the lead, since most failures can be traced to breaks in the sheath which have allowed moisture to enter and cause insulation deterioration. Since the strains imposed by flexing depend on the effective length and width of the offset provided in the manhole, the probable life of the cable depends on the manhole dimensions.

Corrosion protection for buried lead sheathed cables can be provided by coating them with an asphalt compound or a jacket of neoprene, plastic or taped coverings applied at the factory. For steel armored cables a tar and jute final cover is often specified.

During the installation of buried cables it is generally desirable for the fieldman or foreman to make a field-book record of the route, location, manholes, splices, depth, etc., of each cable. All monuments should be accurately located on this record and the cable tied into these locations. Monuments should be located above each cable joint or group of joints and at the point of intersection of the two tangents to a bend.

Joint Installation

Before a splicer begins work on a cable, every precaution should be taken to assure that the cable is not energized.[12] Each company has a standard procedure for clearing a line or circuit and for blocking it to prevent it from being inadvertently energized. This procedure should be followed and, while the clearing and blocking is being done by the operators in the station, steps should be taken to identify the cable in the manhole. This guards against cutting into the wrong cable.

The cable should be identified by its position in the duct bank and by tags or other markings in the manhole where the work is to be done. This information should be checked in adjacent manholes. Cable marking is not infallible and, therefore additional checks must be made to avoid cutting an energized cable.

As an additional check, a statiscope may be used to determine if the circuit is energized. Where a metal covering exists, it is necessary to make an opening in the covering before using the statiscope. When the statiscope is placed against the exposed cable or joint insulation, the tube will glow if the cable is energized. After the test, the statiscope should be checked, such as against the spark plug of a running gasoline motor, to be sure it is operating.

As an additional means to determine whether a cable is energized or not, some companies use a cable spear. The spear is

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[12] As a last resort work can be done on energized cables up to 600 v. We will discuss it a little bit later.

fitted to the piston of a pneumatic or hydraulic jock set in a harness and is forced into the cable or joint before a workman is permitted to cut into it. A sufficient length of hose is provided to permit the operation of the jack from a position outside of the manhole. The spear is grounded. If no flash occurs when it pierces the cable or joint, the cable may be cut. Some companies use a cable pike driven manually from outside the manhole. On multi-conductor cable, the spearing operation is repeated until it is certain that at least two conductors have been grounded by spear. The spear point is examined for discoloration from contact with the copper or aluminum conductor after each spearing to verify that contact has been made.

Working on energized cable is a very hazardous practice which should be undertaken only as a last resort on circuits operating at more than 600 v to ground. Cables on low-voltage network systems are generally spliced while energized. Extreme caution must be observed. The conductor ends must be kept covered except when installing the connector. The lead sheaths of the cables being spliced and the sheaths of the adjacent cables must be covered with rubber blankets. The same applies to the adjacent manhole hardware, walls and equipment. The workman should stand on a dry rubber mat and wear rubber sleeves. Asbestos mats are used to protect the rubber mats from hot solder. Leather gloves and goggles should be worn when handling hot solder and compound. The tools used in applying the connector should be insulated and, if a hydraulic press is used, it should be placed on a firm insulated base.

Transformers

By definition, a distribution transformer is any transformer having a rating between 3 and 500 kva, inclusive. Transformers with ratings above 500 kva are classed as power transformers. Note that by the definition only kva rating is involved (12).

In the selection of a transformer for a particular application, consideration must be given to the following characteristics which determine its rating structure:

1. kva rating,
2. Voltage ratings and ratios,
3. Voltage taps,
4. Types of cooling,
5. Insulation level,
6. Sound level.

The kva rating must primarily be sufficient to handle the immediate load required. Consideration should be given also to possible future load growth which might be required by expanding facilities and consumers.

The voltage ratio and taps are selected to provide the correct voltage at the load terminals, taking into account the variation in the supply voltage as well as the voltage drop through the transformer and in the distribution lines. These taps are for de-energized operation only, and hence are not intended for adjusting the output voltage with variations in load. The taps above noted voltage in a step-down transformer will increase the turns in the high voltage winding.

Table 5 defines various types of transformer cooling methods.

Table 5. Classes of transformer cooling systems.

Type Letters	Method of Cooling
OA	Oil immersed, self cooled
OW	Oil immersed, water cooled
OW/A	Oil immersed, water-cooled/self cooled
OA/FA	Oil immersed, self cooled/force air-cooled (above 500 kva)
OA/FA/FA	Oil immersed, self cooled/forced-air-cooled/ forced-air-cooled (10,000 kva and larger)
OA/FOA/FOA	Oil immersed, self cooled/forced-air-forced-oil cooled/forced-air-forced oil cooled (10,000 kva and larger)
FOA	Oil immersed, forced-oil-cooled with forced-air-cooler (10,000 kva and larger)
FOW	Oil immersed, forced oil cooled with forced-water-cooler (10,000 kva and larger)
AA	Dry-type self cooled
AFA	Dry type, forced-air-cooled
AA/FA	Dry type, self cooled/forced-air-cooled (above 500 kva)

Table 6 gives representative impedance values of power transformers. These values are useful for calculation of voltage regulation, and short circuit currents.

Table 6. Transformer approximate impedance values.

	Power Transformers	
High Voltage Rating	Low Voltage Rated 480 Volts	Low Voltage Rated 2400 Volts or Higher
2,400 to 22,900	5.75	5.5
26,400, 34,400	6.25	6.0
43,800	6.75	6.5
67,000		7.0

Secondary Unit Sub-Station Transformers	
Rated kva	Design Impedances
$112\frac{1}{2}$ through 225	Not less than 2 percent
300 through 500	Not less than $4\frac{1}{2}$ percent
Above 500	Power transformer values

Audio levels are becoming more important. Handy representative values are given in Tables 7 and 8. The tabulated values represent the average sound level which will not be exceeded on the base transformers, exclusive of sound emitted by integral load tap changing mechanisms, disconnecting switches, or grounding switches.

Utilities are becoming more concerned with reducing voltage spread in the interest of better performance and longer life of electric equipment. This is generally accomplished by regulating equipment, such as the automatic-tap-changing-under-load feature on power transformers or individual circuit regulators.

Table 7. Audible sound levels for dry type transformers 15,000 volt and below insulation class.

Equivalent Two-Winding kva	Average Sound Level, Decibels Self Cooled, Class AA		Equivalent Two-Winding kva	Average Sound Level, Decibels Forced-Air-Cooled, Class FA and AFA
	Ventilated	Sealed		
0-300	58	57		
301-500	60	59		
501-700	62	61		
701-1000	64	63	3-1167	67
1001-1500	65	64	1168-1667	68
1501-2000	66	65	1668-2000	69
2001-3000	68	66	2001-3333	71
3001-4000	70	68	3334-5000	73
4001-5000	71	69	5001-6667	74
5001-6000	72	70	6668-8333	75
6001-7500	73	71	8334-10,000	76

Table 8. Audible sound levels for oil immersed transformers class OA, OW and FOW.

Distribution Transformers		Network Transformers	
Equivalent Two-Winding kva, 15 kv and Below Insulation Class	Average Sound Level, Decibels	Equivalent Two-Winding kva, 69 kv and Below Insulation Class	Average Sound Level, Decibels
0-50	48	300	55
51-100	51	500	56
101-300	55	700	57
301-500	56	1000	58
		1500	60
		2000	61
		2500	62

The fire and explosion hazard of oil-insulated and compound filled equipment is one of the most common hazards to safeguard against. Fires or explosions in oil insulated transformers occur infrequently, but where they do the results may be disastrous depending upon the arrangement of the equipment and the safeguard provided. The old practice of locating oil-filled transformers in the same room with an important switchboard or switchgear or other valuable apparatus should be avoided because a fire in the transformer will usually involve the other equipment increasing the damage and prolonging the outage.

The National Electrical Code clearly outlines the installation requirements for transformers of all types. Oil-insulated transformers installed indoors must be installed in a vault of fire resistant construction if the total capacity exceeds 75 kva. Where a vault is required adequate ventilation and drainage facilities are necessary to prevent overheating of the transformer and to drain away, to a safe place, any oil that may be released or expelled (12).

Where oil insulated transformers are installed outdoors they should be located at least 25 feet away from combustible buildings or structures. They should not be located under important bridges, conveyors, tanks or similar structures, where heat from a fire in the transformer may cause collapse of or serious damage to the structure. Facilities such as crushed-stone filled basins or drained concrete basins should be provided under the transformers to drain away any oil that may be expelled from them in time of trouble. Where a fire in one outdoor oil insulated transformer is likely to involve other transformers in the same bank, a non-combustible barrier or wall is sometimes provided between adjacent transformers to confine the fire to the unit in which it started.

Network Transformers

For many companies, it is the accepted practice to install protective equipment on the primary side of transformers. Here it not only minimizes outages on the rest of the feeder caused by faults in the transformer or in the secondary cables, but it also helps protect the transformer for secondary cable trouble. Where primary fusing is not practiced, primary circuit sectionalizing devices may be used to a greater extent. For instance, switches may be installed on each side of a transformer and transformer treated as part of the primary cable system, such as is the practice in secondary network systems. The no-load top changer and the primary switch are the principal network transformer accessories.

Network Protectors (29)

A "network protector" is a packaged unit consisting of;

1. Air circuit breaker

2. Fuses

3. Step down transformers

4. Relays.

The network protector:

1. Trips on load or fault current flow from the network to the supply.

2. Closes if the supply and network voltages are such that, if closed, the protector transformer will deliver power to the network.

3. Will not operate for network faults except that the fault can be cleared by the protector fuses if the fault does not burn clear.

Circuit Opening Devices

An adequate fault study is a necessity in almost all relay applications. Which relay or which method to apply is a good question--and in the protection field there are no categorial answers (29).

Circuit opening devices provide for normal circuit switching operations and provide a means for disconnecting a faulty circuit or equipment from the electric system with minimum damage and disturbance.

There are six general types of circuit opening devices for medium- and high-voltage applications. These are:

1. Circuit breakers
2. Fuses
3. Interrupter switches
4. Load break switches
5. Disconnect switches
6. Contactors

The first two types only are suitable for automatic operation to clear fault currents. Circuit breaker-fuse combinations and interrupter switch fuse combinations may be used for automatic fault clearing. The load break switch is normally designed to carry 1.5 times rating. Interrupter switches and disconnecting switches are manually operated switch devices used for circuit and equipment isolation. Generally, interrupter switches are suitable for opening and closing normal load currents whereas disconnect switches may, in general, be safely operated only on de-energized circuits (12).

A circuit opening device should meet the following requirements for short circuit protection:

1. It should be capable of carrying and opening the normal load current within its rating.
2. It should safely interrupt any current that may flow through it within its rating.
3. It should be capable of being safely closed on any load current or short circuit within its rating.

Successful operation of switchgear embodying electrically operated devices is dependent on a reliable source of control power which at all times will maintain voltage at the terminals of such devices within their operating voltage range. In general the operating voltage range of a switchgear equipment is determined by the rated operating-voltage range of the component electrically operated circuit breakers.

There are two primary uses for control power in switchgear: tripping power and closing power. Since an essential function of switchgear is to provide instant and unfailing protection in emergencies, the source of tripping power must be one that always will be available. It is generally preferable that the source of closing power also be independent of voltage conditions on the power system associated with the switchgear. However, more consideration may be permitted, cost as a factor in selecting a source of closing power than is permissible with the essential tripping power.

Four practical sources of tripping power are:

1. Direct current from a storage battery
2. Direct current from a charged capacitor
3. Alternating current from the secondaries of current transformers in the protected power circuit.
4. Direct or alternating current in the primary circuit passing through direct-acting trip devices.

Where a storage battery has been chosen as the source of tripping power it can also supply closing power. An added consideration, however, is the present trend to incorporate stored-energy (spring-mechanism) closing on both low-and-medium voltage power circuit breakers. General distribution systems, whether alternating-current or direct-current, cannot be relied upon to supply tripping power because outages are always possible, and are most likely to occur in times of emergency when the switchgear is called upon to perform its protective functions.

Other factors influencing the choice of control power are:

1. Availability of adequate maintenance for a battery and its charger.
2. Availability of suitable housing for a battery and its charger.
3. Advantages of having removable breaker units interchangeable with those in other installations.
4. Necessity for closing breakers with the power system de-energized.

1) Circuit Breakers (12): By definition a circuit breaker

> . . . is a device for interrupting a circuit between separable contacts under normal[13] or abnormal[14] conditions.

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[13]Normal indicates the interruption of currents not in excess of the rated continuous current of the circuit breaker.

[14]Abnormal indicates the interruption of currents in excess of rated continuous current, such as short circuits.

Ordinarily circuit breakers are required to operate only infrequently, although some classes of breakers are suitable for frequent operation. The rating of a circuit breaker should be equal to or greater than the system short-circuit duty.

Circuit breakers are commonly used instead of fuses on utility and industrial power distribution systems in order to provide essential switching flexibility and circuit protection. They may also be used, in certain applications, as motor starters.

Circuit breakers are available for the entire voltage range and may be furnished single-, double-, triple-pole or more and arranged for outdoor or indoor use, except that breakers above 34.5 kv are generally open type and used outdoors.

The rating of a power circuit breaker in the medium- and high-voltage class includes the following items.

1. Rated voltage
2. Maximum design voltage
3. Minimum voltage for rated interrupting mva
4. Rated impulse withstand voltage
5. Rated frequency
6. Rated continuous current
7. Rated momentary current
8. Rated 4-second current
9. Rated 3-phase interrupting mva
10. Rated interrupting current at rated voltage

11. Rated maximum interrupting current
12. Rated interrupting time in cycles.

The voltage and current ratings generally listed are based on altitudes up to 3300 feet. Derating factors, as well as detailed information on the above, are given in the American Standards.

The rated momentary and interrupting-current-carrying capacities are very important factors for use in the application of the medium- and high-voltage circuit breakers. Low-voltage power circuit breakers have the following ratings:

1. Rated voltage
2. Rated maximum design voltage
3. Rated maximum voltage
4. Rated frequency
5. Rated continuous current
6. Rated short-time current
7. Rated short-circuit current
8. Rated control voltage.

The circuit breaker must be capable of closing, carrying and interrupting the largest fault current possible at that location. It is essential to select a circuit breaker whose short-circuit (interrupting) rating at the circuit voltage is equal to or greater than the available short circuit current at the point of installation. Specific information on mechanical and electrical features may be found in manufacturer's publications.

2) Fuses: A fuse is an overcurrent device with a circuit opening fusible member heated and destroyed by the current passage through it. Fuses may be used instead of circuit breakers for certain applications. They are available in a wide range of voltage, current, and interrupting ratings, current-limiting and non-current-limiting types, and for indoor and outdoor applications.

Current limiting fuses are extremely fast in operation at very high values of fault current, and may act to limit the current in less than one-quarter cycle to a value well below the available peak short-circuit current. Non-current-limiting fuses may operate in one or two cycles depending on the level of fault current. Several types of low-voltage current limiting fuses are now available for alternating-current service with interrupting ratings as high as 200,000 amperes (rms symmetrical), in accordance with NEMA Standard FU-1-1963.

3) Fuses Versus Circuit Breakers: Fuses have the following advantages:

1. Fuse interrupting ratings are greater than those of available circuit breakers.
2. Less expensive.
3. Simple mechanically.
4. Less space requirements.
5. Current-limiting fuses will limit damage to protected

equipment by the let-through current of short circuits.

6. Fuses are easier to co-ordinate since their melting and clearing characteristics are more consistent.
7. Fuses are fail-safe devices, while deterioration of a breaker may cause unsafe operation.

Fuses have the following disadvantages:

1. Fuse time blowing characteristics are less accurate than relay controlled circuit breaker tripping characteristics with the result that co-ordinated circuit protection is less reliable. In some cases it is impossible to provide adequate overcurrent protection to specific equipment such as transformers, regulators, motors, etc.
2. Failure of one fuse in a three-phase circuit may result in single-phase operation of alternating-current motors with consequent possible damage to the motor as well as to process operation driven by the motor.
3. Fuses are not capable of remote operation.
4. Fuses are more hazardous to personnel than circuit breakers during replacement of fuse elements, unless drawout fused switches are used.
5. Fuses must be replaced after blowing, with the possibility that an incorrectly rated fuse element may be reinstalled
6. In a polyphase circuit, the opening of a fuse, in response to a

fault condition, may severely reduce the magnitude of current continuing to flow to the fault and make impossible the operation of remaining fuses in the circuit with the result of an inability to interrupt current flow to the fault.

7. It is necessary to stock replacement fuses.

4) Switches: The types of switches generally used in distribution systems are: disconnecting switches for circuit isolation for all voltages, interrupter switches, generally in the medium-voltage class, and the so-called safety switches for low-voltage service.

A disconnecting switch is a form of switch used for changing connections in a circuit or system for isolating purposes. It is used for all voltage classes. It has no interrupting rating and is intended to be operated only after the circuit has been opened by some other means. It should, except for light duty, be equipped with latches to prevent being opened by mangetic forces existent with heavy fault currents.

A load break switch, generally associated with load center unit sub-stations, for medium-voltage use, is a switch combining the functions of a disconnecting switch and a circuit interrupter for interrupting, at rated voltage, currents not exceeding the continuous current rating of the switch. Load-break switches are of the air, fluid immersed, or oil-cut out type.

This type of switch is an economical compromise to the more ideal, but also more costly, circuit breaker. Such switches are used in industry to interrupt transformer magnetizing currents, and low value of load currents at locations where the cost of a circuit breaker may not be justified to perform at its interrupting rating.

It is desirable, from a safety standpoint, to interlock the operation of an interrupter switch with a secondary breaker in the case of a transformer application so as to prevent operating the interrupter switch at a time when currents exceed the rating of the switch.

For low-voltage service "safety switches" are commonly used. These are enclosed, and may be fused or unfused. This type of switch is operable by a handle from outside the enclosure and furnished with interlocks so that the enclosure cannot be opened unless the switch is open. Many safety switches have quick-make and quick break contact features.

A draw out fused interrupter switch is available for use independently or with unit sub-stations. This switch is an economical compromise for a circuit breaker where manual operation is possible, and it should have a quick-make, quick break mechanism independent of speed of handle operation.

Apparatus Selection

The fundamental consideration in selecting equipment is to choose the optimum equipment consistent with the requirement. Frequently it costs no more in the long run to use the best equipment available as it pays dividends in service continuity and lower maintenance (12).

Properly prepared specifications can minimize the purchase of inferior or unsuitable equipment. The lowest purchase price is frequently the most expensive either on a long- or short-term basis (13).

Electric failures are caused by possible source irregularities, improper application of materials, improper designs, faulty materials, poor workmanship, and lack of proper maintenance. Good workmanship is also a factor in the prevention of electric failures. Therefore, the design should incorporate features that are conductive to good workmanship.

It is necessary to know the maximum short circuit currents that can occur at the various points of the system[15] in order that circuit breakers may be selected that are adequate to withstand the currents and operate successfully to cut out the faulty section, and also in order that the protective relays may be selected for correct operation. The breaker rating structure is complicated because of the time of operation of the circuit breakers when a short circuit occurs (14).

Circuit breakers and relays, according to their speed and

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[15] Also, when changing transformers.

according to whether or not reclosing[16] is employed, may be divided into the following classes (15):

1. Slow-speed circuit breakers and relays.
2. High speed circuit breakers and relays.
3. High speed reclosing circuit breakers and relays.

The clearing time is the sum of the relay time and the breaker interrupting time.

The relay time is the elapsed time from the instant when a fault occurs until the instant when the relay contacts close the trip circuit of the circuit breaker. The breaker interrupting time is the elapsed time from this instant until the instant when the current is interrupted. It is the sum of the breaker opening time (the time required to part the breaker contacts) and the arcing time.

Reclosing time is the elapsed time for the instant of energizing the trip circuit, the circuit being in the closed position, until the instant when the breaker arcing contacts touch on the reclosing stroke; it includes breaker opening time and time during which the breaker is open. All these times, if short, are customarily expressed in cycles on the basis of the usual power-system frequency of 60 (or 50) cps.

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[16]Most cable faults are permanent faults and as such reclosers are not necessary. On permanent faults reclosers are more drastic.

System Protection

On an actual distribution system, a fault can occur at any time, but the exact time is never known. Therefore, since most protective devices must operate during the transient period, they must be designed to interrupt the maximum fault current possible (18).

It would be neither practical nor economical to build a fault proof power system. Consequently, modern systems are designed with reasonable precautions to provide sufficient insulation, clearances, etc. but a certain number of faults must be tolerated during the life of the system. Even with the best design possible, materials tend to deteriorate, and the likelihood of fault increases with age. Every system is subject to short circuits and grounds that must be removed quickly, and a knowledge of the effect of faults on system voltages and currents is necessary to design suitable relay protection, since these quantities are used to actuate the relays (12).

The ordinary types of faults that protective relays must detect are three phase, phase to phase, two phase to ground, and single-phase-to-ground short circuits. Knowledge of the effect of time of fault initiation is useful in the testing of protective devices. Conditions can be developed in testing laboratories to produce maximum fault currents. Severe short circuit tests give an adequate safety margin to equipment interrupting ratings because actual conditions are never so severe as test conditions (18).

Protection in an electric system is a form of insurance. It pays nothing as long as there is no fault or other emergency, but when a fault occurs it can be credited with reducing the extent and duration of the interruption, the hazards of property damage and personnel injury. Economically the premium paid for this insurance must be balanced against the cost of repairs and lost revenues. The fact should not be overlooked that protection well integrated with the class of service desired may reduce capital investment by eliminating the need of equipment reserves.

This work is specialized and often very complex, and it is neither safe nor fair to the operating engineer to expect him to do it as a side-line.

Cable and Underground Equipment Loading

The fundamental problem of cable and equipment loading is the determination of load capabilities based on over-all economies. Usually this means establishing load capabilities as high as feasible, on the basis of obtaining the following:

1. Adequate reliability of service for the types of equipment and service requirements involved.
2. A life equal to at least the expected time when obsolescence or system changes will result in abandonment of such

equipment.

Allowable loading of underground cables is generally limited by maximum allowable temperature, or maximum allowable daily range in temperature, but voltage regulation acts as a limit in some cases. In rare cases, the loading may be limited as the result of an economic study following an approach similar to that set forth in Kelvin's Law (7).

The limit from a voltage regulation standpoint becomes a factor in some cases. It is easy to set and is determined by the variation in voltage within which the customer's equipment will operate reasonably well.

It is difficult to establish exact values for temperature limits, but some industry standards have been evolved from the information on laboratory data and operating experiences for the cable and equipment. In general, the higher the temperature, the faster the rate of deterioration in the physical properties of the insulation, including the formation of voids in solid-type paper insulated cable. The deterioration usually results in dielectric losses and material decreases in dielectric strength. High ranges in daily temperatures accelerate the possibilities of:

1. Sheath cracking on cable in manholes
2. Loosening of contacts of bolted or clamped connections.

A short time high over-load and accompanying high temperature can produce aging in the equipment equivalent to operation for a much longer time at a lower temperature. In this regard, for oil-impregnated paper insulation, investigations show that the deterioration rate doubles for a temperature increase of roughly 8 C.

The electric and mechanical stability of an insulation, or of a set of contacts in a protector or in a bus, or of a lead sheath must be considered in determining the thermal limits for equipment involved. Thermal stability is of particular importance in determining the safe temperature for emergency loading of cables. Power factor and ionization data obtained from accelerated aging tests during which the temperatures are gradually raised are highly valuable in determining these limits. Temperature range, rather than the maximum temperature, is the controlling factor where expansion and contraction may cause cable sheath failure in the manhole due to flexing caused by the daily temperature cycle.

Laboratory tests show that insulation life depends not only on the magnitude of the temperature to which it is subjected but also on the length of time that the heat is applied. The maximum permissible insulation temperature can, therefore, be somewhat higher for cables that operate at low load factors than for cables that operate at high load factors, especially after taking into account the effects of thermal time lag. The frequency at which emergencies are expected to occur is an important factor in determining the maximum permissible temperatures for emergency operation.

The maximum permissible insulation temperature or temperature range is not always the factor which limits the load capability of an underground cable system. The temperature of the soil adjacent to a buried cable or conduit system must also be considered. If permitted to become too high, the resulting moisture migration from the soil will cause a considerable increase in the soil thermal resistivity. This will lead to thermal instability of the soil and further increases in its resistivity which, in turn, will cause excessive cable temperatures, and, perhaps, even immediate cable failures.

To obtain fullest utilization of equipment, studies of the following three factors are required:

1. Relation between temperature or temperature rise, or both, and life.
2. The load characteristics of the installation.
3. Relation between the load characteristics and resultant temperature or temperature rise.

With regard to the first factor, it is necessary to establish the maximum temperatures or temperature rises, or both, to which the equipment could be subjected safely for durations and frequencies expected for emergency operations, as well as to establish the maximum temperature values permissible for normal operation.

In actual service, the equipment is usually operated at or near its normal load capability for only a small fraction of its life. Some of the reasons include allowance in design for load growth, variation in load in each day, variations in demands between days and between seasons and variation in ambient with season (7).

Much study had been devoted to operating records and thermal investigations have been made, all in order to assist in determining allowable temperatures. Figures 17, 18, 19 and 20 are graphs of some tests by one company.

Figure 17 shows the deterioration rate (in tearing strength) with temperature for oil filled insulation. Similar tests have been made on other insulations.

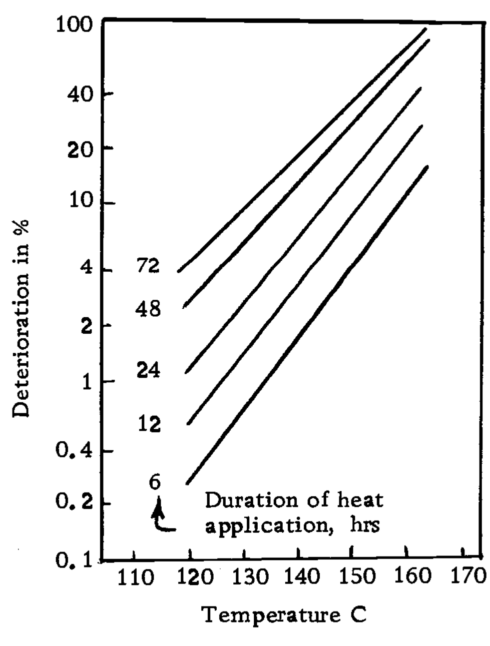

Figure 17. Deterioration of oil impregnated paper insulation with temperature based on tearing strength.

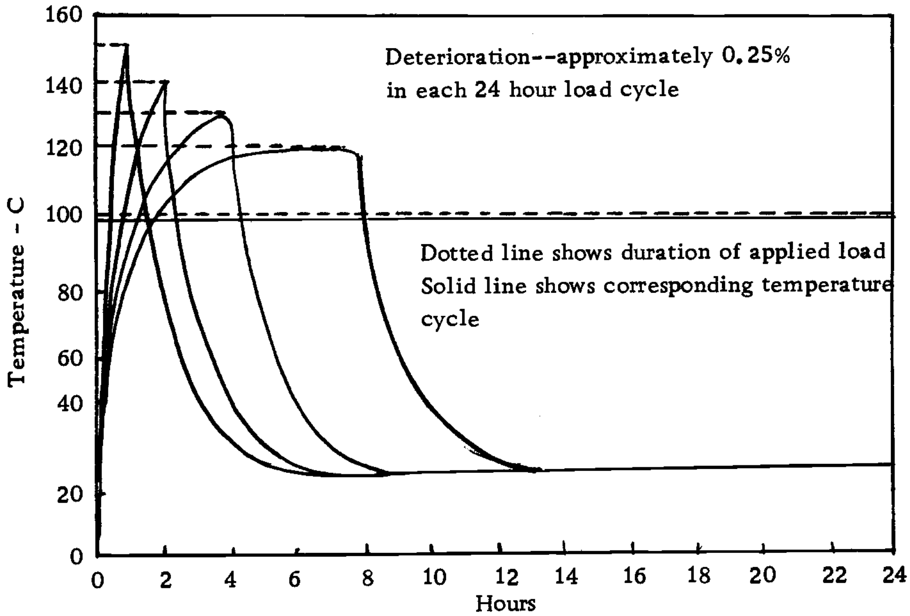

Figure 18. Daily load cycles and corresponding temperature cycles.

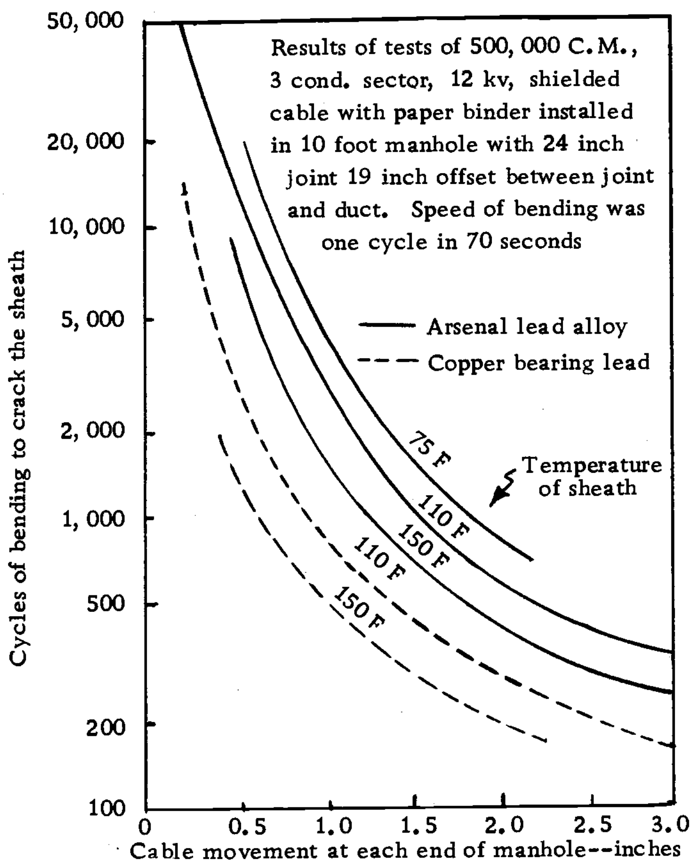

Figure 19. Life of sheath in dummy manhole tests.

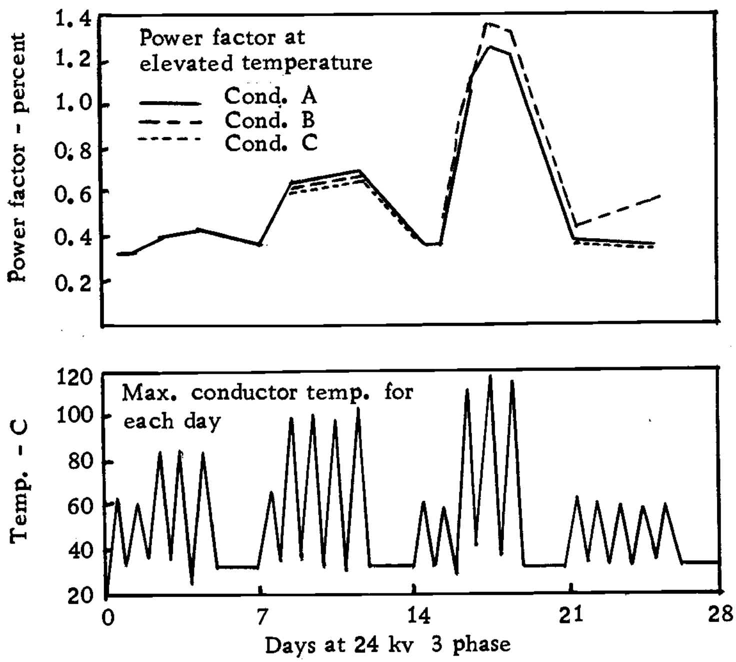

Figure 20. Accelerated aging test of 3 conductor cable.

Figure 18 shows various 24-hour load cycles which result in the same total amount of mechanical deterioration of the insulation in each 24 hour period. This kind of curve is invaluable in determining permissible emergency operating temperatures. It shows that 24 hr. at 100 C has the same effect as a 1 hr. load that brings the temperature up to 150 C followed by a cooling period, or a 4 hr. load with a maximum of 130 C and subsequent cooling. These values give approximately 0. 25 percent deterioration in tearing strength.

Figure 19 shows the expected life of lead and arsenical lead alloy sheath as a function of the movement produced by thermal expansion and contraction of the cable at the manhole. These curves represent the average results of tests in a laboratory made on cable including a joint in a full-sized manhole. The cable was moved at a rate of one cycle in 70 sec, whereas in service the movement is usually at the rate of one cycle per day. The life to cracking in service is roughly of the order of one-half of that in these tests. These data are of value mainly to indicate the relative effects of varying cable movement (related to load cycles) and sheath temperature on the life of the sheath. For 12-kv cable of this kind on a well-loaded line, the daily movement at the manhole is about $\frac{1}{2}$ in. and the temperature of the sheath is about 100 or 110 F. For such conditions the tests indicate a life-to-fracture of lead sheath of about 2800 cycles and of alloy sheath of about 16,000 cycles. During emergency loading the sheath temperature might increase to 150 F and the cable movement might become $1\frac{1}{2}$ or 2 in. The sheath life might then be only 200 cycles for lead or 450 cycles for lead alloy. The cable would be subjected to cycles of this kind for only a few cycles during its entire service life. Thus only a very small part of its life would be spent in such emergencies. Cracking of the sheath is produced almost entirely by the cumulative effect of the normal daily load cycles. For commercially pure lead sheath, such cracking may occur in relatively short service life.

Figure 20 shows the effect of temperature and duration of an overvoltage on the power factor of a sample of good cable. Accelerated aging tests of this kind are made not only on new cables, but also on samples removed from a line after about ten years of service. The information gained is not only useful in gauging high-temperature stability, but is also useful in determination of dielectric losses needed in calculations of load capabilities.

The second of the general problems is a study of the load characteristics of the installation. This involves a study of the over-all load characteristics, such as average daily loading in relation to maximum values established for normal and for emergency loading. This study must include such factors as load growth, diversities in loading, load fluctuations, nature of load cycles and load factors, relation of actual amperes carried by a specific piece of equipment to kilowatts or kilvolt-amperes delivered and determination of the firm capacity of each installation. For an installation consisting of parallel circuits of equipment or lines, the firm capacity is usually the total load capability of the installation, including the effects of unbalance in loading of the parallel circuits, when one circuit is out of service.

It is obvious that a high maximum load may be carried if the equipment is required to carry only a fraction of its load capability for the majority of the time. On the other hand, a daily fluctuation between a moderate load and no load has a greater effect on sheath life of underground cable than a heavy base load with little fluctuation.

Finally, it is necessary to know the relation between loading and actual temperatures reached. A knowledge of this relation becomes increasingly important as the temperature limits increase. A careful study must be made of all the variables affecting the temperature or temperature range of the equipment, such as the following:

1. Rate of temperature increase with time over a period of hours.
2. Electrical and thermal proximity effects.
3. Effect of adjacent equipment.
4. Effect of enclosures.
5. The total thermal path, including such cases as cables in floors or walls; and the relation of the hottest spot conductor temperatures in a transformer, in an underground cable or in other apparatus, to the temperatures which are measurable.

A knowledge of the physical, thermal and electrical properties of various materials is frequently necessary for solving problems pertaining to cables and equipment. Tables 9, 10 and 11 give thermal and physical properties of conducting materials, insulating materials and miscellaneous materials, respectively. Table 12 gives electrical properties of conductor materials. Table 13 gives dielectric constants for various insulating materials and Table 14 gives thermal resistivities for materials for joints.

Table 9. Thermal and physical properties of conductor materials.

Material	Thermal Resistivity deg. C cm/w	Specific Heat cal/G/ deg. C	Thermal Capacity w sec/ cu in/ deg. C	Specific Gravity G/cu cm	Density lb/cu in	Heat of Fusion		Melting Point deg. C	Coefficient of Volumetric Expansion deg. C	Tensile Strength psi
						cal/G	w-sec/cu in			
Aluminum	0.49	0.22	41	2.70	0.098	76.8	14,200	657	75×10^{-6}	10×10^{3}
Brass, yellow	1.17	0.094	56	8.70	0.306	--	--	900	60	70
Constantan	4.4	0.100	61	8.88	0.321	--	--	11,900	45	60
Copper	0.26	0.091	55	8.89	0.322	42.0	25,600	1083	50	35
Everdur	3.0	--	--	8.5	0.308	--	--	--	--	--
German silver	3.4	0.094	54	8.4	0.304	--	--	1100	55	90-150
Gun metal	--	--	--	--	--	--	--	--	55	25-50
Iron, cast	2.13	0.12	58	7.1	0.260	5.5	2,700	1230	32	15
Lead	2.88	0.030	23	11.34	0.410	5.86	4,600	327	88	3
Manganin	4.6	0.096	56	8.50	0.307	--	--	910	--	150
Monel	--	--	--	8.90	0.322	--	--	1300	45	80
Silver	0.24	0.056	40	10.5	0.380	21.1	15,200	960	56	42
Steel, mild	2.23	0.11	59	7.85	0.284	--	--	1510	36	60
Steel, stainless	3.86	0.11	63	7.75	0.281	--	--	1400	30	90

Table 10. Thermal and physical properties of insulating materials.

Material	Thermal Resistivity deg. C cm/w	Specific Heat cal/G/deg. C	Thermal Capacity w-sec/cu in/deg. C	Specific Gravity G/cu cm	Density lbs/cu in	Coefficient of Volumetric Expansion deg. C
Air	4000	0.24	0.021	0.00129	0.0000467	---
Asbestos	600	0.25	34-38	2-2.8	0.072-0.101	---
Braid, weather proof	500-600	0.45	32	1.05	0.038	---
Fiber	480	--	---	---	---	---
Gutta percha	--	--	---	---	0.035	---
Jute, covering	500	0.400	92	3.35	0.121	---
Mica	150	--	---	2.6-3.2	0.094-0.116	---
Neoprene	600	0.4-0.45	46	1.5	0.054	---
Oil for solid, oil filled and pipe type cables	610	0.51	31	0.89	0.032	0.00075
Paper, gas impregnated	700	--	---	---	---	---
Paper, oil impregnated	550	0.336	34.5	1.15	0.042	0.00010
Paper, solid	550-700	0.336	34.5	---	---	---
Paraffin	--	--	---	0.9	0.032	---
Polyethylene	320	0.55	35	0.92	0.033	0.00055
Polystyrene	800-1200	0.32	23	1.06	0.038	0.00021
Porcelain	60	--	---	2.3-2.5	0.083-0.090	---
Rubber, performance	500-600	0.350	42	1.75	0.063	0.005
Rubber, 30 percent	500-600	0.280	26	1.35	0.049	---
Rubber, silicone	250-500	--	---	1.1-2.1	0.040-0.076	0.002
Rubber, oil base	500-550	--	---	---	0.05	---
Tile duct	100	--	---	---	---	---
Transite duct	200	--	---	---	---	---
Varnished cambric	600	0.400	32	1.15	0.042	---

*Compounded with carbon black and vulcanized.

Table 11. Thermal and physical properties of miscellaneous materials.

Material	Thermal Resistivity deg. C.cm/w	Specific Heat cal/G/deg. C	Thermal Capacity w-sec/cu in/deg. C	Specific Gravity G/cu cm	Density lbs/cu in	Thermal Diffusivity sq in/hr
Concrete:						
Light aggregate	110	0.22	30	2.0	0.072	3.0
Heavier aggregate	70	0.20	31	2.3	0.083	4.0
Soil:						
Average dry	130	0.23	23	1.49	0.054	3.0
Average wet	70	0.36	44	1.78	0.065	3.0
Sandy dry	120	0.20	20	1.46	0.053	4.0
Sandy wet	50	0.28	36	1.86	0.067	5.0
Clay dry	140	0.26	27	1.52	0.053	2.5
Clay wet	80	0.45	53	1.71	0.062	2.0
Somastic	210-270					
Transite;						
Building material	200					

Table 12. Electrical properties of conductor materials.

Material	Resistivity Microhm-cm	Ohms Cir Mil Per Foot at 20 C	Temperature Coefficient of Resistance at 20 C	Percent Conductivity
Aluminum	2.828	17.0	0.00403	61.0
Brass, yellow	6.62	40	0.002	26.0
Constantan	50.0	300	0.00001	3.45
Copper	1.724	10.37	0.00393	100.0
Everdur	26.5	159	---	6.5
German silver	33.3	200	0.0004	5.18
Gun metal	4.0	24	---	43.0
Iron, cast	10	60	0.005	17.2
Lead	22.3	134	0.00387	7.73
Manganin	44	265	0.00001	3.9
Monel	42	252	0.0020	4.1
Silver	1.641	9.84	0.0038	105.1
Steel, mild	14	84	0.004	12.3
Steel, stainless	73.0	439	0.00094	2.4

Table 13. Electrical properties of insulating material.

Materials	Dielectric Constant
Air	1
Gutta percha, Mica	3 -5
Neoprene compound	4 -6.5
Oil for solid, oil filled and pipe-type cables	2.2-2.4
Transformer oil	2.2-2.4
Askarel	4.0-4.2
Paper in gas filled cable	2.5-3
Paper, oil impregnated paper, solid	3.3-4 2
Paraffin	2 -2.5
Polyethelene	2.3
Polystyrene	2.4-2.8
Polyvinylchloride	6 -10
Porcelain	6 -8
Rubber and rubber-like compounds	4 -6
Rubber communication	2.5-3
Varnished cambric	4 -6

Table 14. Materials for joints.

Material	Thermal Resistivity Deg C cm/w
Paper, impregnated	550
Varnished cambric	600
Rubber	500-600
Transformer oil	610
Heavy oil	730
Castor oil	557
Vaseline	544
Glycerine	345
Bitumen	635
Pitch	680
Nitrogen gas	4565
Concrete	70-110

It may be necessary to increase the loading of cables beyond their normal ratings or other local conditions may cause abnormal temperatures, and so, until additional capacity can be added some form of cooling is desirable. There are quite a few ways by which the duct cables can be cooled; however it is difficult to cool buried cables. The only thing that can be done for buried cables is to unload them during off peak hours and weekends. The weakening of cable insulation prior to cable failure may be a slow process and any efforts to reduce service failures by periodically testing cables to detect insulation deterioration would seem desirable if they can be economically justified.

Buried Cables

Here we will discuss the following:

1. Armoring for buried cables.
2. Current carrying capacity of isolated cable.
3. Current carrying capacity when more than one cable in a trench.
4. Short circuit load capabilities.

1) Armoring for Buried Cables (7): Buried cables are commonly furnished with either

1. Flat-band armor

2. Interlocked armor or

3. Wire armor.

The armoring material is usually steel for multi-conductor cables and for very small single-conductor cables. Steel wire armor is frequently used for somewhat larger single-conductor cables, especially for submarine service. However, for large cables of this type a nonmagnetic material, such as copper or aluminum, is advisable for the armor because of the losses in a steel armor.

The comparative losses in cables with different types of armor and other forms of protection may be estimated from Table 15. These data were obtained for a cable with the following specifications:

single conductor, 350,000 cir mil, 44 kv, paper leaded cable with and without armor; four foot spacing between conductor.

Because of these losses, band steel armor is not used on single conductor cables, except when the conductors are very small, as is often the case in series street lighting work.

A band steel armor on a 3-conductor cable increases its reactance from 15 to 25 percent over that of a similar non-armored cable, the smaller figure being for the larger conductor. The added losses with steel tape or steel wire armor are small in comparison to those for single conductor cables, but not necessarily negligible in refined current rating calculations. The order of magnitude of the losses is about the same as those in the lead sheaths. Such an armor is economical and resistant to abrasion and accidental damage. It has little tensile strength, and where tensile strength is required, wire armor is preferred.

Table 15. Comparative values of loss of single conductor cables.

Conductor loss, open circuited sheath, no armor	100%
Cable loss, short-circuited sheath, no armor	240%
Cable loss, open circuited sheath, open-circuited steel wire armor	230%
Cable loss, short circuited sheath, short-circuited copper wire armor	135%
Cable loss, short circuited sheath, short-circuited steel armor	290%
Cable loss, short circuited sheath, short-circuited band steel armor	1230%
Cable loss, no sheath, steel pipe over-all (one cable in a pipe)	2500%

2) Isolated Cable: The current carrying capacity of an isolated buried cable may be calculated as follows:

$$I = \sqrt{\frac{T_c - T_a - T_d}{R_c R_t}} \qquad (1)$$

where

I = load current, amperes

T_c = permissible copper temperature, deg C

T_a = ambient temperature, deg C

T_d = temperature rise due to dielectric loss, deg C

$$T_d = W_D(R_i/2 + R_s + R_j + R_e)$$

W_a = armor loss (including circulating current loss, eddy current loss and hysteresis loss), watts per foot

W_c = conductor loss (including skin effect and proximity effect), watts per foot

W_D = dielectric loss, watts per foot

W_s = sheath loss (including circulating current loss and eddy current loss), watts per foot

R_c = conductor resistance, including skin effect and proximity effect, ohms per foot

R_e = thermal resistance of the soil, thermal ohms per foot

R_i = thermal resistance of the cable insulation, thermal ohms per foot

R_j = thermal resistance of the jacket between shealth and armor, or thermal resistance of pipe covering for pipe cable, thermal ohms per foot

R_s = thermal resistance from outer surface of the cable to inner surface of the pipe, thermal ohms per foot (for pipe cable only)

R_t = total thermal resistance, thermal ohms

$$= [R_i + R_s + (1 + \frac{W_s}{W_c}) \times R_j + (1 + \frac{W_s}{W_c} + \frac{W_a}{W_c})R_e]$$

For buried cables, the ratios $\frac{W_s}{W_c}$ and $\frac{W_a}{W_c}$ are calculated in the same way as they would be for cables in free air or in ducts, with the same spacing and arrangement as is used in the actual buried cable installation. For three-conductor cables, W_s and W_a are taken equal to zero and R_c is multiplied by the a-c/d-c ratio. For pipe cables, W_a is taken as zero and W_s/W_c is the ratio of pipe loss to conductor loss. R_i is calculated in the same way as for cables in free air and R_s is calculated following the usual procedure for pipe cables. R_j is given by the following equation:

$$R_j = \frac{\rho_j}{191.5} \ln \frac{e_a}{f_s} \quad \text{deg C/w/ft} \qquad (2)$$

where:

ρ_j = the thermal resistivity of the jacket or pipe covering, usually taken at 300 thermal ohm-cm.

e_a = the inside diameter of the armor, or the outside diameter of the pipe covering in the case of pipe cable, inches.

f_s = the outside diameter of the sheath, or the outside diameter of the pipe in the case of pipe cable, inches.

R_e is usually calculated from the Kennelly Formula, following:

$$R_e = \frac{\rho_e}{191.5} \ln \frac{4D}{f_a} \quad \text{deg C/w/ft} \qquad (3)$$

where:

ρ_e = the thermal resistivity of the soil, thermal ohm-cm

D = the depth of burial in inches

f_a = the outside diameter of the armor, inches, or the outside diameter of the protective covering in the case of pipe cable.

3) More Than One Cable in a Trench: If there are n cables buried in a trench at the same depth below the surface, Equation 1 is still used with the value of R_e modified as follows:

$$R_e = A + \sum_{k=2}^{k=n} B_k \qquad (4)$$

A is the value of R_e calculated from Equation 3. B_k is given by the following equation:

$$B_k = \frac{\rho_e}{191.5} \ln \sqrt{1+\left(\frac{2D}{x_k}\right)^2} \qquad (5)$$

In this equation x_k is the center-to-center distance from cable 1 to cable k in inches.

In order to use Equation 4, proceed as follows:

1. Calculate B_k for each of the other cables in the trench, using Equation 5 or Figure 21.

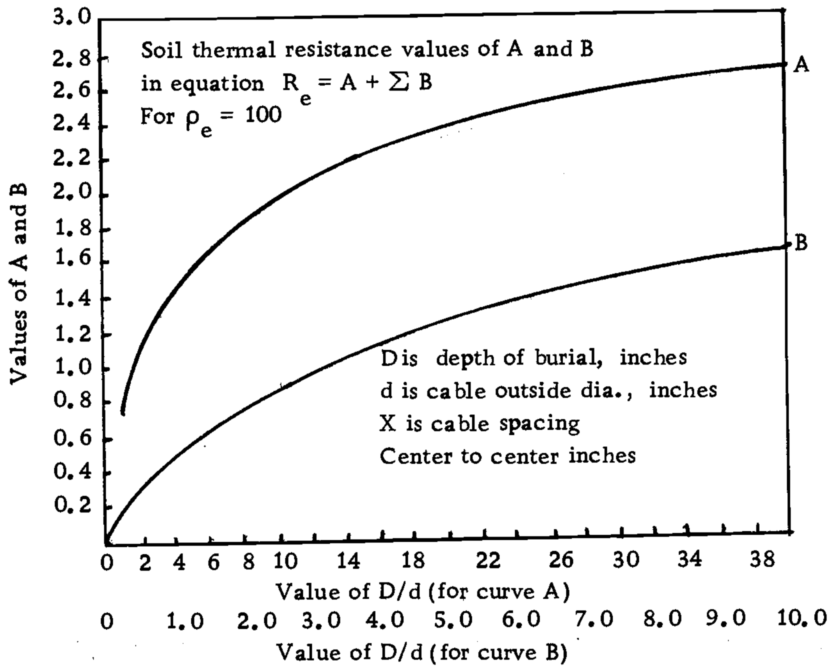

Figure 21. Mutual thermal resistance for more than one cable in a trench.

2. Calculate B_k for each of the other cables in the trench, using Equation 5 or Figure 21. In each case, x_k is the distance from the center of the cable under consideration to the center of cable k.

3. Add up the various values of B_k obtained in step 2 and add to their sum the value of A obtained in step 1. This will give R_e for cable 1.

4. Repeat steps 1, 2 and 3 for cable 2. This should give the value of R_e for this cable.

5. Repeat steps 1, 2 and 3 for each of the other cables in the trench in order to get R_e for these cables.

Values of A and B are plotted in Figure 21 for a soil thermal resistivity of 100 thermal ohm-cm. In order to use this chart for another value of soil thermal resistivity, say ρ_e, multiply the values of A and B in Figure 21 by the ratio $\rho_e/100$.

If all cables are similar and equally loaded, the cables in the middle of the group will be found to have the highest value of R_e. Hence it is not often necessary to calculate R_e for all the cables in the group.

If the cables are dissimilar or unequally loaded, the value of B_k for cable k should be multiplied by the ratio $\frac{\text{loss in cable k}}{\text{loss in cable 1}}$ when calculating R_e for cable 1. Similar ratios should be used when calculating R_e for each of the other cables.

For cables buried at different depths, R_e can be found by replacing B_k in Equation 4 by B_{kd}, where B_{kd} is given by the following equation:

$$B_{kd} = \frac{\rho_e}{191.5} \ln \frac{d'_k}{X_k} \qquad (6)$$

where:

d'_k = the distance from the image of cable k projected above the surface of the earth to the center of the cable under consideration. Other nomenclature same as for Equation 5.

4) Short Circuit Load Capabilities (7): The flow of short circuit

current improves mechanical and thermal (heating) stresses on all components of the system through which such current flows. This includes power cable, circuit breakers, current transformers, disconnecting switches and buses.

Multiple-conductor power cables posses high mechanical strength. Three samples of 3 conductor, 350,000-cir mil, shielded cable with 220 mils of insulation and 125 mils lead (one with a steel binder one with a wire-stitched cloth binder and one with a butt-wound 7 mil paper binder tape), when subjected to a momentary overload of 12,000 amp, the current flowing in one direction through one conductor and in the reverse direction through the other two conductors connected in parallel, gave no indication of perceptible movements of the conductors. Neither was any conductor movement detected when tests on these samples were repeated with lead sheath removed and with binder tape tied only at each end of the samples to prevent unwrapping.

This is not true with regard to thermal effects. In common with other current carrying parts of the electric system during short-circuit flow, the abrupt elevation in conductor temperature will be limited only by the ability of the conductor metal to absorb the heat developed.

On the basis that all heat produced by the fault-current flow is initially absorbed by the conductor metal (which has proven to be valid for conductor sizes of No. 8 AWG or larger), the conductor heating is governed by:

$$\left(\frac{I}{c.m.}\right)^2 t = \frac{1}{K} \log_{10} \frac{(T_2+234)}{(T_1+234)}$$

or

$$t = \frac{1}{\left(\frac{I}{c.m.}\right)^2 K} \log_{10} \frac{(T_2+234)}{(T_1+234)}$$

where:

K = 33 for copper, 76 for aluminum, and 1055 for lead

t = duration of current flow, sec

I = rms amp during the entire interval of current flow

c.m. = conductor cross-section, cir mils

T_1 = initial conductor (or sheath) temperature, deg C

T_2 = final conductor (or sheath) temperature, deg C

An illustration of allowable short-circuit currents on insulated conductors is shown in Figure 22. Service experience with insulated aluminum power cables is very limited. The problem of transient heating should be approached with caution and particular attention should be given to possible accentuated thermal distress at joints and terminations.

Load Capabilities for Transformers

We will give herein the basic assumptions and outline a few references for determining the load capabilities for transformers.

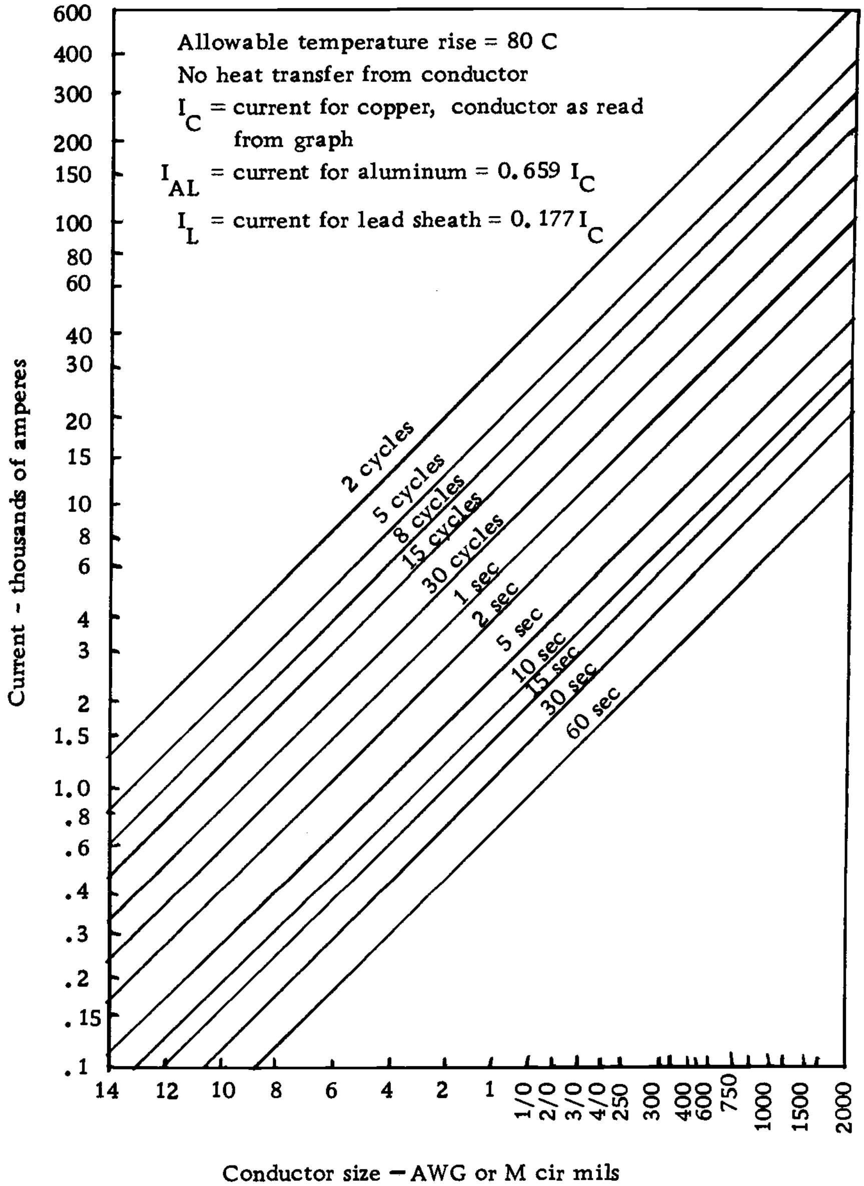

Figure 22. Allowable short-circuit currents for insulated conductors.

The basic loading condition of a transformer for normal life expectancy is continuous loading at rated kva and rated delivered voltage with the temperature of the cooling air at no time exceeding 40 C, and with the average temperature of the cooling air during any 24-hr. period equal to 30 C.

As indicated earlier, deterioration is a function of time and temperature. Any deterioration is cumulative. In other words, when a transformer is loaded in excess of its rating, for say an hour or two, a higher than normal rate of insulation deterioration will occur. Conversely, when the transformer is only partially loaded for any duration, an effect of lower than normal rate of deterioration will occur. It is possible to adjust the load and time combination, such that the average rate of deterioration will be the same as when the transformer is carrying rated load continuously. Various loads and combinations, such as shown in ASA Table 32. 015(e) have been worked out to give normal life expectancy.

When it is necessary to load a transformer with a moderate sacrifice of life expectancy, charts given in ASA Figure 32. 016(b) 1 to 6 will assist the operator in selecting loadings and loss of life most suitable to his condition.

Ambient temperature is an important factor in determining the load capability of a transformer. A loading schedule is given in the ASA loading guide, Table 32. 015(c), and is reproduced here for convenient reference as Table 16.

Table 16. Loading of transformers on basis of ambient temperature.

	Percent of Rated kva per Deg C Change from 30 C	
Type of Cooling	Decrease Load for Higher Temperature	Increase Load for Lower Temperature
Self cooled	1.5	1.0
Forced air-cooled	1.0	0.75

Transformers may also be loaded on the basis of load factor, as shown in the ASA table reproduced here as Table 17. When the load factor for a period of time not exceeding 24 hr. is below 100 percent, the maximum loading of a transformer during that period may be increased above rated kva by the percentages shown in Table 17 above, for each percent, except that no further increase should be made for load factors below 50 percent.

Table 17. Loading of transformers on basis of load factor.

Type of Cooling	Increase in Percent of Rated kva	Maximum Percent Increase*
Self cooled	0.5	25
Forced air-cooled	0.4	20

*Corresponds to 50 percent load factor.

Design Consideration

So far we have discussed in Chapters 2 and 3, in broad perspective, distribution systems, materials and allied procedures for designing and selection. However, any procedure will not automatically design an electric power system, in itself; it must be used with good, sound, basic engineering judgment.

Determination of the load is the electrical engineer's first problem and may be difficult to solve. The size and number of primary and secondary sub-stations, the size, number and arrangement of primary feeders, and the type of secondary distribution, are largely dependent on the amount and nature of the load and its distribution. Even after a system is in operation, loads may change in size and location. Changing environments, stabilized economy, increasing incomes, better social status, extending facilities and conveniences, all call for continual change in the distribution system, but these changes can be minimized by careful planning.

How to make preliminary estimates of loads is a problem deserving the closest study. These estimates may have to be used as the basis for major decisions. At this stage the electrical engineer often has available a few drawings and some incomplete maps. Co-ordination between the various engineers, including the architects, structural engineers, mechanical engineers, town planner etc. are of utmost importance. The electrical engineer is only one member of a large team, and as such, only by very close cooperation and coordination can the distribution scheme be made satisfactory, safe, flexible and economical.

Sound engineering practice demands that savings be made in areas not affecting the principal operation of the electric system. Hunch decisions are dangerous. Not only engineering training and experience, but also some imagination may be required to find the most economical method of solving a given problem. It is obvious that one way in which an economy study can reach a wrong conclusion is by the omission of an alternative that is better than those that have been considered (9). In fulfilling his professional obligations, it is the engineer's responsibility to see that the proposed system will be compatible with the requirements. No matter how much is spent on trim, the system cannot function properly with inadequate equipment, feeders and other basic components.

The power system engineer should also know the methods of making load studies, fault analyses, and stability studies, for such studies affect the design and operation of the system and the selection of apparatus for its control (26).

Computer modeling and simulation can help a great deal in the system design and analysis and save the unnecessary expenditures on equipments and material. However, before analysis can take place a network must be designed and this will be based on the following considerations:

1. Standards of security
2. Degree of utilization of network
3. The existing system if any
4. Standardized sizes of circuits and voltage level
5. Facilities and amenities available
6. Geographical location.

To meet a number of requirements, several schemes may be produced and then the optimum, on grounds of cost, number of circuits and other factors chosen. Loads will have to be predicted in most cases, (the system will come into existence after the initial design stage) and rough checks, such as generation meeting load-requirements may be made.

Of great importance is the reinforcement of an existing network to meet the growing load. As the latter is a continual process the examination of the existing network must also be frequently performed. The delay of adding an extra-link may save considerable expenses, even if delayed for only a year and this must be borne in mind.

The process of obtaining an optimum design is thus one of design-analysis-design-analysis and so on until the design constraints are met. Further development here, as with many design operations, lies in the realm of automatic computation. The data regarding load growth and the other considerations, already mentioned, must be stored along with the methods of design and analysis, engineers have traditionally used. A flow diagram illustrating the sequence of operations is shown in Figure 23.

The methods of logical design and linear programming are being used to express the design constraints in mathematical terms (30).

Keeping aside the engineering aspects of a distribution system, technical and management aspects of the distribution system must also be quite sound. For safe working, precautions and training is necessary. We will discuss about the safety precautions and the splicer's training in the next chapter.

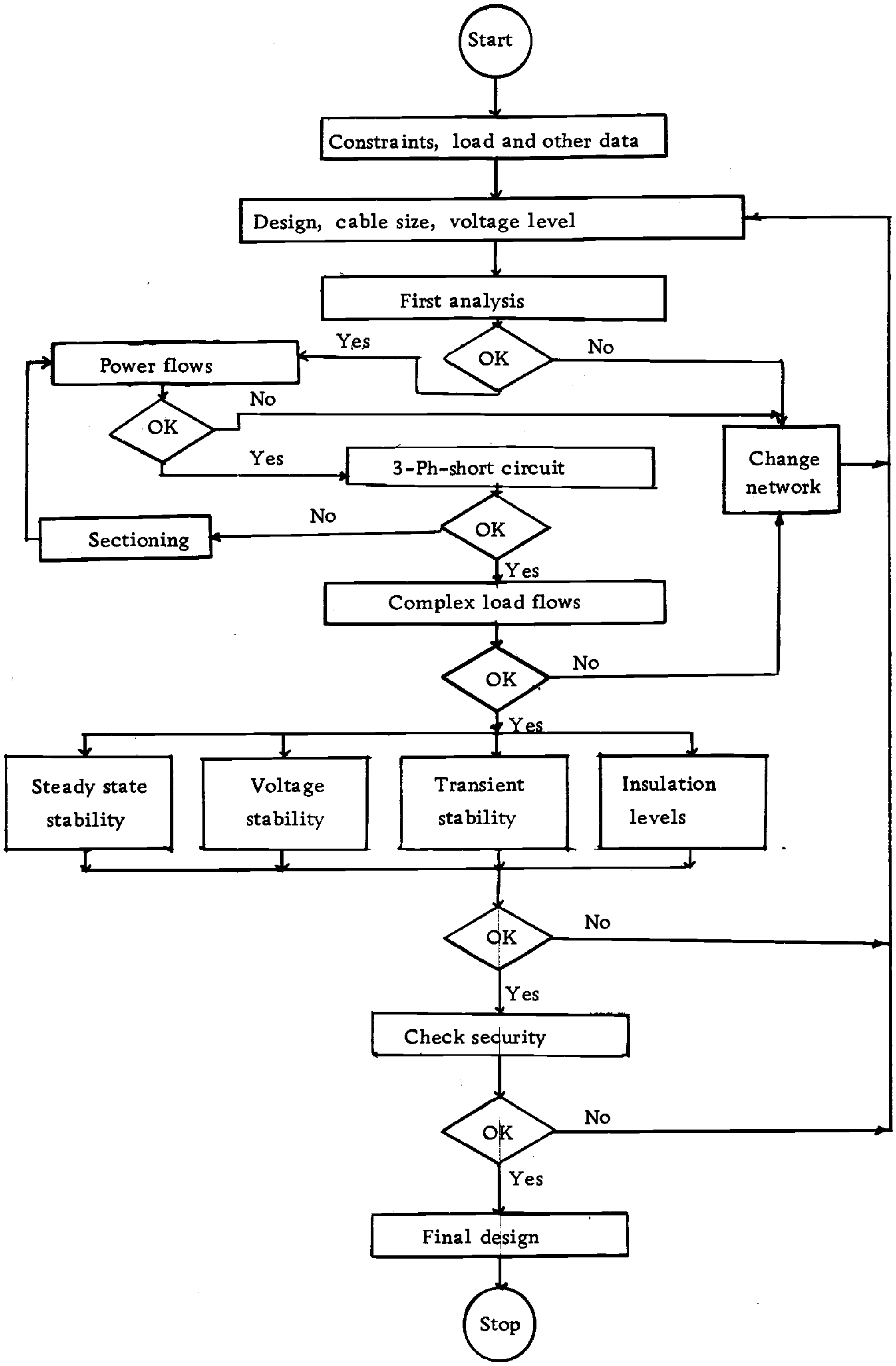

Figure 23. Flow diagram for design-analysis operation.

4. SAFETY PRECAUTIONS AND SPLICER'S TRAINING

Introduction

We will discuss in this chapter about safety precautions necessary for accident prevention and the general procedures for selecting and training splicers.

In order to discuss the principles of accident prevention, let us define the term "safety." Safety means the prevention of all accidents and all losses--or the absence of danger and freedom from harm. An accident, on the other hand, results in a delay or upsetting of the routine program, sometimes resulting in injuries to persons, property damage and loss of business or goodwill.

Compensation and medical losses are only a minor part of the total loss. These are known as direct costs, i. e., money paid to employee or physician following an injury, by the insurer. The so-called indirect costs are those which result from lost time of the employee, time lost by other employees directly associated, time lost by supervisors, cost of first-aid materials and services, damage to machinery, interruption of service, cost of continued wages in full while the employee is on limited duty assignment and dozens of other items which are not easily identified but which are very real. Estimates indicate that the hidden cost is several times that of the direct cost. When the hidden cost is added to the actual cost, the total assumes staggering proportions and is an extremely important item of operating costs. However, the humanitarian aspects of accidents must not be lost in an overemphasis of the dollar value. The future efficiency of an injured employee may be decreased appreciably, as well as his capacity to enjoy the fruits of his labor. His future economic status and that of his dependents may be seriously affected. Although the injured may be recompensed for his injuries, he is seldom thoroughly satisfied. Accidents may be truly called the poorest form of public relations. On the other hand, a forceful and positive safety program in the interest of the company and the employee is the good public relations.

Positive Actions

A man must choose, either consciously or otherwise, the degrees of risk he will tolerate in the methods he will use in practically every activity in which he engages during his working hours. Unfortunately, his judgment in these selections is affected by his temperament, habits, frame of mind, instructions received, and his reactions to happy or unsettling incidents both within and outside of his working hours (11).

Safety instructions and rules are only one part of the influences affecting a man's activities, but they are an important part. At least they set standards against which a man's activities can be measured and provide recognized guidelines when direction or disciplinary action is required. Any man who takes a minute to check for hazards and to plan methods and sequence of his operations is taking positive action (11).

Safety Program

A safety program should work under the supervision of a Safety Supervisor--who should be a brave and versatile man.

A well balanced safety program should contain the following elements:

a. Sustained management support and executive direction.

b. An adequate safety organization.

c. Supervisory acceptance, responsibility and active participation.

d. Effective employee safety education.

e. Adequate method of hazard elimination and control.

There are ten essentials to safety practices:

1. Safeguarding of machines and equipment.
2. Establishment of safe methods and practices.
3. Control of occupational disease hazards.
4. Provision of personal protective devices.
5. Safeguarding the public.

6. Proper first aid and medical facilities.
7. Frequent inspection of plant tools and equipment.
8. Thorough accident investigation and follow-up on recommendations.
9. Adequate fire prevention and fire fighting program.
10. Establishment of an effective off the job program.

Among these ten essentials are found the functions of a good safety organization which are Education, Inspection, Fire Protection, Driver Training and Safe Vehicle Operation instructions.

Accident Statistics and Investigation

Inspiration and continued enthusiasm must be foremost in safety education. Since incentive is promoted by the spirit of competition, contests are very helpful in accident prevention. Trends of accidents are most graphically shown in the statistical record. These statistics can be used to establish the cause of accidents and give valuable safety education material.

All accidents should thoroughly be investigated with a view of finding causes. After the primary causes have been established it will then be possible to determine methods to prevent recurrence.

The result of investigation should be recorded on the proper form. A suggested form is shown in Appendix I.

While accident prevention is the responsibility of management, all levels of supervision should be encouraged to fully accept and put into practice safety rules as determined by operating heads. The issuance of rules and procedures and providing safety devices is not in itself accident prevention. These rules must be implemented and enforced by the job foreman, who is management's representative in the field. It is the function of management to apply disciplinary measures in all infractions of rules.

The safety organization is responsible for promotion of accident prevention, but it is not responsible for the prevention of an accident to an individual.

<u>Personnel Safety</u> (12)

The following items should be considered in order to provide safe working conditions for the personnel.

1. Interrupting devices should be able to function safely and properly under the most severe duty to which they may be exposed.
2. Protection should be provided against accidental contact with energized conductors by elevation, barriers, enclosures, and other similar equipment.
3. Disconnecting switches should not be operated while they are carrying current, unless designed to do so. Suitable barriers should be provided between phases to confine accidental arcs

unless adequate space separation is provided.

4. In many instances interlocks between the disconnecting switch and power circuit breaker are desirable, so that the breaker in series must be opened first before the disconnects can be operated, thus preventing accidental opening of the disconnects under load.

5. Sufficient unobstructed room in any area containing electric apparatus must be provided for the operator to perform all necessary operations safely.

6. A sufficient number of exits with "panic type" door features should be provided from any room containing electric apparatus such as sub-stations, control room or motor room so that escape from this area can be easily effected in the event of failure of apparatus in the room.

7. A protective tagging procedure should be set up to give positive protection to men working on equipment. Such a procedure should be thoroughly co-ordinated.

8. The distribution system should generally be designed so that all necessary work on circuits and equipment can be accomplished with the particular circuits and equipment de-energized. The system design should provide for locking out circuits or equipment for maintenance. Lockout switches should accept three or more padlocks and should be located

near the driven equipment convenient for mechanical maintenance personnel so that non-electrical personnel need not enter motor and control rooms. In very special situations where it is necessary to work on energized circuits, especially trained crews with adequate safety equipment should be used.

9. Rubber gloves deteriorate and consequently should be checked regularly, otherwise they may become more of a hazard than a safeguard because they give the operator a false sense of security. In general, they should not be used without leather protectors if the work is such that the glove may be snagged or torn.

10. All circuits should be marked in the switching station so as to be readily identified. Cables should be identified with suitable tags at both ends and in all manholes for protection of men working on them.

11. Consider the fire and explosion hazard of oil-filled apparatus and whether such equipment is permitted by codes. Wherever possible, substitute apparatus such as air circuit-breakers, air load-interrupter switches, and askarel[17]-insulated or dry type transformers.

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[17]Askarel is very toxic and some people are highly allergic to it.

12. A fire brigade should be formed of local employees[18] who are familiar with the equipment and the hazards involved. This group should be trained in the proper procedures to follow in the event of fire in the electric apparatus, the proper use of the various types of extinguishers and methods of fire fighting.

Grounding of the Equipment

The subject of grounding may be divided into two main parts. That is, the grounding of the system for electrical operating reasons and the grounding of non-current-carrying metal parts for safety to personnel (12). The principal reason for grounding an electric system are discussed in detail in Chapter 2. The grounding of electric system and equipment has been a National Electrical Code requirement for many years. This Code states specifically that

> Circuits are grounded for the purpose of limiting the voltages upon the circuit which might otherwise occur through exposure to lightning or other voltages higher than that for which the circuit is designed; or to limit the maximum potential to ground due to normal voltage.[19]

Failure to provide proper grounding for electrical equipment may be considered as the primary cause of many accidents which have

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[18] Of jointers and their mates, electricians and their mates.

[19] The latest requirements for grounding low-voltage systems may be found in Article 250 of the 1953 Edition of the National Electrical Code.

resulted in the death of personnel[20] and no system is complete unless adequate grounding connections have been made. Grounding of equipment is such an important phase of the electrical installation, that it must not be passed over too lightly. This is particularly important when we realize that high voltages are not necessary to cause death from electric shock. Many deaths are recorded annually resulting from shock received from the usual 115-120 volt lighting and appliance circuits and many of these could and should have been avoided by proper grounding procedures.

Electrocution and Its Physiological Effects (16)

Although the physiological effects of accidental shock range from mild sensation to electrocution, oddly enough the greatest threat to man's life comes not from higher but lower amperage values.

Most electrical engineers and electricians are aware that the principal danger from electricity is that of electrocution, but few really understand just how minute a quantity of electrical energy is required for electrocution. Actually, the current drawn by a $7\frac{1}{2}$ watt, 120 volt lamp, passed from hand to hand or foot, is enough to cause fatal electrocution. Just as it is current, and not voltage, that heats a wire, it is current that causes physiological damage.

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[20] In Mecca as well.

The different values of 60 cycle alternating current and their effect on a 68 kg (150 lbs) human are listed in Table 18.

Table 18. Current range and effect on a 68 kg man.

60 cps Current	Physiological Phenomenons	Feeling or Lethal Incidence
<1 mA	None	Imperceptible
1 mA	Perception threshold	
1- 3 mA		Mild sensation
3-10 mA		Painful sensation
10 mA	Paralysis threshold of arms	Cannot release hand grip; if no grip, victim may be thrown clear (may progress to higher currents and be fatal)
30 mA	Respiratory paralysis	Stoppage of breathing (frequently fatal)
75 mA	Fibrillation threshold 0.5%	Heart action discoordinated (probably fatal)
250 mA	Fibrillation threshold 99.5% ($\geq$ 5 second exposure)	
4 A	Heart paralysis threshold (no fibrillation)	Heart stops for duration of current passage. For short shocks, may restart on interruption of current (usually not fatal from heart dys-function)
$\geq$5A	Tissue burning	Not fatal unless vital organs are burned

In short any current of 10 mA or more may be fatal, those between 75 mA and 4 amperes are fatal from heart discoordination, and those above 5 amperes may be fatal from severe burns. It is a fact, however, that shocks in this last current range are statistically less dangerous than those from 75 mA to 4 amperes. In view of the wide diversity of injuries derived from contact with electric energy, it is only logical that, to prevent electric shock or electrocution, there must be minimum exposure to energized parts.

To determine the current, Ohm's law is applicable, with the human serving as the resistive element of the circuit. The R, which is the variable, is actually the controlling factor. Essentially, it is the human skin, along with such factors as area of contact, tightness of contact, dryness or wetness of skin, and cuts, abrasions, or blisters that introduces the variables. Except for the skin, human resistance is about 250 ohms per arm or leg, and 100 to 500 ohms from shoulder to shoulder or hip. The more muscular the person, the lower the resistance. Skinny arms or legs, and those made up principally of fat, have higher resistance. Bone too, has a high resistance. Table 19 shows the range of human resistance variations. The total human circuit resistance is, of course, the sum of the two contact resistances and the internal body resistance. (Compare with Table 20.)

Figure 24 provides a ready means of evaluating the physiological effect of a human resistance and a 60 cycle voltage source. Note that at about 600 v the resistance of the skin ceases to exist; it is simply punctured by the high voltage like capacitor insulation. For higher voltage, only the interal body resistance impedes the current flow. It is usually somewhere around 2400 volts that burning becomes the major effect; below this voltage, fibrillation and/or asphyxiation are the usual manifestations.

Table 19. Human resistance for various skin-contact conditions.

Conditions (Area to Suit)	Resistance, ohms	
	Dry	Wet
Finger touch	40 k-1 M	4-15 k
Hand holding wire	15-50 k	3-6 k
Finger-thumb grasp	10-30 k	2-5 k
Hand holding pliers	5-10 k	1-3 k
Palm touch	3-8 k	1-2 k
Hand around $1\frac{1}{2}$ in. pipe (or drill handle)	1-3 k	0.5-1.5 k
Two hands around $1\frac{1}{2}$ in. pipe	0.5-1.5 k	250-750
Hand immersed	--	200-500
Foot immersed	--	100-300
Human body, internal, excluding skin = 200 to 1000 ohms.		

Table 20. Resistance values for equal areas (130 cm^2) of various metals.

Material	Resistance ohms
Rubber gloves or soles	More than 20 M
Dry concrete above grade	1-5 M
Dry concrete on grade	0.2-1 M
Leather sole, dry, including foot	0.1-0.5 M
Leather sole, damp, including foot	5 k-20 k
Wet concrete on grade	1 k-5 k

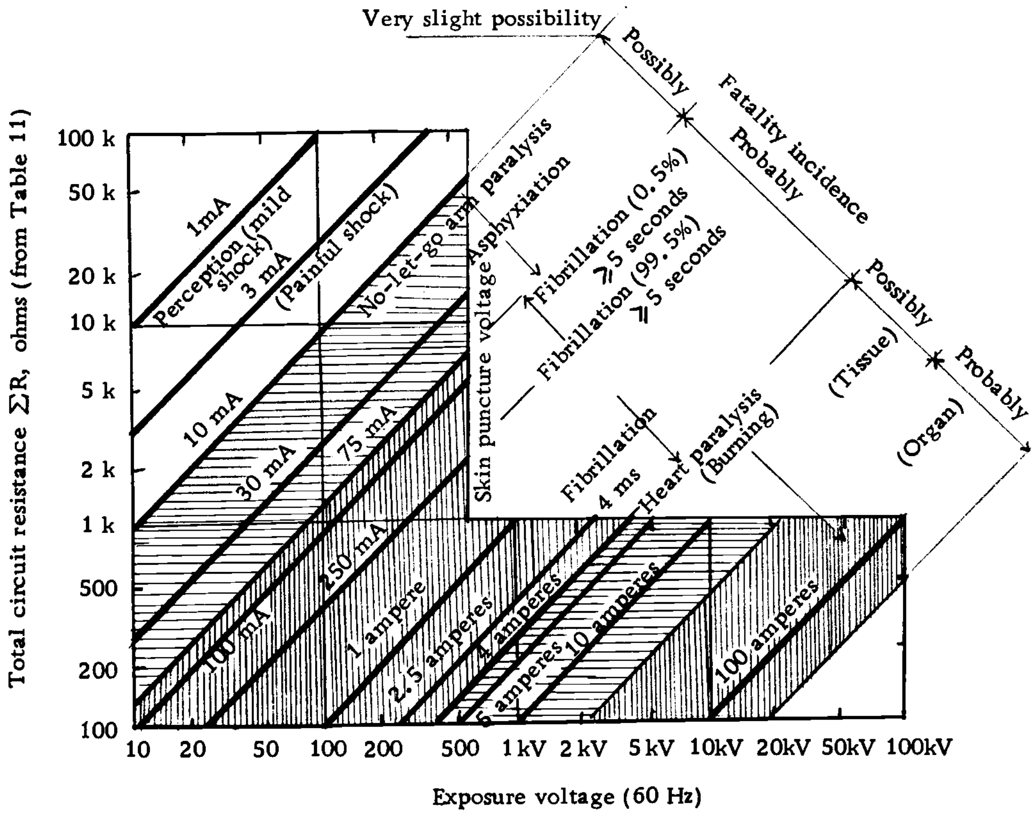

Figure 24. A resistance-voltage-current shock appraisal chart.

In fibrillation, the victim may not recover consciousness. On the other hand, he may be conscious, denying needing help, walk a few feet, and then collapse. Death may occur within a few minutes or, at most, hours. Detection of the fibrillation condition requires medical skill. Application of closed-chest massage--a treatment in which blood is circulated mechanically in a fibrillation viction--can result in death of a subject whose heart is not in fibrillation.

In Figure 24, the fibrillation line is shown at 75 mA. Actually, this is the threshold sensitivity for an exposure of five seconds or more. For shorter times, the threshold current is higher, along a constant I^2t times. It should be noted that, if the duration of shock is only 0.008 second or one-half cycle of the 60 cycles, the fibrillation threshold current is raised to 1800 mA or 1.8 amperes. Referring back to Figure 24, such a siatuation moves the threshold over almost to a heart-paralysis and tissue-burning zone, and reduces the pertinent area of the fibrillation zone.

This sensitivity, increasing with time, explains why a victim who is "frozen" to a current source is much more likely to be electrocuted than one whose contact does not involve hand grasp. A full hand grasp immobilizes the victim such that he cannot let go; hence the exposure time may extend to many seconds, placing it in range of the 75 mA threshold. In comparison, a casual contact (such as with a fingertip) causes instant retraction of the arm, interrupting the shock-circuit path. In this case, the victim is exposed for only a few thousandths of a second and is much less likely to sustain an injury. According to Figure 24, an exposure of 10 ms could sustain a current of 1.5 amperes or 20 times as great as when a paralyzing hand grasp was involved.

Man having sweat-soaked cloth gloves on both hands, and a full grasp of a large energized conductor and a grounded pipe or conduit develops a circuit resistance of 500 ohms. Moreover, cuts, abrasions, or blisters on a man's hands can negate the skin resistance, leaving only internal body resistance to oppose current flow. A circuit value as low as 37.5 volts could be dangerous in this instance. For a 1000-ohm man, 75 volts could be dangerous, and 120 volts would require only a 1600-ohm human resistance.

Since humans are affected in direct proportion to the duration of the shock, the following practice in handling parts or equipment that may possibly be energized appears most logical in reducing this duration:

1. When potentially exposed to values above 50 volts, employ light finger touch only, rather than hand grasp. The strong muscles of the arm, reacting from the muscular contractions of a 10 mA or higher shock, will pull the fingers away, whereas a full hand grasp will probably not be overpowered by the upper arm muscles.
2. Whenever contact is made in such a manner as to be able to retract the contracting portion of the body, duration of current flow is extremely short, since the retraction is instantaneous, with the muscles operated directly by the shock current, rather than from the relatively low motor nerve currents from the brain, which require reaction times of 0.7 seconds or so.
3. This short duration of shock is much less dangerous than one of the same current having longer duration such as incurred

by "freezing" to the contacts from a full hand grasp.

Where voltages above 2300 volts are involved, the victim can not grasp the energized conductor, since an arc is initiated to his hand, causing it to retract before he can complete a grasp. For this reason, high-voltage shocks are nearly always of very short duration, reducing the magnitude of burning (watt-seconds) as compared with the result of a long-duration shock.

Special Techniques for U/G Safety

Safety habits acquired in working overhead systems can be the very means by which accidents can occur when operating and maintaining underground systems. Opening a fused disconnect switch on an overhead radial line is a farily sure way to de-energize the tap it feeds and provides a visible disconnect to indicate that the tap is no longer alive. Yet, cables on both sides of an open U/G switch and both sides of the switch itself remain alive if the underground switch happens to be in a loop feed supplied from both ends. Safety for men who must alternate between overhead and underground lines can result only when they are aware of these differences and remain alert to their consequences.

Strict operating procedures, careful training, and close supervision are absolutely required when even the most careful linemen trained in overhead operations first start to work on underground lines. Sources of energy are concealed, methods of testing for live conductors are more complex, and solid grounds are within inches of line conductors. A man accustomed to insulation given him by the wooden pole or insulated bucket from which he works can forget that when he is standing on damp ground it is the first contact that can result in an accident, while generally two simultaneous contacts are necessary before serious trouble develops when he is aloft (21).

The critical differences between underground and overhead operations are that clearances of live parts to ground are much less in underground construction and that the men themselves are at ground potential at all times. It is absolutely necessary that protective equipment be used always whenever work must be done on underground systems after they have first been put into service. This includes hard hats, eye glasses and rubber gloves, and hot sticks not less than 8 ft long. In case of underground systems any contact with live equipment immediately completes the circuit and man is always effectively grounded.

For safety in U/G systems the following should be remembered:

1. Absolutely nothing, including both cable terminations, both sides of the switch and taps to equipment, can be considered dead when a switch on a loop-feed underground system is opened, even though there is a visible air break.
2. A cable that has been energized will still carry a dangerous

potential even after all switches supplying the cable have been opened. This is because of inherent capacitance of the cable. A high-voltage electrical charge stored in this capacitance during operation does not drain off until the cable is grounded.

3. If two cables are laid side by side in a trench and only one of them is alive, the idle cable will pick up a high voltage charge, even if it has never been put into operation. This charge will remain until the idle cable has been grounded effectively at both ends.

4. Phase identification on underground cables is more difficult than with overhead conductors which can be traced visually. Extreme caution in identifying phases should be used when installing a loop supplied from two isolated terminals or a phase-to-phase short could result when the loop is closed.

5. It is extremely important that grounds be installed and remain on both sides of a cable section that is to be worked on as close to the work site as possible. Particular care should be paid that there are no disconnect switches between a ground and the work site, for the ground is lost if such a switch is opened.

6. Pad mounted apparatus as distribution cabinets etc. must be securely fastened at all times when workmen are not present, even for a moment. It is a temptation to leave a padlock on

a cabinet door unfastened if a workman must leave the site temporarily but plans to return shortly to complete the job. However, padlock can, and have been unfastened and then forgotten, leaving energized equipment accessible to the public and particularly to curious children.

7. All circuits should be marked in the switching station so as to be readily identified. Cables should be identified with suitable tags at both ends and in all manholes for the protection of men working on them.

8. The grouping together of a number of valuable or important cables or wires in trenches, cable boxes, junction boxes and manholes should be avoided, particularly if they have combustible insulation. This applies to both low, medium, and high voltage installations, and lead sheathed cables as well. A failure in one cable or conductor can cause an arc that ignites the insulation on one cable and fire may destroy the entire group, or the arc can do extensive damage in the event of sustained arcing. Where it is necessary to group such cables together, they should be fire protected with a fireproof covering.

Work Area Protection

The traffic problem of today makes it essential that every company set up a standardized program for protection of the work area exposed to automotive traffic. The "hit" or "miss" method of protection is utterly inadequate. Hence, a manual containing the best thinking on the problem in the form of orders, illustrations and specifications, is most helpful for use of the forces performing this work. A description of protective equipment, layout of the work area, typical traffic problems, exceptions and rules of common sense should be contained in this manual.

Necessarily contained in the problem of working on the streets and highways is maintaining the all-important good relations with the public. The motorist and pedestrian are inconvienced and the manner in which a formalized program is conducted must take into consideration their protection and good will.

The three "musts" of Planned Work Area Protection are:

1. Maximum protection for the employee while working on the streets and highways.
2. Maximum protection to motorist and pedestrians.
3. Maintaining the free flow of traffic through a minimum use of the streets for a work area and compliance with local rules and ordinances pertaining to traffic movement.

We lay down a few general principles for work area protection. However, a knowledge of the area, nature of traffic and the application of good common sense will make them valuable aids to greater underground safety. The recommended general principles are:

1. The amount of space utilized and the protective set-up needed depend on how much traffic there is--and whether the traffic is slow or fast moving.
2. The smaller the confines of the work area, the easier it is for traffic to avoid it.
3. With a smaller work area, traffic flows more easily.
4. The essential difference between day and night work is illumination which must be supplied for both warning and work visibility.
5. Wherever possible, pedestrian crossings should not be obstructed.
6. Personnel and equipment or materials needed on the job must be kept within the boundaries of the work area.
7. Housekeeping and general order of arrangement in the set-up promotes efficiency and safety.
8. Emphasis must be placed on protecting the side of the area from which traffic is approaching.
9. When distant warning is given, ample opportunity is afforded for oncoming traffic to avoid the area.
10. Warning devices should be so designed and of sufficient height to attract the attention of drivers and pedestrians.
11. Tool carts, trucks, barricades, or excavated materials

should be placed between approaching traffic and the work area. The obstruction to traffic should be no greater than the width of the equipment involved. Area required for storage and additional equipment may be obtained by increasing the work area in the direction of traffic.

12. In excavation work the same principles apply except that it may not be possible to confine the width of the area to the equipment involved. Instead the job should be performed in steps to minimize the obstruction to traffic.
13. The set up should be maintained only as long as absolutely necessary to perform required operations.
14. Work should be scheduled, where practical, to avoid the hours of peak traffic.
15. Municipal authorities or police should be consulted when construction work results in prolonged obstruction to traffic. Permits granted by municipalities usually require such notification.
16. Use of a flagman while setting up or breaking down a work area provides additional protection.
17. If it is necessary to maintain pedestrian or automobile corssings at an excavation, suitable bridging should be used.
18. Tape and stanchions, barricades or trafficones should be used to enclose the work area.

19. Blinkers mounted on trucks or flashing lights used independently, as well as flags, lanterns and kerosene bombs are essential equipment for warning purpose.
20. A guard rail is necessary to enclose the open hole even though the work area is enclosed.

Gas Detection and Ventilation

We will first discuss about gas detection and then about ventilation.

The atmosphere we breathe contains 21 percent oxygen, 78 percent nitrogen and one percent of other gases. Poisonous gases are usually carbon monoxide and or hydrogen sulphide. They are toxic in very small quantities; in fact, several hours exposure to workmen in an enclosed area with concentrations as small as one part in one thousand may be fatal. Furthermore, the effects are cumulative so that exposure to even lesser concentrations over a long period produces serious results.

When the air is diluted, as in a confined place, with additional nitrogen, carbon dioxide or other inert gases, the oxygen in the air will not support respiration. Sudden unconsciousness and death can be caused by entrance into this oxygen-deficient atmosphere.

The physiological response to oxygen deficiency varies according to conditions. As the concentration of oxygen is reduced, breathing and pulse rate increase and muscular co-ordination becomes disturbed. Further reduction in oxygen content causes increased disturbance and the slightest exertion results in abnormal fatigue. As the deficiency increases the victim may become nauseous and unable to move about, and at extremely low contents respiration stops and heart action ceases in a few minutes. It is unfortunate that untrained persons can not readily recognize oxygen deficiency. The early symptoms of rapid pulse and breathing rate may not be noticed until the victim is too weak. This is unfortunately the case when it is necessary to climb stairs or ladders to get out of the oxygen-deficient atmosphere. Every exertion increases the breathing rate and further depletes the oxygen from the blood stream.

Subsurface structures, such as manholes, transformer vaults, splicing boxes, etc., are subject to accumulation of dangerous gases. The gases may be:

1. Combustible or explosive
2. Toxic
3. Atmospheric deficient in oxygen.

In general, sub-surface structures are considered hazardous until proven clear by test or until ventilated. Some companies test all manholes before entering. Others follow a practice of marking all manholes in areas where toxic gases, explosive mixtures or oxygen-deficient atmospheres are found. Some companies rely to a considerable extent on ventilation in lieu of testing.

If manhole covers are provided with holes suitable for the insertion of tubes attached to gas detection indicators, it is not necessary to remove the cover of the manhole before testing for the presence of gases. If holes are not provided the cover should only be raised sufficiently to admit the sampling device. In raising the cover care should be taken to prevent the creation of sparks.

In some cases the sense of smell has been relied upon to detect the presence of explosive gases. However, natural gas, which is fundamentally odorless, is odorized by chemical agents which may scrub out through oxides or passage through earth so that gas may be present in a manhole with insufficient odor to be detected by the sense of smell. For these reasons, in locations where gas may be present, tests with suitable equipment for the determination of gases are made before manholes are entered for continued work.

There are two basic types of equipment suitable for the detection of dangerous combustible gases. One is a hot wire detector, the other a safety lamp. In using either instrument a sample is drawn from the manhole through a suction tube preferably by inserting the tube in the hole in the manhole cover or raising the cover only sufficiently to permit insertion of the tube under it (7).

The increasing use of nitrogen in high tension cable work has introduced new hazards in oxygen deficiency. Purging of pipes for high-pressure pipe-type cable has resulted in fatal accidents. A prolonged leak in a gas-filled cable may possibly lead to a dangerous condition in a manhole. The use of CO_2 fire extinguishers can also produce an oxygen-deficient atmosphere. Tests for oxygen deficiency may be most readily made with the safety lamp. As the concentration of oxygen decreases, the flame height is reduced, and at dangerous levels the flame will be entirely extinguished. For checking the oxygen-concentrations, gas samples from a manhole be taken and tested in a laboratory.

Ventilation is best accomplished by a power-driven blower, the output of which is blown into the hole so that any gases will be replaced by fresh air. Blowers should be so located that exhaust fumes from vehicles or the equipment itself shall not be forced into the manholes.

If an explosive quantity of gas is found and it is decided to ventilate the manhole, any workmen in the adjoining holes should be notified, as the ventilating operation may result in circulation which will distribute the gas to other locations.

Should an explosive mixture be indicated, care should be taken not to create a spark in removing the cover prior to ventilation, and proper precautions with regard to smoking and other open flames should be enforced so that there is no source of ignition within a reasonable distance of the hole to be opened.

Injection of CO_2 in a manhole will reduce the possibility of an explosion if gas is known or suspected. The manhole should be properly ventilated to guard against oxygen deficiency before entering. Manholes in which the presence of gas is indicated should not be entered. However, should it be necessary in emergency to enter a manhole deficient in oxygen or where toxic or flammable gases are present before ventilation can be accomplished, a gas mask of suitable type, which will furnish oxygen sufficient for breathing should be worn and extreme care should be taken that no sparks or open flame are carried in the presence of an explosive gas.

A precatuion which should not be overlooked is provision for rescue of a man entering a manhole in which gas is known to be present. A man, entering a manhole in which gas is present, should be equipped with a rescue rope or harness and sufficient personnel should be available on the surface to effect a rescue if necessary.

Fire Fighting

It is important to understand the fundamentals of fire to know the ways to fight fire with least personal injury or equipment damage.

Fire is the rapid oxidation of some material,[21] accompanied by flame and the liberation of heat. An explosion is extremely rapid oxidation usually occurring in a confined place. In order for fires to

[21]We call this material, "fuel."

progress, three conditions are necessary:

1. Presence of a fuel or material which will burn

2. Air, which contains oxygen, and

3. The surface, at least, of the fuel must be heated above its "flash point."[22]

These three elements form the fire triangle, as shown in Figure 25. Logically, if all three conditions are required for fire to exist, the removal of any side of the triangle, will cause the fire to go out. Theoretically, putting a fire out is just as simple as that. Practically, it is not always possible to remove the fuel, but, if the fuel can be cooled sufficiently the fire will go out. Also, it may be possible to smother the burning material with foam or inert gas. If the fire is small enough it may be covered by a blanket to exclude the air and thus cause extinguishment. In fact, it is by cooling or smothering, or a combination of the two methods, that all extinguishing agents work.

In case of an underground structure, if smoke is issuing, do not remove the cover. Arcing may still be taking place and the smoldering of the insulation and oil may have produced a too-rich mixture of vapor and air. Removing the cover may admit enough air to cause a violent explosion. Inject CO_2 or dry chemical through the holes in the cover. If the cover is solid and does not have vent holes, lift it

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[22]This is the temperature to which, if a material is heated a sudden flash will appear, but the material will not continue to burn.

slightly and inject the extinguishing agent. When the air in the manhole or service box is made inert, it is safe to remove the cover but due caution and care in removing it should be exercised.

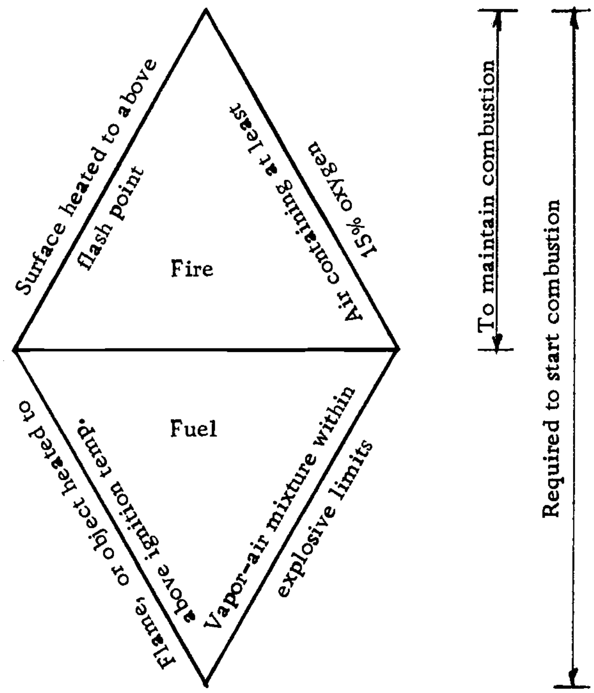

Figure 25. Fire triangle.

First Aid, Resuscitation and Rescue

An occasional injury may occur inspite of all precautions. For such emergencies, preparation must be made for first aid attention. First Aid Kits should be conveniently located on trucks and tool carts, in shops and station. The contents of the kit will vary according to the number of men, particular location and the kind of work which they perform. All the employees who are exposed to hazardous environment or work should be trained in the use of the kit. In particular, they should be taught artificial respiration, how to stop blood, the use of antiseptics, the treatment of burns, application of bandages and the handling of victims with broken bones.

One form of first aid which requires special emphasis, training and periodic retraining is the resuscitation from electric shock or gas asphyxiation. Immediate and properly applied treatment is absolutely essential to be successful in these cases. Therefore, all employees should be thoroughly trained before being assigned to any work where exposure to these hazards may exist. Regular charts showing the Back Pressure Arm Lift Method and Schafer Prime Prone Pressure must be available.

It should be remembered that an unconscious person becomes cold very rapidly and chilling means a further strain on a vitality already weakened. Experience has shown that the cold to which the victim of gas or electric shock are often carelessly exposed is probably the most important cause of penumonia, and this disease is the most dangerous after-effect of all these accidents. As far as possible, keep the victim covered while artificial respiration is being given. If it should be necessary to move the victim, keep him lying down and do not permit him to erect himself.

Even though normal safety precautions are observed, there are occasions in connection with underground construction and operation where personnel may be overcome or injured. In all such cases following principles are important and must be observed.

1. Rescue without delay is most important.
2. Personnel engaged in rescue should protect themselves--another victim should not be added to the accident.
3. In cases of asphyxiation or gas poisoning it is advisable to ventilate with a blower or wind curtain immediately while preparing for the rescue.
4. Bring the victim through the manhole chimney or opening carefully to prevent further injury.
5. In injuries resulting from a fall into a manhole or excavation, give first aid and wait for an ambulance so that a hospital litter can be used in lifting the victim.
6. If the victim is not too far gone, assist him under his own power (7).

In the rest of the chapter we discuss about the selection and training of Cable Splicers.

Splicing Personnel Requirements and Work Load

If an underground system is to be reasonably free from service outages and expensive repairs, it must have well made cable joints. Good cable joints are the end result of an efficient and well-trained splicer, supervised by an equally well-trained and experienced foreman. With the modern development of cables the need for adequately trained splicers becomes increasingly evident. It is not practical to obtain men so qualified in the open labor market and it is not wise to get this job done by contract. It requires years of training to prepare a cable splicer to become fully qualified in today's broad field. To ensure that an adequate number of cable splicers are available to meet the demand, a training program must be planned and be geared to the anticipated work load in the same manner that generating capacity must be planned in advance of its needs.

The cable construction load must be forecast on a long range basis, usually 5 to 10 years. This forecast must be extended and reviewed with the passage of time. Local conditions will determine how frequently it is necessary to bring this forecast up-to-date. The following sources of information provides facts for anticipation of the work load:

1. Predicted system load growth.
2. Planned new generating stations or additional capacity in existing stations.
3. Planned new transmission or distribution feeders.
4. Planned extensions and reinforcement.
5. Normal system maintenance.

The available working days and the total splicer-days determine the number of splicers required per day for each project. Available working days are determined from the required completion date and the earliest possible starting[23] date. The anticipated work load is then the addition of splicer days required for all work subdivisions (7). Figure 26 shows a typical work-load forecast.

In the following table completion dates or maintenance schedules can be adjusted if there is some deficit or excess in the availability of the splicers. If there is a rising deficit or increasing surplus, this should be investigated. Such trends should be confirmed by other information generally available. Most utilities must maintain a forecast of system load in advance, on which planning for expansion of system facilities is based. Suppose the forecast indicates the system is expected to grow one percent faster in the next five years that it did in the last five years. Increased growth means increased splicer needs, both for installing the new facilities and to maintain the increased facilities.

Other factors must also be considered before arriving at final forecast figures of work load. Technological advances, such as future increases in primary or secondary voltages, increased cable lengths and anything which would reduce failure rate, would all operate in the reverse direction on work load as would increased system rating.

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[23] See a project scheduled by CPM techniques in Appendix III.

Description of Job	Job Identification Number	Splicing man-days required/day											
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Network extensions	NE/SEC	7	7	7	7	7	7	5	5	7	7	Completion due Nov 1	
Establish new feeders	ENF/SEC	3	4	4	4	4	4	3	3	4	4	12	12
Reroute and reinforce	RR/SEC	2	2	6	6	6	6	4	4	6	6	4	4
Substations	SS/SEC	2	2	2	2	2	2	2	2	6	6	9	9
Transformer connections	Various	11	10	11	11	11	12	10	9	11	11	11	11
Removal & miscellaneous	Various	15	14	10	10	11	11	9	8	7	7	7	7
System improvements	SI/SEC	25	24	25	25	25	25	20	20	25	24	24	25
Emergency repairs	ER/SEC	38	38	38	38	38	38	32	32	38	38	38	38
Splicers required	SR/SEC	103	101	103	103	104	105	85	83	104	103	105	106
Splicers available (a)		Authorized personnel--100(b)											
Splicers deficit		3	1	3	3	4	5	5	3	4	3	5	6
Splicers excess		0	0	0	0	0	0	0	0	0	0	0	0

(a) Actually available--absence due to sickness etc.

(b) Except for 20% reduction in July and August for vacations.

Figure 26. Typical work load forecast.

Conversely, use of larger copper sizes, changes in governmental policy and changes in international conditions could all operate to increase the work load.

Forecast of Splicer Training Requirements

Once the number of splicers required in the predicted future is determined, it is then desirable to examine the availability very carefully. The degree of attrition is surprising when a long range study is made. Some of the reasons for exit applicable to cable splicers are:

1. Retirement for age
2. Death
3. Early retirement
4. Transfers
5. Promotions.

The number of splicers who must leave the available force each year for reason of age can be determined easily. The incidence of exists due to death can be closely approximated from acturial tables. Optional and disability retirement do occur and can be evaluated as to number of exists only by the experience of a particular organization.

"Troublemen" and splicer foremen are chosen from the splicer force; "over-age" splicers are assigned to less severe duties; these changes cause transfers from the splicer force. "Over-age" splicers, as referred, include those not yet of retirement age who must be transferred to less severe duty. These men, while not able to withstand the rigors of working in manholes or service boxes, are still valuable for salvage work, inspection of rubber protective devices, service installation, safety inspection, etc. The reduction in the number of available splicers, for these reasons, depends on the policy in an organization.

Factual information as to the magnitude of construction work more than five years in advance is generally not available. Even if it were, it could be so subject to change that a training program could not be efficiently geared to it. Furthermore, a period of five years is generally sufficient to train the required additional personnel. Such training will not, of course, furnish craftsmen equal to those being lost. However, the new men will be able to execute the less difficult assignment and, by gradual upgrading all along the line, the force will be kept in balance.

The splicer deficit must also be considered from various other angles before a decision is made as to the number of splicers to train. It is inefficient to encounter a surplus. A deficit can be eliminated by spreading the work load or by working the available force overtime. Economic policy within a particular company will determine the decision. The number to be trained should be adjusted to the minimum for the immediate period ahead.

It is of prime importance that trainees selected are not only the best available material for learning the mechanical skill required to make a joint, but also that they are the kind of individuals who fit the best into the working team. Modern industry thinks of the employees as a team and weakness in any position weakens the team. Failure to continuously feed high qualities into the force will cause a waste of training time for the individual and a waste of time and money by the employer. Later, poor selection will be reflected in system performance by early and more frequent failure of joints or cables. Eventually, it will be difficult to find men suitable for promotion to higher titles and supervision in the splicing force.

Instruction Method and Curriculum

Four general methods of training may be used. They are basically:

1. Training in the field--pick up method.
2. Training in the field--apprentice method.
3. Training in the field with classroom methods.
4. Training in the classroom.

Training in the field by pick up is that method where the splicer's helper gradually learns from the splicer during the regular job assignments. There is no organized program. This method is sometimes referred to as the "old school experience." While much learning is still acquired in this way, the organized program is by far the better.

In the apprentice method, a trainee learns by doing productive work in the field under the tutorship of a qualified cable splicer. He may be continuously under the guidance of the same splicer or he may be scheduled to work with a number of different splicers. The program is specific.

Splicers can also be trained in manholes designated for training only. In such cases the program is set up in much the same manner as when training is given in an indoor classroom and therefore includes many of the advantages of the latter. In addition it permits incorporation of repeated practice of the street surface set up, including work area protection and all the procedures that must be followed in a day. It necessitates making a splice under conditions which, in a number of ways, are more rigorous in the street manhole than in an indoor classroom. Training of this kind is carried on irrespective of the weather. Variety in weather necessitates the application of the procedures necessary in normal work, in mitigation of the discomfort and harmful effects of rain, cold, heat and windswept dust. The importance of having a job prepared properly in advance becomes very obvious. In a school, when a necessary tool or material is not procured in advance, the omission is rectified with little loss of time. Any such omission in the field will cause delay. This method is more realistic in many ways. There are disadvantages too. It is more cumbersome to train a large number of men at one time. The training time is usually longer because of the inclusion of more detail and the less convenient working conditions. Due to this, a splicing force may not be expanded as quickly and training must be planned to start further in advance of anticipated need of additional splicers. Training in the field does not permit much use of visual aids or the more involved and expensive mock set ups. The operation of such a program can not be observed as readily by upper-level supervision.

In the classroom method, all training is done indoors under most favorable working conditions and under the direction of a thoroughly qualified instructor. Time spent is all overhead expense, since no productive work results. This method can be very closely controlled as to subject matter because it is operated in accordance with a specified program. The duration of training is also in direct control, since the program of instruction includes a time schedule. A single instructor for a number of trainees makes this method efficient. When two or more people are trained together, they usually mutually profit by each other's accomplishments, errors and comment. This system of training includes group lectures and demonstrations before the group as well as individual practice on splicing technique. Uniform evaluation of accomplishment is inherent. It also readily lends itself to quick expansion of the splicing force, since training is accomplished in less time. New methods, new procedures and new working rules can be easily transmitted to the trainee group. The whole training operation is accessible for inspection by upper-level supervision and this is important in keeping the quality of the training at a high level.

Choice of which system to use is largely determined by local requirements and policy. Although a greater number of advantages have been indicated herein for the classroom method, these must be evaluated in terms of their particular significance locally. Cost is always a primary factor. If only a few splicers are to be trained each year, the cost of a classroom may not be justified. Methods and duties of first-line supervision may be a pertinent factor. Where a foreman supervises only a few men in a small area, he can do much training on the job. A program of selected work assignment for the new splicer may assist in reaching a conclusion. In addition to the factors indicated in the foregoing, consideration should also be given to what agency shall give the training and at whose expense it shall be (7).

The curriculum should be designed to impart the required general information to the trainee and to enable him to develop the necessary craftmanship. To better understand his work and his surroundings, the splicer also requires a minimum knowledge of the fundamentals of electricity, such as units of measurement, wire and cable sizes and current carrying capacity, circuit representation symbols, difference between direct and alternating current and transformer and condenser action.

The trainee should also be made to realize the dollar-and-cents value of the underground cable system. Inadequate recognition of these factors often leads to cable or joint failures which might otherwise be avoided.

A most important early detail is the knowledge of how to create a safe work area. Maximum safety does not exist without good housekeeping. With ability to recognize any condition at or within a manhole which is a hazard or may cause interference with system operation, the student becomes a safer worker and a valuable manhole inspector.

The program must include adequate instruction on the general theory of operation, method of use and proper care of tools. Tools cost money, but more expensive is the delay when a job is ready for a particular tool and it is either missing or defective. Further, if the frustration and effort to correct the operation of a defective water pump, furnace or indent tool is observed by the general public, it does not assist in maintaining good public relations.

Certain materials that the splicer uses require specific handling to obtain best results and economy. The trainee should learn how to maintain good solder, proper handling and heating of insulating fluids and the protection of tapes and other constituents of a joint or terminal from moisture and foreign material while stored on the job prior to use. The student should be further impressed with the importance of a reliable job in the manhole by a consideration of specimens of joint and cable failures. Not only should there be exhibits of failures due to poor workmanship, but it is desirable to compare the cost of having done the job right with the cost of the failure which resulted. The student must be shown the proper way of promoting each of the following operations (7):

1. Racking and training of cable and protection at duct edge.
2. Cutting cable to length.
3. Beating the sleeve ends.
4. Removing proper length of cable sheath and belling same.
5. Binding manufacturer's tape to prevent unraveling.
6. Penciling and stepping of high voltage insulation.
7. Testing cable tape for moisture.
8. Phasing cables for multi-conductor circuits.
9. Installing connectors--sweat and mechanical types.
10. Flushing out moisture and foreign material.
11. Taping and oil seals.
12. Application of shielding tape.
13. Tinning cable sheath, joint sleeve and terminal for tightness.
14. Wiping--horizontal and vertical--and seams.
15. Testing sleeve and terminal for tightness.

16. Filling sleeve and terminal.

17. Bonding and test strips.

18. Insulating from ground--saddles and insulated terminals.

19. Arc proofing.

20. Working on live cables.

21. Installation of shunts.

22. Use of fusible and non-fusible crabs.

23. Installation of limiters.

24. Clearing burnouts.

The best teaching methods should be chosen for each detail. In some cases, only reading assignments may suffice. Reading assignments teach a man where to find information which can always be reread if forgotten. Lecturing is of course, more effective because of the human touch that can be added. The use of slides, strip film, motion pictures and other visual aids greatly increases the effectiveness of a lecture. Adequate time must be allowed for the practice of all manual techniques. When some particular operation has been mastered, there should be sufficient slack in the schedule to allow the trainee to practice until he is proficient.

There is no better way of knowing how well instruction is absorbed than by testing. Reviews with questions and answers, written answers to questions, "true or false" tests, "pick out the right answer" test or "fill in the proper word" tests are recommended periodically. Practice in the development of technique must be critically observed throughout the practice session. Awkward, improper or unsafe execution of any part of an assignment must be detected and corrected. As a result of thorough testing, the instructor will be well fortified to evaluate the relative capabilities of any number of trainees and the extent of field assignment possible.

Records and Follow Up

The larger an organization, the greater the need for records for sizing up the level of craftmanship available. Since no formal training program can be all inclusive and since human nature is what it is, the long accepted policy of inspection of work in progress by the foreman and higher supervision must be included as part of cable splicer training. Even though the trainee is assigned to jobs in which he has been instructed in every detail, the may be lacking in confidence in his ability or he may be overconfident. A pat on the back for the good work found on sincere inspection will help immeasurably in developing the desired technique. Overconfidence may lead to errors. This quality must be discerned and diplomatically throttled, showing the ambitious worker where his overconfidence has lead him into undesired practices.

To maintain continuous knowledge of the progress of splicers, a rating system should be maintained. Ratings are made at six-month intervals for the first five years after training a splicer and annually thereafter. Such ratings are useful not only in following the progress of newly made splicers, but also in selecting individuals for additional training and promotion and determining if an individual has passed the peak of his ability. Further, the ratings together with such over-all factors as failure rate, accident rate, ability to meet schedules and public reaction to the impact of construction inconveniences may also be used to judge the effectiveness of the entire training system--formal and field.

Absence of adequate inspection by supervision provides the opportunity for human nature to allow the entrance of improper practices. The foreman is the key man in this situation. By accurately sizing up his work load and his workers and with mature judgment, sensing as to where the weaknesses are likely to occur, he is able to utilize his time to maintain a high quality of work completed on schedule. The greater the ability of the foreman in obtaining this goal, the more assured is the success of the newly made splicer and the greater the value of the foreman to his employer.

An engineer deals with men, material and management. A close liaison and understanding results in a successful project. In the next chapter we will discuss about engineering management in brief.

5. ENGINEERING MANAGEMENT

Introduction

It is said that if you can see the problem in your mind's eye, the rest is A, B, C. An engineer is basically a problem solver. In the modern society, an engineer works on diversified assignments in the same organization, and as such needs a broader qualitative thinking. This chapter discusses a utility engineer who may move into management, and suggests some techniques for his professional establishment.

Science, Engineering and Engineer

Science is the organized and systematized knowledge of the working of Nature. It has been called the great instrument of social change; its end is to promote human happiness, and it is owing to the efforts of those who have advanced science and applied it that, in the last hundred years, the whole material setting of civilized life has altered.

Engineering is the application of science to the needs and customs of everyday modern life.

The engineer is the man with educated brain and trained fingers who, within the limitations of our knowledge of science, controls and directs the forces of Nature for the benefit of himself and his kind.

Consulting Engineering Practice

Upon engineers rests the responsibility for conceiving and designing all types of engineering works, and for providing the assurance that they are properly and economically constructed and used. The health, safety, and comfort of the public depend on a considerable extent upon how well the engineer fulfills his obligation. His success in fulfilling his responsibility depends upon complete understanding between the engineer and his employer.

"Consulting Engineering," as the term is used in the United States, includes not only consultation, advice, and expert testimony, but also the furnishing of extensive and diversified services by engineering firms especially organized and maintained for that purpose. Such firms draw on the combined talents of designers, technical analysts, specification writers, draftsmen, inspectors, surveyors, and other experienced engineers, as well as practitioners in other fields.

Service offered by consulting engineers may include conducting field investigations and collecting engineering data; preparing engineering reports based upon such investigations; furnishing designs, drawings, and specifications; securing bids and assisting in the award of contracts; inspecting construction; testing and approving equipment for acceptance; making appraisals; and other services.

Where construction is involved, the Consulting Engineer is usually responsible for planning which will commit his client to the expenditure of large sums of money. The value of the work to be constructed from this planning, and the suitability for the project's intended function must often be accepted by the client at face value if he is unfamiliar with the technical aspects of such works. By their very nature, then, consulting engineering services must be performed on a highly ethical plane. These services must be carried out in a competent and efficient manner, and in an atmosphere of mutual trust and appreciation between client and engineer. Any failure to meet these requirements will inevitably result in dissatisfaction on the part of all parties concerned.

The Consulting Engineer who has made preliminary investigations in a manner satisfactory to the client normally is best qualified to perform the engineering services in the design and construction phases, unless he is also acting as an advisor to the client under circumstances that may involve a conflict of interest.

In the development of any engineering project, no decision is more important to the client than that involving the selection of the Consulting Engineer. Upon the skill, integrity, and judgment of the engineer rests the suitability and structural soundness of the proposed work for its intended function. The engineer's decisions, affect costs that influences the economic feasibility of the entire undertaking.

Consulting Engineers should be engaged on the basis of their qualifications and experience and their compensation should be based on negotiations. Competitive bidding is not suitable for engineering work because neither the quality nor quantity of engineering services can be neatly defined. The client that "buys" engineering services by competitive bids has no realistic basis on which to compare the value of what he will get. In public works, the courts have held repeatedly that statutes and ordinances requiring competitive bidding do not apply to professional engineering services.

It is not in the best interest of the client or the public, for the engineer to accept employment on contingency basis. This does not refer to general discussions with the client, but to such practices as preparing preliminary reports and estimates without charge, in the expectation of being retained if the project is undertaken. The danger inherent in such a practice, which requires a favorable recommendation for the project under investigation by the engineer as a condition of his compensation, is self evident (2).

The Estimating Engineer

The preparation of estimates, either of first costs or of the costs of operation, is one of the most important responsibilities of engineers and administrators, which becomes especially complicated during times of changing prices, changing wages, or changes in supply.

A poor estimate reflects discredit on its author, even if it does not seriously embarrass the enterprise; in many cases poor estimates are much more harmful and may jeopardize the company or upset its financial stability.

There is a tendency in human nature to underestimate difficulties. This is doubtless a desirable psychological trait, but it can create unfortunate situations when carried into engineering or business affairs. It is a common experience to underestimate, for example, the time it will take to finish a given task or the money it will cost. Besides our optimism which leads to low estimates, we are inclined to overlook many of the difficulties that may arise and tend to provide only for those things we know will be necessary, omitting the less obvious items. In a similar manner, many estimators may ignore items such as overheads, the cost of financing, and taxes.

In order to compensate for this, the estimator should include every item he can foresee and then add a reasonable amount for contingencies. For example, owners with incomplete plans and specifications should add perhaps 10 percent for contingencies; bidders with more complete information should add less so as to avoid overbidding.

Estimates are made with varying degrees of detail, depending on their use and on the time and money available for preparation. Estimates for capital costs or original investments; estimates for operating costs follow the same general principles.

It is evident that the precision with which an estimate may be made depends on the following:

1. The cost data available.
2. The degree of similarity between the proposed project and the projects for which cost data are available; that is, how nearly repetitive.
3. The minuteness with which the estimate for the project is subdivided or itemized. Errors tend to compensate, and the careful study of plans and specifications needed to estimate the quantities and cost of small items requires consideration of the ways and means of executing the work.
4. The skill of the estimator (24).

The Construction Engineer

The actual construction work for an organization is usually accomplished under the direction of the construction engineer by contractors or by company or governmental forces. Which of these is used will depend on conferences between the construction engineer and management.

The construction engineer represents the owner and is expected to secure good construction while enforcing contract provisions fairly. He also acts as liaison between the science of engineering (represented by the designing engineer) and the art of construction management (represented by the contractor or his construction organization). Providing that he demonstrates the necessary interest and ability, his work gives him opportunity to become a professional manager.

In a large organization, the construction engineer has responsibility for the construction and temporary operation of new facilities, for extensive replacement and re-construction, and sometimes for maintenance and repairs. Often these are scattered over a wide area and over many separate plants or installations.

He assumes complete responsibility for seeing that construction work done by contractors or by his own forces meets the standards of his organization and operates within budget limits. Even slight departures from these requirements can seldom be tolerated, since they are like the camel pushing his nose under the tent; then soon his head and body. Enforcement of construction standards is easier when operated as a "taut ship," that is, by a rather strict requirement of "good and workmanlike results." In fact, no other attitude is practicable, nor is it permanently acceptable or helpful to contractors, construction forces, construction engineers, professional engineers, or the public.

His work includes co-operation with the engineering department in designing the project; complete co-operation with the cost-accounting department in making broad policy decisions in the type and amount of accounting records needed; organizing company forces for their part of the work; advertising, securing bids, and letting contracts (in collaboration with legal and business officers) for the project; supervising execution of contracts by contractors or of work by company forces; making progress reports and monthly and final estimates; accepting the completed work for the owner; monumenting construction and perfecting construction records; operating for a brief period; and repeating all this on current and subsequent projects.

The construction engineer, rather than designers, originates change orders and revises construction specifications to reduce variation in construction inspection on the job and to give the contractor advance notice of what is to be expected of him.

His work also includes participation in research by and in co-operation with engineering designers, contractors, suppliers, and others--all with a view to better, quicker and cheaper construction. Research will include improved design, equipment, materials, applications, procedures, transportation, mass production, automation, and operational analysis.

The Construction Engineer must not think so much about the economics of construction costs that he gives too little consideration to the service to be rendered by the structure. It is well to save where saving is wise, to be generous where generosity is equally wise (24).

Engineer as a Professional Manager

In the rare cases when the engineer enters management from a strictly technical position, he is apt to find the transition difficult, frustrating, distasteful, and worrisome.

A special advantage for the construction engineer grows out of the large number of changes in plans that are made during construction. One often learns while irritated, and the irritating nature of these change orders teaches the construction engineer that top management mainly has its eye on the future and is willing to incur delay and additional expense in order to make any alterations in plans that may be expected to improve the future prospects and operations. Thus the construction engineer becomes indoctrinated with the important and proper conviction that a primary duty of top management is to foresee the future; in other words, to become "future minded." Since the great depression of the 1930's, and especially since World War II, the need has become recognized for professional managers, frequently engineers--not those rugged individualist of the early period nor the capable specialists of the middle period. Engineer-managers are men of judgment and balance who deal with people, not gadgets.

Management and Decision Making

Management's primary function is to make decisions that determine the future course of action for the organization over the short and the long term. These decisions may be directed in every conceivable physical and organizational area; they may deal with financial planning, marketing personnel, as well as with the operating or production phase. More often than not, decisions cut across these functional lines.

Decision theory is directed toward determining how rational decisions ought to be made. It attempts to establish a logical framework for decisions that is firmly rooted in science and mathematics, as well as in the real world; in this scheme, which correlates the two areas of science and the real world for various alternative action paths, risks are assessed so that the decision maker, by his knowledge of the probable results, can decide what to do. These deicisions are concerned with every factor in the organization. For day-to-day operating or repetitive decisions, a set of decision rules makes possible continuity and smooth operation, as with industrial quality control, for example. Large-scale decisions, such as the design capacity of a new plant, employ the same general concepts of decision theory, but occur only once in a while (4).

Management Techniques

Many personnel problems in management arise, because emotional undercurrents often are not recognized, or are ignored, or challenged by people in the organization, or perhaps even by an administrator. At times he may not even be aware of his own emotional bias or residues. On still other occasions that very awareness of such emotional undercurrents may tend to paralyze administrative action. Such undercurrents may also give rise to strong feelings on the part of those who are discussing the case, and may obscure or overshadow other elements. It is important, therefore, to learn to discern the relationships between emotional and non-emotional elements in a case (17).

Modern management has found that the one best way can be determined only through the free interchange of experiences, and that the test of good management is the willingness to so profit from the experience of others. "A man's judgment is as good as his facts"; the more facts, the more accurate his judgment. Many an important decision has been made and then proved wrong because the available facts had not been obtained before arriving at the dicision. Standards are not static; they may be changed at any time by a new idea, from anyone from the president of the company to a laborer. Very frequently the laborers find better ways to perform operations. These should be recorded and sent throughout the organization as quickly as possible, so that the maximum economy may be obtained by putting a money-saving idea into effect rapidly (27).

The executive who tries to run every little detail is only fooling himself. The facts upon which decisions are based are often incomplete as well as inaccurate. Also the decisions are effected by the fact, whether the executive supports theory X or theory Y.

Responsibility for the execution of work must be accompanied by authority to control and direct the means for doing the work. Delegation of authority means conferring by one to whom the authority is delegated becomes responsible to the superior for doing the job, but the latter remains responsible for getting the job done. The history of industrial organizations shows that an effective executive delegates authority to others as soon as the total job which he is carrying taxes his own time, energy, and knowledge.

When responsibility and authority is delegated, an executive should be careful in criticizing mistakes made by the men to whom delegation has been made. If, every time a mistake is made, sharp criticism results, the assistant will have his initiative dulled. His major effort soon is directed not to doing the work with the maximum efficiency, but rather to avoiding "catching hell from the boss."

Managerial efficiency is greatly increased by the concentration of managerial attention solely upon those executive matters which are variations from routine, plan, or standard. A high-priced executive does not profitably spend his time doing routine work or worrying about matters that can be handled best by others in the organization who are familiar with the details and who are daily taking care of such matters.

In many organizations in various industries, much managerial activity is handled by means of a committee or committees. Experience shows that it is a form of management with distinct limitations. The popularity of the committee with some companies appears to arise from defects in organization structure, fear of assigning executive authority to individuals, and the tendency of executives to escape responsibility, even when their authority is clear. Much of the weakness of a committee form of management can be overcome when the committee is headed by a thoroughly competent chairman. His competency should, among other things, consist of the courage to make a decision even when the majority is against it. In other words, a committee, to be thoroughly effective, should not make managerial decisions by a majority vote but should be a place for discussion to bring out all facts and all ideas bearing on the problem. After that, when the time has come for a decision, it should be made on the basis of facts and not upon the basis of a majority vote.

One of the advantages of committee discussions is the fact that everyone who is going to have anything to do with the introduction of a technological change or a change in method has an opportunity to express his ideas. After they have been thoroughly heard and mere argument separated from facts, a capable chairman will, most of the time, be able to get changes effected with the minimum of organizational friction.

The main objective of any organization should be to get things done. To this end, decisions must be made at times that will not receive the complete support of everyone concerned. However, if the matter is handled with skill and understanding of personnel relations, only extremely difficult people will fail to co-operate (27).

CPM and PERT

Few if any new management tools have received such wide acclaim so rapidly as CPM and PERT.[24] The complexity of many of today's projects, even those of moderate size, demands not only consistent, disciplined thinking but also a method of summarizing and presenting the results of this thinking in a systematic manner. The graphical networks and associated calculation techniques assist effective thinking by sponsoring a step-by-step routine for co-ordinating work assignments and resource utilization with project objectives. Control criteria for the evaluation of work progress are established,

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[24] The literature on CPM and PERT has become voluminous since its development in 1958.

and the most economical means of correcting delays are diagnosed. Thus, network scheduling contributes to the two critical features of project planning:

1. Formulating the initial plan.
2. Monitoring the progress.

It operates in the delicate interface where ideas are converted to acts (23).

Fundamentally, PERT and CPM are techniques of project management useful in the basic managerial functions of planning, scheduling, and control. The planning phase of any venture involves a listing of tasks or jobs that must be performed to bring about the venture's completion. Gross requirements for material, equipment, and manpower are also determined in this phase, and estimates of costs and durations for the various jobs are made. Scheduling, on the other hand, is the laying out of the actual jobs of the project in the time order in which they have to be performed. Manpower and material requirements needed at each stage of production are calculated, along with the expected completion time of each of the jobs. Control, generally regarded as "the underlying managerial function," begins with reviewing the difference between the schedule and actual performance once the project has begun. The analysis and correction of this difference forms the basic aspect of control (30).

The first step in a CPM application is to break the project down into its component operations to form a complete list of essential activities. An activity is a time-consuming task with distinct beginning and end points called events. As the activity list develops, an order of completion is established by a restriction list, a statement of pre-requisite-post-requisite relationships for each activity. From the two lists evolves a network drawn according to conventions, where arrows representing activities connect nodes showing the sequence of events. Dummy arrows are included to allow distinctive nodal numbering for computer applications and to show certain event restrictions. A single activity duration is estimated in the deterministic approach; a range of time estimates is used in the statistical PERT approach. With PERT, expected times t_e result from the formula,

$$t_e = (a + 4m + b)/6$$

where a and b are respectively, optimistic and pessimistic estimates and m is the most likely duration. With activity durations estimated by either method, boundary times are calculated for all network activities to determine the float available for non-critical activities and the chain of activities that sets the total projection--the critical path.

In PERT networks the variance of activities $\sigma^2 = [(b-a)/6]^2$ can be used to determine the probability of meeting a certain scheduled completion time called a milestone. With the deterministic durations, time cost tradeoffs can be used to identify the least cost measures to reduce the project duration.

Computer programs for CPM applications are widely available. Manual calculations are feasible for smaller problems, but electronic assistance is almost a necessity for larger ones. In network analyses, a computer can perform the boundary time calculations and generate bar charts for easier checks of resource assignments (23).

A Project by CPM Techniques

Whereas, here it is not possible to go in more detail about CPM and PERT, we analyze the project of building and commissioning a sub-station in the distribution system of Mecca, Saudi Arabia, by CPM techniques, for interest.

This project embodies the complete job right from the data collection to sub-station building construction, installation of equipment in the S/S, connecting the S/S in the loop, and finally energizing and commissioning it. The fine details of the project are given as different activities with the corresponding constraints. The duration of the completion of the activities are deterministic and based on experience. Critical path will be marked on the arrow network, time chart will be drawn and boundary time table will be prepared.

Please see Appendix III for details.

6. POSSIBLE IMPROVEMENTS AND RECOMMENDATIONS

Introduction

Whereas, in Chapters 2 to Chapters 5 we have discussed in fair details about different aspects of distribution system, we have avoided to pin point the specific improvements possible in Mecca Distribution. To the well initiated these chapters may serve as a reference and guideline to suggest improvements for Mecca Distribution. In this chapter we will discuss a few improvements that can be made in the existing[25] circumstances.

Improvements Needed

Renovation of town electrification is a highly specialized field and needs a well planned and organized team work. It starts with a thorough study and sound analysis of the present system--moves with the feasibility reports and improved designs, methods, procedures and philosophies--and ends with improved voltage conditions, neater atmosphere, safer and more realiable system. Before renovation can be suggested, it is imperative that a need for it be realized. The need for system renovation as that of Mecca Distribution has been demonstrated time and again, by the numerous faults and voltage drop

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[25] As of Dec. 1969.

complaints by the consumers. It is high time that the Power Company may review and revise its philosophies and seriously start considering for the renovation of the system before more serious troubles arise. The economics of renovation, like all other economic problems, may be established by comparing future revenue requirements if:

1. The existing system is renovated and restored to use, versus
2. The existing system is totally discarded and replaced by new.

Most companies are profit minded, but they should be goodwill conscious as well. For any utility company, goodwill is by far more important to maintain than to lose some of its profits. Whereas the situation may not be so bad for a monopolistic organization, times are changing and people are getting more and more aware of their rights.

Particularly, for a city like Mecca with its influx of pilgrims, inavailability of skilled labor and immobility during pilgrimmage,[26] it should be realized that the allocation of all the possible resources is not enough[27]--shortage of time and immobility may play a havoc. During Haj in the Mona area, where a lot of world dignataries may be present a failure of distribution system may not only be annoying but also very injurious. The monopoly of the company may get paralyzed,

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[26]See Appendix II for details.

[27]As demonstrated by the CPM Project in Appendix III.

and a corporation or Government Power Administration may evolve.

In controlling initial investment, far more can be accomplished by proper selection of circuit arrangements than by economizing on equipment. Where cost reductions are necessary they should never be made at the sacrifice of safety and performance by selecting inferior equipment. Reconditioning of cables differs substantially from the reconditioning of most other equipment. Where other work consists largely of taking apart and repairing or replacing elements, there is little of such procedures to be done with cable. It is not taken apart; repairs are limited to cleaning and patching the sheath surface; replacements are not generally feasible. Judgment must be made in selecting a cable size to meet both present and reasonable future requirements. For instance, provision for development and flexibility for future system changes may make it advisable to install "feeder size" cable for mains and laterals instead of smaller sizes which might be satisfactory for present conditions. In any event, the conductor size must be adequate to carry normal and anticipated emergency loads without exceeding recommended temperatures.

All inflexible systems, as that of Mecca, have the disadvantage that faults are difficult to locate and the system has to be dug up at the point of fault in order to make repairs. In cases it is also difficult to keep an exact route record of the system and fault localization may be very laborious and back breaking. Also when the system becomes outgrown, the conductors can not be withdrawn and replaced with larger ones. Flexible systems[28] will have to be preferred on account of inconvenience and expense of digging, especially through pavement in times of Haj, to make repairs or replacements. Furthermore with the flexible system it is possible to install initially many extra ducts with little additional cost to take care of growth for many years to come. Also, smaller conductors, when they become overloaded, can be withdrawn and replaced without disturbing the surface.

Recommendations for Improvements

A detailed and conglomerate synthesis of the author's experience and recommendations for improvement in Mecca Distribution will exhaust our reader's patience. However, we will discuss in brief the following:

1. Methods and Philosophies
2. Reorganization and Training of Technical Staff
3. Planning and Design Procedures
4. Records Maintenance and Suggestions
5. Study of the System and Forecasts
6. Materials Handling
7. Construction Procedures and Radio Dispatch

[28] With conduits and manholes.

8. Safety Precautions and Codes

9. Hiring of Consulting Engineers.

Methods and Philosophies

The responsibilities of the engineer include among other things, the practice of sound stewardship in making designs which provide the required quality of service at the lowest total cost. Whereas, the top management is profit minded the engineer should also see in the future. A strict check on the wasteful employees is necessary. A record can be maintained to convince the jointers that their wasteful attitude has not only cost the organization a money loss but also a loss of goodwill. To save the wastage incentives as efficiency bonuses may be practiced.

Research should be given its due time and funds allotted to it. Time and money spent on research is well spent. It is a patience demanding job and discouragement from the side of the management may be detrimental. It is only research which may enlighten some hidden corners. Adequate laboratory facilities may be provided for testing instruments. Testing of protective equipment is especially important. Testing of protective equipment is generally thought of in terms of relay testing, but its value goes far beyond mere verification of the relay's calibration. In fact, the greater number of irregularities found do not involve the relays as instruments. The testing should be so planned as to check, as far as possible, the entire scheme from instrument transformers to circuit breaker operation.

Responsibilities and power of different engineers may be well defined and the line of heirarchy should be clearly marked. Talent is a nature's gift and every engineer has specific talents. The specific talents of the engineers should be exploited for the benefit of the organization.

Training of the newly recruited engineers should be properly arranged and every endeavor must be made to let the engineer understand the system thoroughly and as soon as possible. Sharp engineers may be trained for executive jobs and more responsibilities.

Proper training of splicer and practice of safety precautions as mentioned in Chapter 4, should be emphasized and put into practice as soon as possible. Splicers should be trained in public relations and complaints handling.

Weekly meetings of the engineers should be arranged and exchange of information should be positive. The purpose is, "A good employee is an informed employee." It should be emphasized that all engineers are a part of a team and weakness in any corner may weaken the entire team. Flow of literature should be organized and generous. Guidelines for important operations should be circulated. Operation charts should be complete and hung in all sub-stations with clear demarkation of the local S/S.

Quality of work should be emphasized and good workers should be given due encouragement. Transportation methods of splicers and communication system should be improved. Tool carts should be provided for the splicers. Crew system with the job foreman may be enforced. Team atmosphere must be created and morale of the low paid employees should be uplifted. Theories X and Y should be explained and sense of conscientiousness be prophessed.

Hiring of the engineers may be on the job specialization basis. Provident fund scheme may be enforced to provide security and establishment to contract employee. Contract employees may be hired on the project basis.

Procedure for a new connection is too laborious and must be revised with minimum back tracking to the consumer and maximum protection to company in case of dispute. A few suggestions are:

1. Clear definition of load to consumers.
2. Clear load declaration by consumers.
3. Enforcement of wireman's license.
4. Clear procedures and policies.

The following are as guidelines:

Where it is not known with absolute certainty that the type or capacity of service desired is available, the utility must be consulted well in advance of the time[29] service is desired. This will save time

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[29]As in marriages, parties etc., in Mecca.

and will prevent unnecessary expense where the load is located a considerable distance[30] from facilities supplying the type of service desired or where additional capacity[31] must be installed (22).

Customer shall be responsible for the cost of all trenching and back-filling for the service laterals.

Space must be provided on the customer's premises for the installation of the meter or meters required. The location should be subject to the approval of the utility.[32] The meter must be installed between the customer's service outlet and service equipment unless otherwise approved in writing by the utility. The meter location must be in a clean and safe area, free from vibrations and physical hazards, and not subject to abnormal temperatures. Each meter socket shall be plumb and level, and have vertical and horizontal clearances from adjacent obstructions, including other meters (22).

No individual single-phase motor larger than 5 hp may be connected to the service without the written consent of the utility. Single-phase transformers; resistance type spot-, seam-, or arc-welding machines; X-ray devices, sign bombarding transformers; or other electrical equipment of similar load characteristics and with input rating or actual maximum input of more than 1,650 volt-amperes

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[30] As in Mona for Pilgrims tents etc.

[31] As in Harem adjoining areas.

[32] Power Company

shall not be connected and operated on a circuit of less than a nominal 400 volts. When additional capacity must be installed by the utility for customer's equipment having highly fluctuating and intermittent demands which seriously affect voltage regulation, the utility may require the customer to contract and pay additional charges (22).

Where any conditions arise which are not clearly defined, the utility must be consulted before proceeding with the work. In case of conflict of utility rules and regulations with applicable governmental codes, law or ordinances, the utility may waive or amend such portion of these utility rules and regulations shown to be in conflict, by the governmental authority having jurisdiction.

The utility engineer should not be asked to check the wiring of premises, rather licenses should be issued to qualified wiremen. A suggested specimen of wireman's license is shown in Appendix I.

This license should be small in size to carry in a wallet. The best recommended size is that of driving license in Oregon, USA. This license should be issued by the company for a maximum period of three years depending upon the date of birth of the applicant. The applicant should be tested in the fundamentals of wiring--both theory and practical and his craft should be acceptable. The pass percentage should be 70 and the license should not be issued till the applicant has attained the required proficiency. This will also improve the work done by the company's electricians.

The routing of papers and unnecessary red tapism should be avoided. For example, it is not necessary to send the LT materials requisition lists, or estimates to the HT engineer. A suggested form for application for a wireman's licence is shown in Appendix I.

Re-Organization and Training of Technical Staff

The present[33] organization of the technical staff is shown in Figure 27.

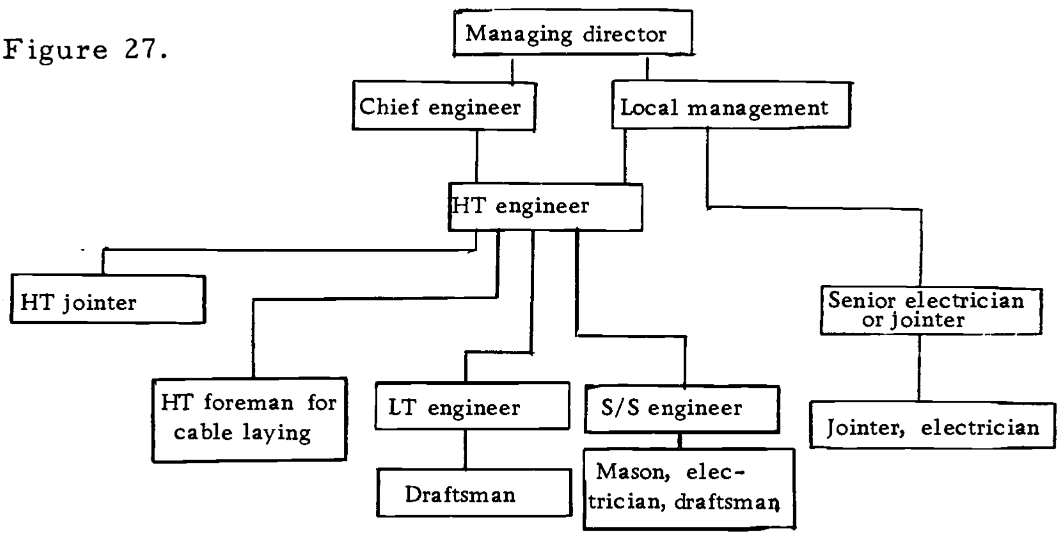

Figure 27. Present organization of technical staff.

The nominal jobs performed by each engineer are:

HT Engineer -- HT operations and renovation. Planning for extension of HT. Supervision of HT foreman work and instructions to jointer. Signing material requisition for stores. Liaison

[33]As of Dec. 1969.

between management and engineers. Car is provided as transportation.

S/S Engineer -- Civil construction of S/S. Erection of equipment. Civil maintenance of S/S. Minor HT operations. Supervision of mason's work. One pickup or jeep in provided.

LT Engineer -- Estimation of individual connections. Planning for extension and renovation. Providing emergency connections. Public relations. Liaison between customer and management. Supervision of LT renovation. Training of staff for renovation and new methods. Supervision of HT cable laying. Planning for HT cable routes. Store organization and requisitions. New connections. Street light maintenance. Pickup is provided.

Senior Electrician -- New connections and faults.

As may be evident this organization is not enough.

By now, our reader must have realized the size of Mecca distribution and will feel that there must be more engineers for the job. A re-organization of staff is suggested in Figure 28. This re-organization is adjustable depending upon need and emergencies.

A new engineer can be routed in all departments so that he understands the line of heirarchy and his position. However, every engineer must train his staff himself. For the general training of new jointers, instructions and curriculum can be explained to the

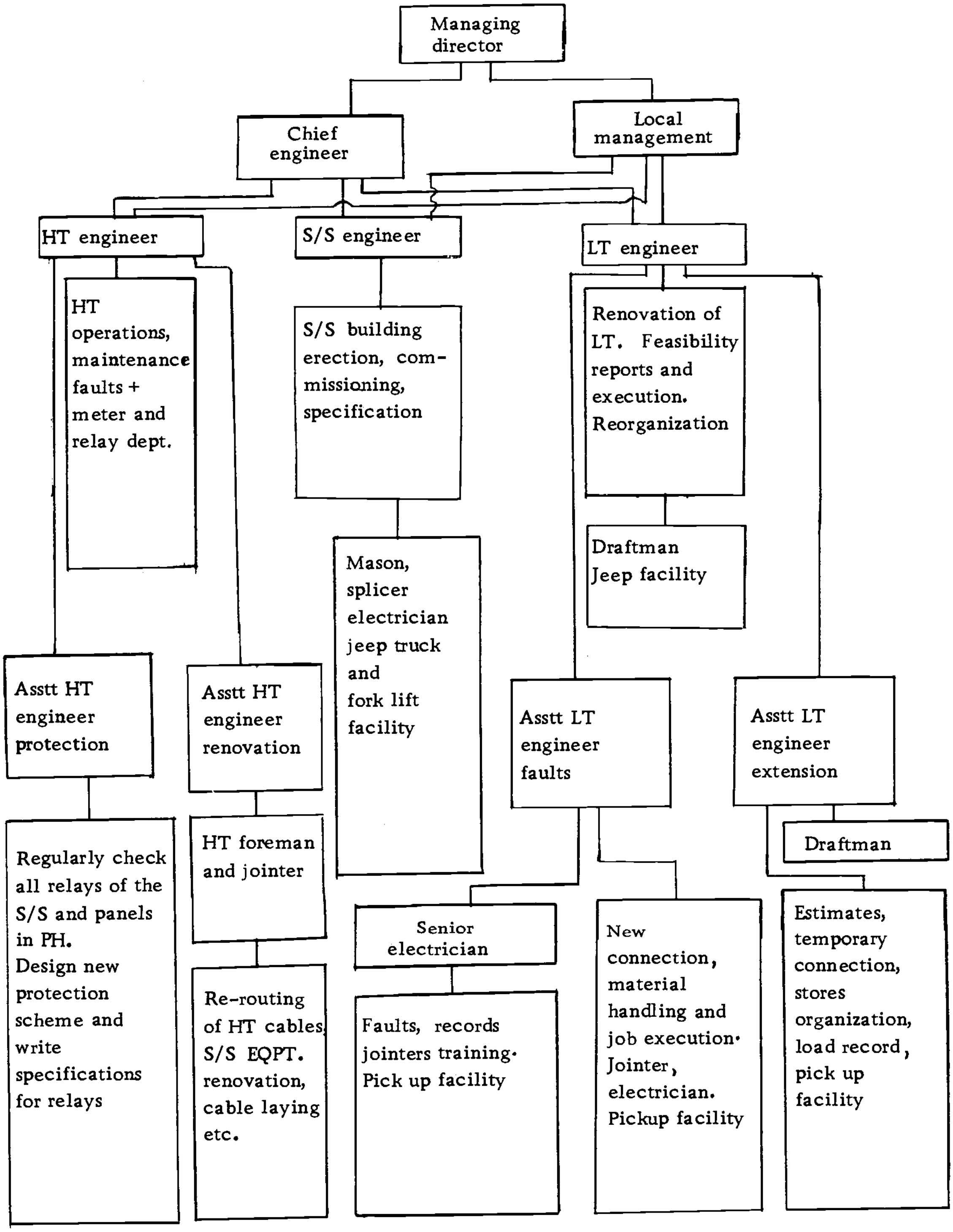

Figure 28. A suggested re-organization of technical staff.

Senior Electrician. Senior Electrician should organize this training.

Small handouts may be made for safety precautions and distributed regularly. The man not following the safety precautions should be penalized.

Planning and Design Procedures

For any LT planning load survey should be carried out and detailed information should be collected. Every light point and plug point should be rated at 100 watts and a high load factor should be assumed.

For any design of LT extension, data from the load survey should be matched with the maximum demand in that area. In the present situation it is not possible to install maximum demand indicators on all feeders. However, load can be noted at regular hours in the night for a few days and an average can be taken. This record plus a sound load survey can predict the future behavior.

There is another check for the load survey. The city maintains some data on the census; and another way of load survey is to assign kwh/head per annum. The 1953 figures for three countries are:

1300 kwh/annum - Britain

4300 kwh/annum - Norway

2900 kwh/annum - USA

These figures change depending on the economy of the society and a fair guess can be arrived at for Mecca. Another method for load survey is kwh/sq meter. This figure can be adjusted depending on the concentration of population in an area. Also, the habits of the inhabitants must be considered while estimating on these basis.

After the maximum demands for an area has been calculated, diversities of load should be noted and the maximum demand on a sub-station should be calculated. This will determine the capacity of the sub-station to feed the area for the estimated load. To this capacity 50 percent should be added for future extensions. The maximum capacity of an indoor sub-station should be taken as 1000 kva. For any additional capacity a new sub-station should be suggested. While selecting the site for sub-station, considerations should be given to load center. The sub-station site should be at least 5m x 8m. The site should be easily accessible and preferably on an open plot so that extension may be carried out in the future. While building the S/S, ground and soil conditions should be tested and provision should be kept for a multistorey building on the S/S.

While designing feeders and laterals, voltage drop conditions should be considered. Since the load is generally concetrated and builds up gradually, full load current can be considered flowing at the feeding end while calculating the voltage drop. The longest distance of service should not exceed 800 meters from a S/S in any case. This radius may be shorter in case of Harem adjoining and Mona S/S.

While designing laterals and suggesting fuse protection, fuse co-ordination should be carried out using TC curves. High resistance faults are detrimental to the system, and a rehappening (similar to that in Zahir area) should be avoided. While changing the transformer in a S/S CT ratio and circuit breaker ratings should also be adjusted.

While designing any protection scheme, a complete and thorough fault study should be made and it should be remembered that a simple protection system is neat and more reliable. One should be very careful when using OCB and off load break switches--a wrong selection may be dangerous as well.

Secondary loop system should not be exercised till the splicers are well trained. Accidents may occur in secondary loop system, by considering the panel or distribution box to be dead whereas the supply may be present from the other side.

For multistorey buildings in the Harem adjoining areas--with maximum demand exceeding 200 kva, underground residential system can be exercised and a strict policy for its enforcement should be laid.

Study of the System and Forecast

Forecast of the network behavior is possible only, when an advanced study is made. As the load starts building up since Ramadan, it is wise to start noting down the maximum demand on the power house, harem adjoining S/S, and individual HT, LT feeders since first Ramadan. Regular forms can be printed and this valuable record can be stored in the master file or magnetic disc.[34] If this record is maintained an instant check on the system is possible. In fact this record can be transferred to graphical form showing the weekly development of load and can be kept in each S/S data file. This graphical representation is easily comprehensible by the management and can help in solving a lot of difficulties; for e. g.

1. Explaining the system growth.
2. Calculating the rate of growth.
3. Predicting the overload period and deciding for extension, reinforcement or renovation.
4. Estimating and scheduling the work load and resources for the distribution personnel.
5. Estimating and demonstrating the need for URD distribution for potential consumers.
6. Planning a load shedding and announcing it to public by press, radio and television before the situation gets out of control.
7. Planning the use, and shifting of unit type mobile substations.
8. Demonstrating to management the need for additional personnel and resources.

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[34]We will discuss about digital computer a little bit later.

9. Demonstrating to general public in case of undue pressures, and thus maintaining good public relation and liaison.

10. Completing the S/S and feeder records and history.

This graphical record should be maintained on 11 x $8\frac{1}{2}$ in. size paper for ease of manipulation and filing.

Maintenance of Records and Suggestions

The experienced investigator does not shy away from paper work because he knows only too well that, in the long run, proper records are time savers. Facts are elusive and the human mind plays tricks of memory.

The records of an underground plant are the working tools for the personnel responsible for the design; expansion, operation and maintenance of the plant. Without a well-planned system of records, required information may not be easily available. To be effective, records should be direct, clear, brief and accurate and should be directed toward providing a service which will assist in maintaining the over-all efficiencies of the activities involved. The records also serve as a history of the operation of different types of equipment, so that plans for plant extension or growth can be patterned utilizing the equipment which has shown the best operating performance with a minimum of maintenance. Complete and accurate records are also essential from a safety standpoint. With the passage of time the older personnel who were familiar with the early development of the system, are replaced and the record system becomes the primary source of such information. Records are also important in the training of new personnel.

We suggest that records should be kept for extensions, faults and renovation of both HT and LT distribution. In case of extensions and renovations there should be one page history of the case in the order shown: Why proposed, when proposed, by whom proposed, what is the proposal? etc. It should then follow the development, changes and final shape of the proposal and its technical details.

In case of faults the records should contain: what happened, when happened, where happened, who reported, what reported, who attended, when attended and what were his findings? Has the fault been repaired? Any suggestions to save reoccurring ______.

For keeping the LT system record, Mecca and its outskirts should be considered as lying on a big rectangular paper with Harem as its core; as Figure 29 shows.

The entire city should be divided in avenues and street planning. Those extending East to West will be called avenues, and will move from Harem towards North or South. The avenue numbers will increase as we move away from Harem. So also those extending from North to South will be called streets, and will move from Harem towards East or West. The street numbers will increase as we move away from Harem. The whole city will be divided in squares of 300 feet sides. Thus a square having its nomenclature N7E5 will locate it in the NE corner of the city. The records of the LT distribution will be maintained according to this nomenclature on books 11 x $8\frac{1}{2}$ inch size on a scale of 1'' = 40'. These records are easy to compile and handle in the field and should be used extensively for LT estimation, extensions, renovation, planning etc.

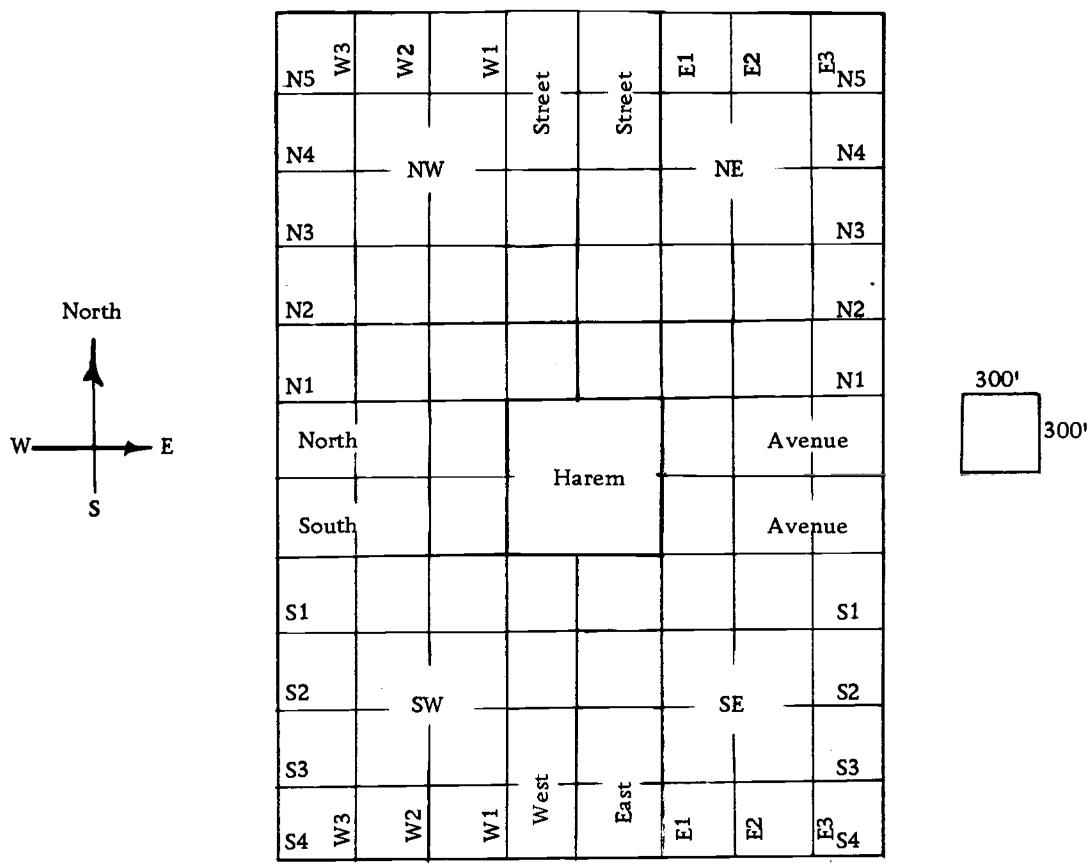

Figure 29. LT record keeping.

In addition to the above a library should be maintained having the indexed details of the LT constructions involving a cable length of

50 meters or longer of 0.1 sq in. cable or above. This library may be used as a cross reference in case of missing data.

A library of technical literature and manufacturer's bulletins is also very useful for specification writing, estimation and comparison.

A complete list of distribution tools and equipment should also be maintained in the office and should be accessible in the library.

The library may also contain a yearly sales record of electricity by sub-stations to have an idea of load growth. We show a sample record maintained by PP & L for 1967, in Table 21, for interest.

Materials Handling

Statistics show that materials handling is the largest single element of labor costs in many industries. Once money is expended in materials handling, it is gone forever. Therefore, very precise and efficient means of handling materials are necessary if economical results are concerned.

In Mecca there is a lot of abuse in materials handling because of insufficient tools and means. A fork-lifter is imperative in the general stores, as well as skids, tractors and trailers are necessary. For transportation of material to hilly areas donkeys can be hired to advantage and use of wheel barrows is suggested for level ground in the city. Special trucks with hook up arrangements are recommended for meters and a motorized tool cart is suggested for HT jointers.

Table 21. PP & L* sales of electricity--by communities.

Community	Residential Sales (Account 440)			Commercial and Industrial Sales (Account 442)		
Oregon	Operating Revenues $	kwh Sold in Thousands	Average No. of Customers	Operating Revenues $	kwh Sold in Thousands	Average No. of Customers
The Dalles	350,667	40,317	2,465	229,586	21,168	421
Albany	820,005	57,978	5,516	787,637	63,008	1,167
Astoria	516,245	36,482	3,768	540,744	40,011	884
Bend	678,463	48,432	4,500	580,904	42,681	928
Corvallis	1,332,480	95,763	8,565	709,932	46,112	1,294
Pendleton	577,209	40,106	4,251	626,724	42,442	974
Portland	3,690,981	316,476	34,180	6,094,578	602,083	7,692
Springfield	411,414	47,289	3,016	607,277	94,440	539
Grants Pass	757,990	46,817	4,406	813,024	57,947	1,174
Klamath Falls	882,100	52,501	5,735	843,112	57,818	1,461
Medford	1,851,682	119,490	9,637	1,428,112	92,573	2,057
Roseburg	829,991	52,449	4,540	750,038	44,205	1,191
Other	23,097,297	1,643,423	138,354	23,075,838	2,601,901	34,603
Total Oregon	35,796,524	2,597,523	228,933	37,087,506	3,804,389	54,385

*Courtesy of PP & L Library, Portland, Oregon.

This cart must be equipped with all the equipment necessary for work area protection and efficient flow of traffic and pedestrians.

Construction Procedures

To finish all the construction jobs on schedule CPM and PERT techniques are highly recommended. Breaking the project into activities and drawing the network is very frustrating for the beginners but conscientious effort may overcome this difficulty. Dispatch of construction materials is very inefficient and time consuming. Because of the communication gap it is very difficult to trace out where the worker has gone after leaving the office. In some cases the worker has met an accident and the office has come to know only after the victim has been moved to a hospital. To check this happening walkie talkie may be provided to all jointers and electricians and all the company cars and trucks must have radio communcation systems connected to the main office and stores. A radio dispatch of material will save harrasement and wastage and provide a control on the staff. All company trucks must be provided with:

1. Revolving flash light
2. Collapsable ladder
3. First aid equipment
4. Radio communication equipment
5. Elementary electrical tools

6. Red flags, cones, barricades etc. for work area protection
7. Spare wheel, engine oil, fan belt, radiator cap and basic mechanical maintenance tools.

Safety Precautions and Codes

All the jointers, electricians, helpers and regular workers must be thoroughly trained in safety precautions and must be emphasized to follow them religiously. Defaulters should be penalized without exception. Workers having no accidents in three years must be granted a certificate of safe working and a cash award as incentive.

Safety codes must be enforced. For guidance, Safety Codes laid down by Water and Power Development Authority, West Pakistan can be taken as a sample. In the meanwhile emphasis must be placed for proper grounding of equipment and time and on methods of good grounding should be demonstrated to wiremen and other company employees.

Hiring of Consulting Engineers

As the company engineers are busy in the operation and extension of the system, it is necessary that additional departments be opened for renovation of the system. This department may be directly responsible to the top management and have a consulting engineer of standing as its head. The consulting engineers may be hired on the project basis, as for surveying, feasibility reports, study, improved design, construction etc. The operation engineer may benefit from their experience and education and a close training program for the operation engineers may also be arranged.

Computer Modeling and Simulation

As a distribution system grows, it becomes more difficult to control. Analysis of the system becomes complex and control gets involved. Records get enormous and tracing becomes tedious. Digital computers can be used to assist in all these operations. Computer modeling and simulation techniques are very powerful tools.

We should apply computer modeling and simulation whenever there is horrendously large volume of computations necessary. Some problems cannot be solved manually because of the sheer size of computational requirement alone. The application of high speed computers has made it feasible to solve huge, complex problems that would otherwise be impossible to solve in a reasonable length of time. Computers are more efficient than humans for tedious, involved computations. Computers can make simple logical decisions based on calculations faster and more accurately than can humans (19).

A good size[35] digital computer can be leased and installed in

[35]Like CDC-3300, IBM 360 etc.

the main office and a few TTY consoles may be provided. One console may be provided in Mona in G4-S/S, one in Power House Control room, one in the accounts office and one in the engineer's office. Punch card system with 2 key punch, and one card reader will be a good combination. Data transmission may be by TTY or by punch card system, magnetic disc or tape. Data may be stored on master file.[36]

On the hour data on different feeders during pilgrimmage may easily be stored and help in planning for extensions etc. The computer may be used for the following tasks:

1. Receiving and storing on the hour data of feeder loads at P.H.
2. Keeping records of load flow.
3. Packaged programs for circuit designs.
4. Keeping records of HT faults.
5. Keeping records of LT faults.
6. Storing instructions for operation of HT network.
7. Storing instructions for emergency operations.
8. Storing instructions for safety precautions and safety codes.
9. Keeping records of pending applications for new connections.
10. Keeping records of new and old connections, categorically; domestic, commercial, industrial, bulk etc.

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[36]For details see CDC 3300 manual.

11. Keeping records of PH auxiliaries, operations, failures etc.
12. Keeping records of PH stores and inventories.
13. Keeping records of distribution stores inventories.
14. Keeping consumers records for accounting.
15. Preparing monthly bills for consumers.
16. Keeping records of meter complaints and repair.
17. Keeping records of mechanical maintenance of company's transports.
18. Keeping records of maintenance in the distribution department.
19. Keeping records of company employees for personnel office.
20. Technical and commercial research.
21. To process data for public, government and other concerns, etc., etc.

What Now

So far we have discussed about the improvements which appear to be on a long range planning and a question may be well asked, what to do now? The answer is that, before the long range renovation begins, it is imperative that the philosophies should be changed and an immediate measure should be to stop the further deterioration of the system. Without any loss of time, safety precautions and codes must be enforced and the butchery which is being done on LT mains should be stopped. Tee boxes may be totally abandoned and appreciation should be accorded to the man extracting them. System shown in Figure A. 11 may be exercised as local renovation for the time being.

A priority list of sub-stations depending on their importance should be made and the work be started as soon as possible. A suggested order is sub-stations of C series and Mona area, then B and A series, then D, E and F and G series. At important places, endeavors must be made to switch over to the flexible system to save happenings like Jiad, Ataibia and Zahir.

Epilogue

We have laid down the broad guidelines for improvement of Mecca Distribution. This thesis is not a complete cook book--or work-order. It only defines the problems and suggests methods and tools to tackle with them. Only an intelligent application of tools and methods to the specific problems will give satisfactory results. Renovation is a process of constant struggle and achievement--and as such the philosophies should be adjusted accordingly before anything else.

Good, better, best
Never let it rest.
Unless your good is better
And, better is best

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APPENDICES

APPENDIX I: FORMS

Date:____________________

REPORT ON INVESTIGATION OF ACCIDENT

AT____

THE INJURED

Name____ Control No:__________
(Please Print)

Address____ Age__________

Sex_________________ Marital Status _____________ Dependents_______

Department____

Regular Occupation______________________ Length of Service_________

Occupation when injured____

How long at this location____

Date of accident____________________ Time of day___________________

Description of accident

____

____

____

Cause of accident

____

____

Was a "job side" safety discussion held on the job?

____

____

What do you recommend be done to prevent a recurrence?

____

____

Your opinion as to responsibility (explain)

____

____

(See Reverse Side)

INDUSTRIAL ACCIDENT CODE CLASSIFICATION

Responsibility

______A--Supervision
______B--Employee
______C--Impractical to control
______D--Supervision of other Department or Bureau
______E--Other employee

Cause of Accident

______1--Physical condition
______2--Poor housekeeping
______3--Defective equipment, construction or design
______4--Improper use, or handling of tools or equipment
    ______a--Using wrong tool
    ______b--Using defective tool
    ______c--Tools or equipment improperly handled
        ____1.--Failure to watch clearance of himself
        ____2.--Failure to watch clearance of fellow workers
        ____3.--Unsafe method or job set-up
        ____4.--Unsafe position
        ____5.--Failure to secure a firm grasp while handling objects
        ____6.--Failure to keep out of line of fire
    ______d--Other causes (name)

______5--Proper safety appliance not provided or used
______6--Improper or inadequate instructions
______7--Inattention
    ______a--Walking, running, etc., too fast
    ______b--Contacting hot surfaces
    ______c--Climbing on equipment
    ______d--Inattention to moving equipment
    ______e--Inattention to footing
    ______f--Inattention to condition
        Low overhead structures, or other objects

______8--Failure to observe rules or orders
______9--Failure to apply adequate protection

____________________________ Supervisor

(Reverse Side)

WIREMAN'S PERMIT
SIGNATURE OF LICENSEE
Name of Holder: ______________________________
Address: ____

Date of Birth	Height	Weight	License No.

Date Issued	Date Expires	Restrictions	Industrial Wiring Endorsement

MECCA ELECTRIC COMPANY
SAUDI ARABIA

(See Reverse)

Restriction Codes

1. Domestic wiring beyond 4 storeys
2. Industrial wiring beyond 50 HP
3. Industrial wiring beyond 200 HP
4. Earth connection to be improved
5. Craft to be improved

(i) This license is not transferable and must be shown on demand.

(ii) An attempt to pilferage may suspend the license temporarily or permanently.

(Reverse)

MECCA ELECTRIC COMPANY

Application for Wireman's License

Photo

Name_________________ Signature_________________

Address_________________________________

Are you an Alien ? Yes ☐ No ☐

If yes, Residence Permit No.:_________________

Expires_________________________

If no, your identification:_________________________________

Did you have any schooling? Yes ☐ No ☐

If yes, how far? Elementary ☐ Middle ☐ High School ☐

Did you enclose a copy of your last academic certificate? Yes ☐ No ☐

Did you have any training in Electric Fundamentals? Yes ☐ No ☐

If yes, where_______________________, how long___________

and under whom _________________________________

(Name and Address)

Did you collect any certificate after this training? Yes ☐ No ☐

If yes, did you enclose a copy of your certificate? Yes ☐ No ☐

Are you willing to take an oral and/or written examination with one of our Engineers? Yes ☐ No ☐

If yes, please deposit SR 10/- in the accounts office and see our Engineer_____________________, for an appointment.

Recd. SR 10/- for test vide______

Stamp of Company

Engineer's Office:

Examination conducted by ____________________ on ____________

Score: Theory_________ Practical_________ Craft_________

License No. ____________________ granted by _______________

on ____________________

Stamp of Company

APPENDIX II: MECCA AND ITS DISTRIBUTION

Introduction

Here we will discuss in brief about Mecca and its persent[37] electrical distribution system.[38]

Mecca has the black draped Ka'ba--uniquely gorgeous and graceful house of God--built by prophet Ebrahim and his son, prophet Eshmail, a few thousand years ago. About 700 million muslims from all over the globe turn towards Ka'ba, five times a day to pray to one God, the Allah.

Mecca is uniquely Holy--its topography, climate, inhabitants, its trade and customs, its pilgrimmage with a mass transfer of about a million people to Mona and back all are fantastically unique.

It has more visitors each year than any other place in the world. Visitors bring in along with them new ideas, customs, concepts and trades and as such environs are changing fast. A lot of sharp contrasts can be seen side by side in the town in different walks of life. It is not uncommon to see the fine Cadillacs and wretched donkey carts in the same traffic lane.

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[37] As by December 1969.

[38] For the technical and allied information concerning the electric distribution of Mecca, thankful acknowledgment is made to the staff of Saudi Electric Company, Mecca, Saudi Arabia.

Topography and General

Mecca, the Holiest city of Muslims, is situated in the Arabian peninsula by the Southeast border of the Red Sea. It is in general a mountainous and rocky place. Harem,[39] the house of God built by prophet Ebrahim and Eshmail is situated in the heart of the city. It is a Grand Mosque, gigantic, magnificant and spacious with a capacity of about 300,000 people to pray here in the congregation (1). It is surrounded by rocky hills on all sides. These hills are inhabited and have multistoreyhouses to house pilgrims in the pilgrimmage season. Areas which are a few miles away from Harem in all directions are almost flat and sandy and not so thickly populated.

Climate and Rainfall

The climate of the city is hot and dry. During summers in day time the temperature may soar beyond 120 F (1). Nights are equally warm except in the hilly areas. Winter has about 2 cool weeks--they are more pleasant but quite warm in day time. The rainfall is irregular. Some years it may have torrential rains and others may be totally dry. Torrential rains may play havoc in the town. They roll down rocks from the mountains which scrap the roads

[39] The Grand Mosque. Place of worship of one God whose proper name is Allah. Allah has 99 attributes.

and may damage communication and electrical systems. Sometimes the flood in the city streets has been so high that it has swept away even big 6 ton trucks off the roads. The reason for this has been the poor drainage and sewage systems. Schemes are in action to improve the existing system to cope with the unexpected floods.

Population and Economy

Correct census data is not available. However, according to an estimate the population of the city is about 400, 000. Most of them are those who have migrated to the city and as such different customs and cultures prevail. The language of Mecca is mostly Arabic. Not all people are literate; but education is expanding fast with modern schools and facilities.

Lunar calendar and sunset timings are observed in the city. All watches are set to 1200 at the sunset everyday (1).

From the beginning of Ramadan[40] pilgrims from all over the world start pouring in the holy city. This influx continues till the 1st week of the Zil Haj.[41] By the middle of Zil Haj the pilgrimmage is over and the city returns to normal. The economy of the city is mostly dependent on pilgrims. Every year pilgrims bring in several million dollars (1). The trade of commodities, house rentals, taxis,

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[40] 9th lunar month.

[41] 12th lunar month.

and consumer goods business is at its apex and the power house touches its peak sometime in the first fortnight of Zil Haj. The pilgrimmage rotates in all four seasons because of the lunar calendar. When it falls in the hot weather, the jumps in the peak loads at the power house are very sharp, because of the air conditioning load.

The city does not have too much industry. The two major factories are a plastic factory[42] and a desert cooler manufacturing factory.[43] Nevertheless, there are quite a few small tile manufacturing factories,[44] flour mills and repair workshops etc.

Transportation is by motor vehicles and there are no electric tramways or trolleys. The tall buildings have lifts and water pumping loads.

Nature of People

The areas adjoining the Grand Mosque are hilly but most thickly populated and have the commercial centers of the city. Tall buildings, big shops, and a score of pilgrim guide offices are situated around. Since it is a brisk business area, things are changing fast and electricity being a boon is demanded in increasing quantity for convenience, comfort and consumption.

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[42] Bogri Plastic Factory.

[43] Zam Zam Air Conditioner Factory

[44] Masna Bilat as known in Mecca.

Because of the sound economy of the city the people living in the central city are mostly well off and quite a number of electrical appliances are used in a normal home, including television, washing machine etc., etc. With the ever increasing demand for more power, electric cooking can safely be anticipated in the central city especially during pilgrimmage when the transportation of gas cylinders or fossils is a problem.

Historical Electrification of Harem

Harem is the core of all the religious activities and exercises in the city. Since millions of pilgrims visit and complete their religious exercises each year, this place of worship is open 24 hours a day in all seasons of the year. Great numbers of people going in circuits around the house of God not only needed light in the night but many more amenities and comforts. Light produced by kerosene-gas lamps was never sufficient nor reliable. So also cooling of the space, need of loud speakers and Zam Zam[45] facilities needed a lot of modifications. This gave rise to a proposal to electrify Harem. With the consent of the Government, Harem authorities and the approval of the religious leaders it was decided to provide electric light in the night

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[45]The Holy Water. The history goes back to Hajer and Eshmael. When Ebrahim left Hajer and Eshmail as a young baby in the mountainous desert with not much provision. Allah sprang a water well in the desert for them. This spring is still running even after several thousand years.

to Harem so that the devout may make their circuits easily. A small diesel generating set was installed and the Harem was lighted. Electric light was a blessing and it not only made the religious exercises easier but also helped in keeping the Grand Mosque neater and relieved the attendants for other duties. Soon it was found that the generating set could be run in the daytime as well, and the power generated could be consumed for fans and loud speakers. So the set was generating to run fans in the day time and lights in the night. With the scorching heat it was necessary many a time to have fans running in the night as well, and the set was not enough for it. These immediate problems of scarcity of power and associated temporary solutions had quite a race for a time until the present Power Company took the challenge and promised to supply the Harem on a 24 hour basis and to meet its increasing demand with the permission to establish and sell power to the inhabitants of the city in the long run.

The proposal being sound met the approval of the Harem authorities and the King and the company started to establish the power system now in existence. They built a small diesel generating station outside the city limits to keep away the noise and to help the mobility during pilgrimmage. They generated at 11 kv-3 phase 50 cps and laid a radial feeder up to the city and built an indoor sub-station close to Harem. They stepped down to 400/230 v and took out radial LT feeders to Harem. Since the company was conscious of the previous hue and cry they were rather wise to have ample capacity in the generation, and distribution. This bit of foresight on the part of the company was a milestone for their success. Now Harem was never in the dark, had ample power for its need and was comfortable and neat for its devout. Cleaner air and absence of generating noise was also much welcomed.

Extension for Street Lighting

Soon the company realized that they were generating too much and that they had surplus power. If they did not take care of the surplus power the business may not be very profitable. So they decided to make use of the surplus power for lighting the streets adjoining the Harem area. This served the dual purpose. It brought them increased revenue from the Government, and it provided a chance for the inhabitants to think and realize that electricity was not meant for Harem only but also for street lighting. The people started thinking that they might also benefit from this source of power and it could be that one day they could flip a switch to light their houses.

Power Demand by the Neighboring Areas

The scheme had worked. More and more people were getting electric minded. The aristrocratic businessmen in the Harem adjoining area were looking up to brighter shops, cooler atmosphere, more customers and more and more profits. The pilgrim guides were thinking to electrify their multistorey houses and have more amenities to attract more pilgrims and ultimately more income.

This healthy change in the thinking of the people was very very beneficial for the Company. The Company will have the privilege to oblige the holy city dwellers and to boost its income.

With this increasing demand the Company declared to extend its facilities to the people and started collecting applications for connections. In the meanwhile they chalked out some preliminary contract forms and imported more materials for house wiring.

Whereas electricity was a new commodity for the city, not many houses had wiring. In fact house wiring was also a problem which the Company had to face. The Company's technical employees who were basically wiremen or cable jointers with not too much experience, also had to take the job of premesis wiring as a complement and necessity. This gave rise to a few administrative and technical problems. On one hand Harem and the adjoining street lights were very important to operate and maintain and on the other hand booming new connections were in great demand. So the Power Company hired one engineer for administration and a few more electricians and cable jointers.

Extension of Harem Supplies to Neighboring Areas

With more staff the situation improved. Harem and its street lighting were attended separately and the extension had its own people.

With the first few houses wired and electrified the damand for more connection increased tremendously. The electricity was clean, convenient and perhaps cheap. Everybody had the right to be supplied. As an immediate measure one LT radial feeder of adequate capacity was taken out and laid straight in the street as the main power channel. People in the vicinity were simply teed off from this feeder. Then more people were teed off from the sub-feeder, then more people were teed off from sub-sub-feeder and so on. Ultimately the system was in great disorder like a cobweb, as Figure A. 1 shows.

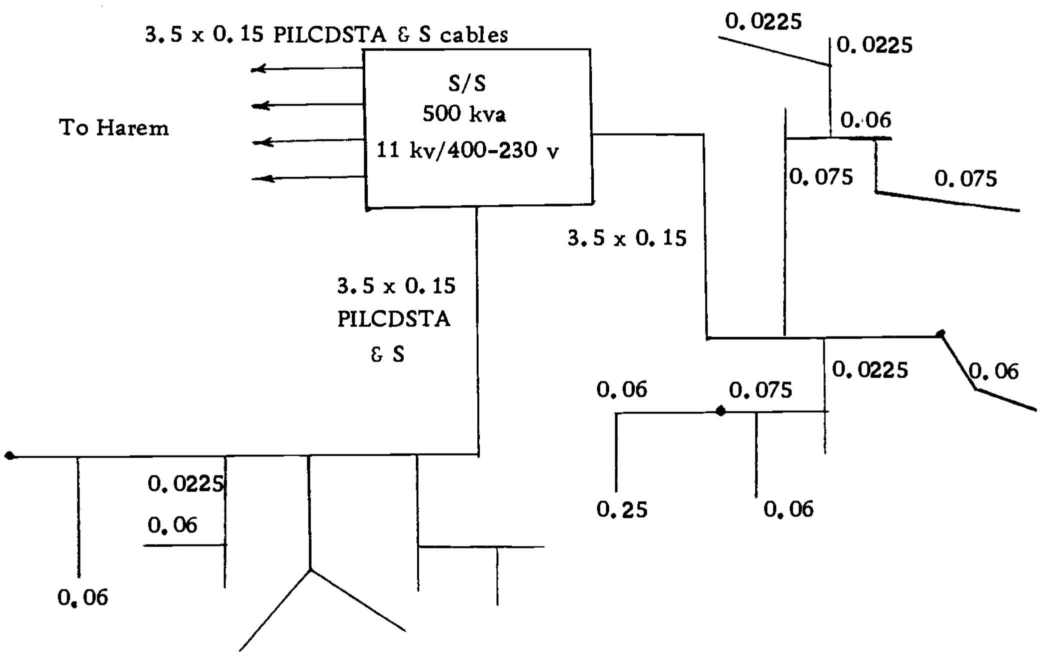

Figure A. 1. LT feeder extension.

Good workmanship could not be maintained because of the rush and lack of craft. Even some temporary connections which were granted in those early days are not replaced or removed until now.

In these early sub-stations the HT feeder and station transformer both were either protected by oil circuit breakers or the feeder was protected by a fused isolator and the transformer by a circuit breaker. The leads from the transformers LT sides were solidly connected to copper bus bars and had no overload or short circuit protection. The main leads, however, had maximum demand indicators. Separate circuits from LT bus-bars were taken through cartridge type fuses and there were neither maximum demand indicators on these separate feeders, nor any switching arrangement. Please see Figures A. 2, A. 3 and A. 4 for clarity.

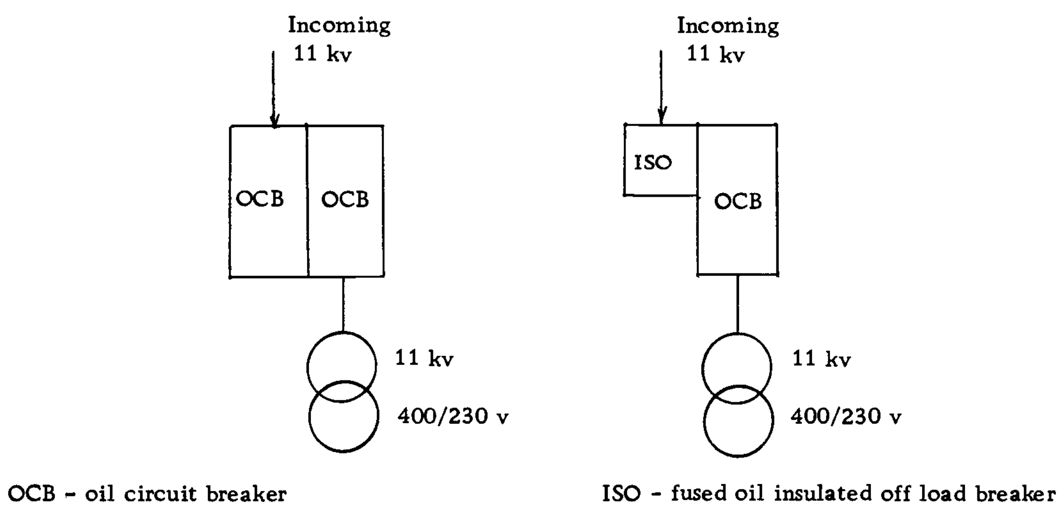

Figure A. 2. HT feeder and transformer protection.

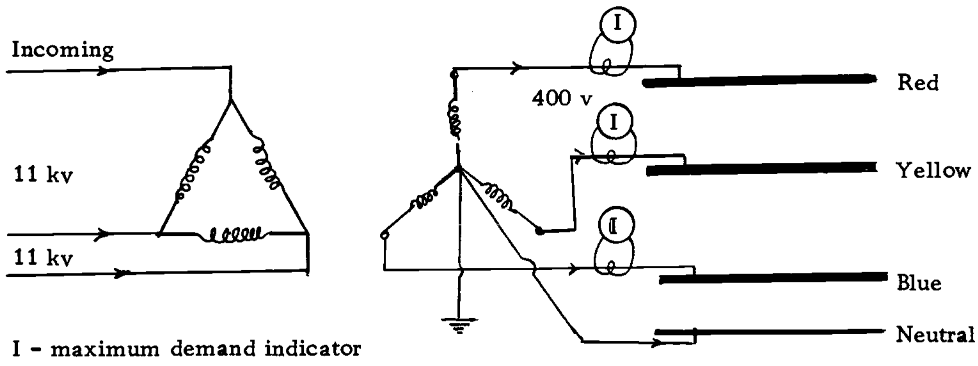

Figure A. 3. LT bus bar connections to transformer.

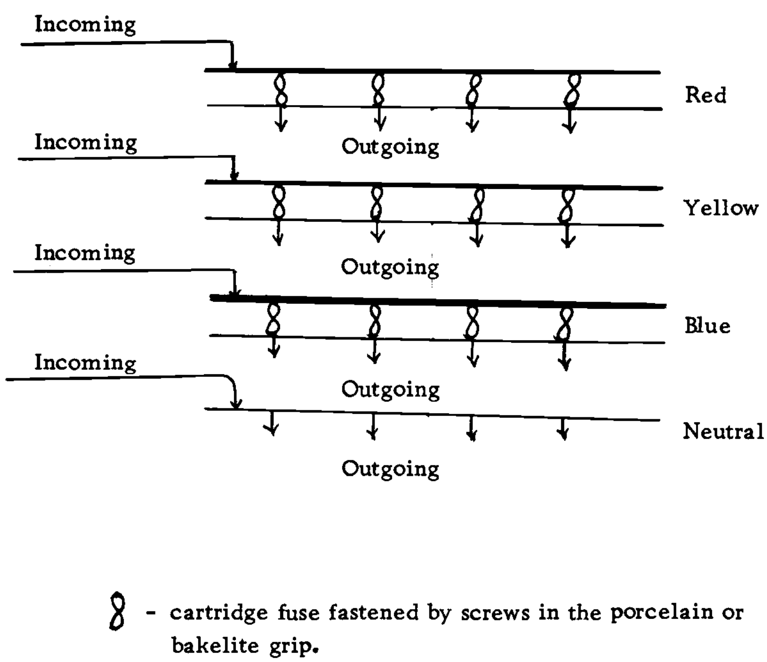

Figure A. 4. Incoming and outgoing LT feeders arrangement inside the S/S.

In case of overload these cartridge fuses were blown and were replaced with fuses of higher capacity if needed. There being no protection on the sub-sub feeders etc. fuse co-ordination was never done nor thought of. In case of a high resistance fault it was generally the slow burning of the entire branch of feeder. In case of pilgrimmage such a fault was highly agitating to the consumers.

Power Demand by the Off Harem Areas

With the power supplied to the people falling in the Harem area, the demand for electricity increased very fastly from all corners of the city. It was an overwhelming situation for the Company. They could utilize their spare generating capacity and extend their network. More feeders were laid and more sub-stations were built to cope with the increasing demands. Whereas the sub-station sites were taken with a minimum of selectivity, no consideration was given either to the load center or the load factor which was constantly rising. Very shortly a time was coming when the power house needed extension as load shedding was not desirable at all.

Consistent Demand of Public and Their Appeals

Electricity was such a marvel. How could a man tolerate to be deprived of it? Whereas people a few blocks away had air conditioning comfort he should be deprived even of a table fan. And he was willing to pay for the expenses. The Company was not doing him any kindness. The Company was a sales organization and he was a customer. If the Company had the monopoly in the area it did not mean that it could take undue advantage of it. The Company engineer declined to connect his premises, perhaps because he was a foreigner. A foreigner can not be allowed to pass orders or judgments on the natives. We will see the manager. The manager said, "Our engineer says we are facing the problem of overload. We can not extend further. They must wait till we renovate." Oh, even this manager does not understand. Let them be without electricity and they will realize. We should not give up. We will complain to their managing director." The manging director said, "You must see the manager. The manager has better information than I do. He will look into your affairs." Perhaps we should see the Governor of Mecca and if necessary the King. You know we are paying and they must supply us with electricity.

Such were the sentiments of those simple hearted people. Management or engineering can not be accused of any apathy. It is the initial mistake which sould be rectified or expanded without regard to future.

Inability of Power Company and Its Policies

With the pressing and increasing demands for the power and the

Company's inability to cope with it immediately, the Company had to adapt a new policy and impose it without delay. The amendments were:

1) The premises will not be wired by the Company.

2) For a consumer who is too much insistent and can not be connected for the existing facilities, an over-expensive estimate will be prepared.

Power Company Situation and Pressures

The policies adopted did not help much. It created some new difficulties as such:

1) People had learned the house wiring and also the Company employees had a chance to have it as their side business. The wiring done by new and amateur wiremen and electricians was not always satisfactory. It did not stop or reduce the demand for power, rather it increased the load of the estimating engineer. Now the estimating engineer had to check the wiring of the premesis. A laborious, time consuming and thankless job, which created complications in case the wiring was defective. In some cases the engineer had to disapprove the wiring purposely to discourage the prospective consumer from asking a connection in an already overloaded area. These sorts of tactics were bad and open to challenge

in a court of law.

2) Exhorbitantly expensive estimates were accepted by some people, others appealed in the court of law or approached the Company or Governmental authorities for relaxation.

As mentioned above the Power Company was not in good situation as far as distribution was concerned and the pressures from all quarters were high. Instead of clearly propagating its situation and policies by radio and press it developed short term policies which put its management and engineering in a tight situation.

Extension of LT Feeders

With the propensities of situations as explained above there was no go for the Power Company, except to comply with the wishes of its customers. In normal situation burden over the already overloaded cables will look a clear folly but considering the common crisis management had to yield. This resulted in the further extension of the overloaded feeders. The engineering staff was condoned with a pretext of better circumstances in the near future. They were advised to use larger fuses or even solid links to protect the LT feeders.

Haphazard Developments and Extensions

With the new philosophy of distribution the development of new connections and feeder extensions was rapid but very haphazard so much so that complete or even broken records are not available from the drawing office. The crew and the engineer who had done the job had left the organization, or forgotten what they did or were purposely concealing the information. The management was helpless in this concern and the man who wanted to study the system had to start from scratch.

Non-Existence of Load Survey

As the development proceeded haphazardly it is obvious no load survey was carried out. There are no records of load survey before or after the job was done. Rather the people do not appreciate the importance of this basic but important data.

Non-Existence of Town Planning

It appears that the entire city developed haphazardly without any planning. Municipality of Mecca which also has a town planner's office do not appear to have many maps of the city. They are more or less working on the newly developed or to be developed areas. However, it is heartening to note that an aerial survey of the city has been carried out and its prints and enlargement may be available after sometime. As nothing can be said with certainty let us hope for the best.

Undue Pressure of Consumers and Company's Inability to Resist

Many times it has happened that the estimate and other conditions are agreed upon but the area appears to be impassable by overhead line or underground cable. The main hitch may be anyone of the following:

1) An undecided area, whether it is a private property or open land.
2) An unclaimed piece of land for which the town planner has no record or information.
3) Soak pit of the prospective or some other consumer.

In all such cases generally the matter was referred to the municipality. Many times there was no rigid positive or negative answer from the municipal authority, and as such the consumer generally took an upper hand. Since there is no strong clause in the contract to deal with such disputes the consumer generally had his way.

Later on, when there was some claimant for that piece of plot or municipal authorities wanted to build some facility which may be hampered by the proximity of the power lines, the Company was asked to remove their equipment. It was not always that the Company could prove its rights and win the case.

Lack of Company's Propaganda and Its Push for Data

There are a lot of things which need sound propaganda and devoted sales push. The Power Company perhaps does not consider it worthwhile to announce to the general public its policies concerning consumers. Facilities of television, radio and press are easily available. Perhaps their importance is not explored or they are not exploited purposely. So also a lot of data which could facilitate in a sound engineering analysis can be gathered from Government and the other utilities as sewage or telephone which also have extensive development projects for the city. It needs a close liaison.

A knowledgeable man assigned to this job is an important investment.

Inability of Engineers and Their Troubles

Quite a few of the engineering staff is foreign personnel. Not all of them understand Arabic.[46] While they may have been well trained and educated in their respective fields, lack of understanding of the language and local customs retarded their efficiency. It is an important phase of the training of the new employee but the organization does not appear to pay any attention.

[46]The native language of the country.

Secondly, and most important--the duties and responsibilities of an engineer remain undefined. It is poor management since it creates dis-satisfaction on both ends. The engineer thinks he has done more than his due and the management thinks that the engineer has not mastered all aspects of distribution. Whereas one man can not be an expert of everything, to expect him to be a jack of all trades is equally harmful to the organization.

Insufficient Staff of Qualified and Trained Personnel

The trouble does not end here. Whereas the Company expects a lot from the engineers, there is a clear shortage of properly trained and qualified personnel. If an engineer wishes to improve some method or process he has to have a team to work with him. The Company is at its best under-staffed. Whatever people are on the payroll are busy extensively in their routine jobs and everybody is in a great rush and hurry. There is no time for research. For any small or big experiment which the engineer may wish to perform, he must himself collect all the pertinent information, material, apparatus etc.; and proceed with the experiment. Now all experiments can not be performed single handed. If at all some staff is available to assist, they are either unconcerned or over-ambitious. They can not be blamed for this attitude. They are unconcerned because the management considers that the time spent in research or method improvement is a waste. At times, the overtime working of staff on such projects has been refused because they were not doing anything constructive. They are overambitious because they did not have any or enough education. For them learning a little or learning something new makes them different and superior to thier fellow workers.

Present[47] Situation of HT Distribution

As will be noticed from Figure A. 5 there is no transmission for this city. The power which is generated at 11 kv-3 Ph-50 cps is brought directly to the sub-stations by different feeders. One of these feeders is overhead and feeds the television repeater station. One more feeder is especially laid for the newspaper printing factory. Out of the rest of 6 feeders, 2 of them run overhead for about 2 miles off the power house, and then, they continue as underground cables.

The entire city distribution including the Harem, Harem adjoining, off Harem and pilgrimmage area of Mona depends on the manipulation and operation of these 6 feeders.

The HT distribution has improved considerably in the past few years with the inclusion of more and more sub-stations. More and more sub-stations have been taken in rings or loops so that in case of failure of one feeder, supply is available from another feeder. This has proved very fruitful in a lot of cases when one feeder has tripped

[47] As of Dec. 1969.

due to overload, incorrect operation or pilferage. However, since different feeders were laid at different times, in different circumstances by different people, synchronization has not been kept and at times it is necessary to shed the load when a higher capacity feeder has failed. But the situation is still better than worst and can be tackled. The protection of feeders is by

1) Oil circuit breakers with maximum capacity of 150 mva.

2) Off load fused switches with oil cooling.

3) Off load fused switches with no cooling.

Without exception all sub-stations are indoor type with pad or floor mounted, natural oil cooled transformers of different makes as Brush, General Electric, Metropolitan Vickers, Siemens, Conti Electro etc.

The maintenance of the sub-station is almost nil. Because of pressure of other jobs and undefined duties no engineer has time to volunteer for this so called non-constructive job. Only that maintenance which can be performed by a vigilant helper is carried out and it includes general cleaning of the S/S building, wall distemper, doors painting, checking the S/S roof for leakage from rain water, providing light bulbs etc. Mechanical and electrical maintenance is hardly carried out. There is no record or data available if the transformer or switch oils were ever tested, replenished or changed.

Oil circuit breakers are of the drawout type and it is hard to say whether their contact were ever checked. Same is true for the off load switches. Off load fused switches with no cooling are rather installed recently, but it is doubtful to assume that spare springs or knives are available in case need arises.

In case of blow out of HT fuses it is also time consuming to search for the fuses in the general stores at odd times.

The purpose of this report is to discuss the LT distribution and its possible improvement so we will avoid any further treatment of HT distribution hence. However, we will compile a brief data on sub-stations and HT feeders with reference to Faigure A. 5. Table A. 1 contains a list of S/S, their nomenclatures, and information whether the S/S is commissioned or not, available HT feeders, feeder number for normal operation, and the capacity of the station transformers. Henceforth for reference to specific sub-stations, its nomenclature will be used. Table A. 1 is the basic table for other tables in the text. As is clear from Figure A. 5, the incoming feeders from the power house touch sub-stations A1, B1, C1, D1, J1 or J2. Sub-stations E1 and G1 do not have any feeder directly coming from the power house. Sub-station C1 has two feeders incoming directly from the power house. This is shown by letters PH on S/S panels.

There is no special reason for this nomenclature. It may be fairly guessed that the S/S with subscript 1 were chosen to mean the feeder incoming directly from the power house. The subscripts in the

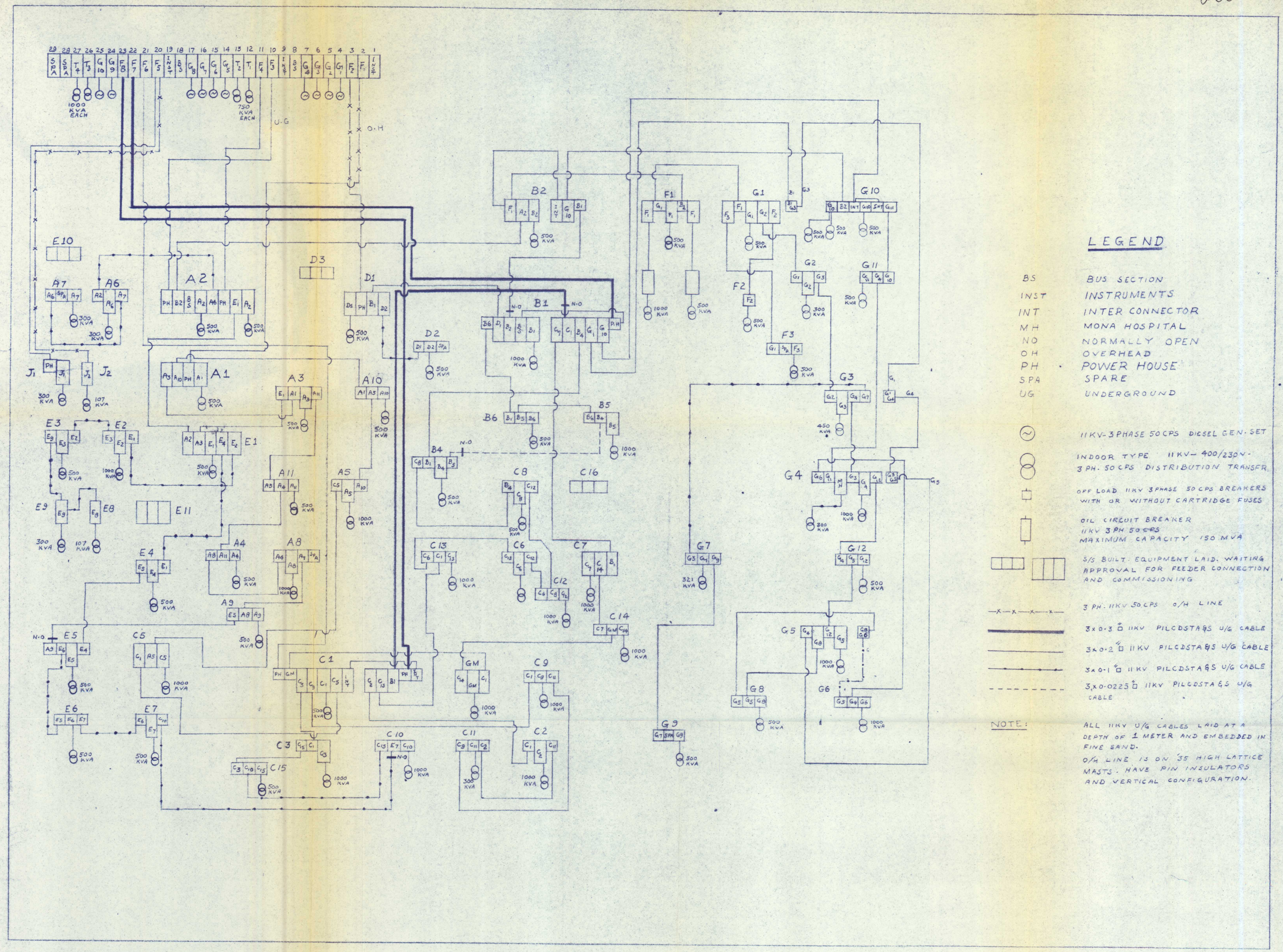
LEGEND
BS BUS SECTION
INST INSTRUMENTS
INT INTER CONNECTOR
MH MONA HOSPITAL
NO NORMALLY OPEN
OH OVERHEAD
PH POWER HOUSE
SPA SPARE
UG UNDERGROUND
11KV-3PHASE 50CPS DIESEL GEN. SET
INDOOR TYPE 11KV- 400/230V- 3 PH. 50CPS DISTRIBUTION TRANSFR.
OFF LOAD 11KV 3PHASE 50CPS BREAKERS WITH OR WITHOUT CARTRIDGE FUSES
OIL CIRCUIT BREAKER 11KV 3PH 50CPS MAXIMUM CAPACITY 150 MVA
S/S BUILT. EQUIPMENT LAID. WAITING APPROVAL FOR FEEDER CONNECTION AND COMMISSIONING
3 PH. 11KV 50CPS O/H LINE
3x0.3 □ 11KV PILCDSTA&S U/G CABLE
3x0.2 □ 11KV PILCDSTA&S U/G CABLE
3x0.1 □ 11KV PILCDSTA&S U/G CABLE
3x0.0225 □ 11KV PILCDSTA&S U/G CABLE
NOTE: ALL 11KV U/G CABLES LAID AT A DEPTH OF 1 METER AND EMBEDDED IN FINE SAND.
O/H LINE IS ON 35' HIGH LATTICE MASTS. HAVE PIN INSULATORS AND VERTICAL CONFIGURATION.

Table A. 1. Substations data sheet.

SNO	Nomen-clature	Name of Substation	Commis-sioned	Available Feeder No.	Normal Operation by Feeder	Transformer Capacity kva
1	A1	Abdullah Faisal	yes	1, 4	1	500
2	A2	Bustan Az Zahir	yes	3, 4	3, 4	2 x 500
3	A3	Bab Jeddah	yes	1, 4, 6	1	500
4	A4	Qishla	yes	1, 4, 6	1	500
5	A5	Jarwal	yes	1, 4, 6, 8	1	1000
6	A6	Zahir	yes	1, 4	4	300
7	A7	Ba Khutma	yes	1, 4	4	300
8	A8	Hafayer	yes	1, 4, 6	1	1000
9	A9	Sooq Al Burndo	yes	1, 4, 6	1	500
10	A10	Bait Al Majid	yes	1, 6, 8	1	500
11	A11	Telephone exchange	yes	1, 4, 6	1	500
12	B1	Masjid Gin	yes	2, 7, 8	2, 7	1000
13	B2	Maabdah	yes	2, 3, 7	2, 3	500
14	B4	Halaqa	yes	2, 6, 8	8	500
15	B5	Shaib Aamer	yes	2, 7, 8	2	1000
16	B6	Imarat Mufti	yes	2, 7, 8	2	500
17	C1	Zoggag Al Janayes	yes	1, 2, 4, 6, 7, 8	6, 8	500
18	C2	Jiad	yes	1, 4, 6, 8	8	1000
19	C3	Misfala	yes	1, 4, 6, 8	6	1000
20	C5	Haret Al Bab	yes	1, 4, 6, 8	1	1000
21	C6	Shamia	yes	1, 4, 6, 8	8	1000
22	C7	SooqAl Lail	yes	1, 4, 6, 7, 8	7	1000
23	C8	Falaq	yes	2, 6, 7, 8	8	500
24	C9	Jiad As Sud	yes	1, 2, 4, 6, 7, 8	8	1000
25	C10	Koodai	yes	1, 4, 6, 8	6	1000
26	C11	Jiad Hospital	yes	1, 4, 6, 8	6	300
27	C12	Bab Salam	yes	1, 2, 4, 6, 7, 8	8	1000
28	C13	Bab Umra	yes	1, 2, 4, 6, 7, 8	8	1000
29	C14	Qashashia	yes	1, 2, 4, 6, 7, 8	7	1000
30	C15	Harat Ar Rushd	yes	1, 4, 6, 7, 8	6	500
31	C16	Madrasah Jabal Hindi	Not yet	Not decided	Not decided	500
32	D1	Ataibia	yes	2, 6, 7, 8	2	500
33	D2	Daghash	yes	2, 6, 7, 8	2	500
34	D3	Malaqqia	Not yet	Not decided	Not decided	500
35	E1	Al Ghazzawi	yes	1, 4, 6, 8	4	500
36	E2	Nuzha	yes	1, 4, 6, 8	4	1000
37	E3	Um Al Daraj	yes	1, 4, 6, 8	4	500
38	E4	Shahrah Mansour	yes	1, 4, 6, 8	4	500
39	E5	Khamis Nassar	yes	1, 4, 6, 8	4	500
40	E6	Mohammed Taufeeq	yes	1, 4, 6, 8	4	500
41	E7	Quoz An Naccasa	yes	1, 4, 6, 8	4	500

Table A.1. Continued.

SNO	Nomen-clature	Name of Substation	Commis-sioned	Available Feeder No.	Normal Operation by Feeder	Transformer Capacity kva
42	E8	Um Al Dood	yes	1, 4, 6, 8	4	107
43	E9	Saroor Sabban	yes	1, 4, 6, 8	4	300
44	E10	Madrasah Zahra	Not yet	Not decided	Not decided	500
45	E11	Madrasak Nuzha	Not yet	Not decided	Not decided	500
46	F1	Old Palace-Maabda	yes	2, 3	3	1000 + 2 x 500
47	F2	Rie Al Miskeen	yes	2, 3	3	500
48	F3	Khansa	yes	2, 3	3	500
49	GM	Harem	yes	1, 2, 3, 4, 6, 7, 8	6	1000
50	G1	New Palace-Maabda	yes	3, 7	3	500
51	G2	Abdullah Hawari	yes	3, 7	3	300
52	G3	Shisha	yes	3, 7	3	450
53	G4	Jumra Kabeer	yes	2, 3, 6, 7	3	1000+ 300
54	G5	King Palace-Mona	yes	2, 3, 6, 7	2	1000
55	G6	Sooq Al Arab	yes	2, 3, 6, 7	2	1000
56	G7	Madrasa Azizia	yes	2, 3, 6, 7	3	321
57	G8	Qasre Malaki-Mona	yes	2, 3, 6, 7	2	500
58	G9	Hoz Al Baquar	yes	2, 3, 6, 7		500
59	G10	Shaibia	yes	2, 3, 6, 7	2	3 x 500
60	G11	Mustashfa Shisha	yes	2, 3, 6, 7	2	500
61	G12	Qasre Ziyafa-Mona	yes	2, 3, 6, 7	3	500
62	J1	Nadwa	yes	5	5	300
63	J2	Television	yes	5	5	107

nomenclature progressed as the feeders were extended and more sub-stations were added in the network.

A study of Figure A. 5 and Table A. 1 will show that excepting the sub-stations J1 and J2 all other sub-stations have more than one feeder available for operation. This has been done to improve the stability of network. In the past few years, more and more sub-stations have been taken in rings and a lot of attention has been paid to improve the network stability. But with different circuit breaking and protection equipment the network has been not made fool proof. Different capacity feeders and poor maintenance of relays can not be depended upon for long. In case of a fault on a feeder, although a dead S/S can be energized by some other feeder, yet a wrong operation of network may cause serious troubles and overload tripping. Although the engineer working in network operation develops quite an expertise in his job yet it is not enough. Operation charts and guidelines are not available and human memory can not be perfect always. The rings or loops in the network are designed not on the basis of engineering analysis but on the availability of switches and space in the S/S.

We give an analysis of the importance of different sub-stations with reference to Harem and Pilgrimmage in Tables A. 2 and A. 3. These tables may show the necessity of ringmain or loop system. It may be added that the HT network in Mecca is operated both as closed

Table A.2. Classification of S/S by location.

S/S Supplying Mainly the Harem Load	S/S in the Harem Adjoining Pilgrimmage Area	S/S Situation Away From Harem
GM C12, C13, C14	A5, A10 B1, B4, B5, B6 C1, C2, C3, C5, C6 C7, C8, C9, C11, C15 C16	A1, A2, A3, A4, A6 A7, A8, A9, A11 B2 C10 D1, D2, D3 E1, E2, E3, E4, E5, E6, E7 E8, E9, E10, E11 F1, F2, F3 G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12 J1, J2
Classified Maximum Demand = 4000 kva	Classified Maximum Demand = 11, 800 kva	Classified Maximum Demand = 24, 325 kva
Total Maximum Demand of S/S = 40, 125		

Table A.3. Classification of S/S by importance to network.

S/S Important Thought The Year	S/S More Important During Pilgrimmage	S/S Very Important When King is Visinting Off Pilgrimmage
GM	GM	GM
A1, A2, A3, A5, A10, A11	A1, A2, A3, A5, A8, A10, A11	A1, A2, A5, A10, A11
B1, B2, B4, B5, B6	B1, B2, B4, B5, B6	B1, B2, B4, B6
C1, C2, C3, C5, C6, C7 C8, C11, C12, C13, C14	C1, C2, C3, C5, C6, C7, C8 C9, C11, C12, C13, C14, C15, C16	C1, C2, C6, C7, C8, C11 C12, C13, C14
D1	D1	D1
E1, E4, E9	E1, E2, E3, E4, E8, E9	E1, E4, E8, E9
F1	F1	F1
G3, G4, G7, G9, G11	G1, G2, G3, G4, G5, G6 G8, G10, G11, G12	G1, G7, G9, G10, G11
J1, J2	J1	J1, J2
Classified Maximum Demand = 25, 078 kva	Classified Maximum Demand = 33, 057 kva	Classified Maximum Demand = 21, 435

and open loop system at different places for several reasons.

The diversity of maximum demands in different locations is also different in different situations. In fact during the rituals of pilgrimmage on the 8^{th} day of Zil Haj there is a mass transfer of about a million people from Harem adjoining areas to the areas fed by G4, G5, G6, G7, G8, and G12 sub-stations, in Mona.[48]

In case of fault on a feeder it is not always possible to shed the desired loads. But shut downs for a reasonable short period can be easily arranged; except in scorching hot weather, pilgrimmage or when the King is visiting. A shut down should be announced well in advance by press and must be strictly adhered. Table A.4 shows a possible load shedding schedule.

The following table may help in visualizing the necessary training and experience needed in the operation of the network especially in the time of pilgrimmage when the mobility in the Mona, the pilgrimmage area is almost nil, because of the swarming devouts.[49] We give in Table A.5 a statistics of the off pilgrimmage, normal operation of the HT feeders.

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[48] A valley $3\frac{1}{2}$ miles southeast of Harem. It has three pillars marking the place where Satan tried to coax Ebrahim from sacrificing Eshmail. These pillars are stoned on the 10th, 11th and 12th of Zil Haj and on the 13th pilgrims return to Mecca.

[49] To visualize the swarming devouts, see National Geographic, January, 1966 and GAF Corporation, View master, Mecca, Saudi Arabia, Famous Cities Series, No. B2282, 1967.

Table A. 4. Classification of S/S by load shedding of S/S.

Load Shedding Possible for Hours							
10-12	8-10	6-8	4-6	2-4	$\frac{1}{2}$-2	0-$\frac{1}{2}$	S/S
N	N	N	AYEP	AYEP	AYEP	AY	A1
N	N	N	AYEP	AYEP	AYEP	AY	A2
N	N	AYEP	AYEP	AYEP	AYEP	AY	A3
AYEP	AYEP	AYEP	AYEP	AY	AY	AY	A4
N	N	N	AYEP	AYEP	AYEP	AY	A5
AY	AY	AY	AY	AY	AY	AY	A6
AY	AY	AY	AY	AY	AY	AY	A7
AYEP	AYEP	AYEP	AYEP	AYEP	AYEP	AYEP	A8
AY	AY	AY	AY	AY	AY	AY	A9
N	N	N	AYEP	AYEP	AY	AY	A10
N	N	N	N	N	AY	AY	A11
N	N	N	AYEP	AYEP	AY	AY	B1
N	N	N	AYEP	AYEP	AY	AY	B2
N	N	N	N	N	AYEP	AYEP	B4
N	N	AYEP	AYEP	AYEP	AY	AY	B5
N	N	N	N	AYEP	AY	AY	B6
N	N	N	N	AYEP	AYEP	AY	C1
N	N	N	N	AYEP	AYEP	AY	C2
N	N	AYEP	AYEP	AYEP	AY	AY	C3
N	N	N	AYEP	AYEP	AYEP	AY	C5
N	N	ODP	ODP	ODP	AYEP	AY	C6
N	N	N	ODP	ODP	AYEP	AY	C7
N	N	N	ODP	ODP	AYEP	AY	C8
N	N	N	AYEP	AYEP	AY	AY	C9
AY	AY	AY	AY	AY	AY	AY	C10
N	N	N	N	N	N	N	C11
N	N	ODP	ODP	ODP	AYEP	AY	C12
N	N	ODP	ODP	ODP	AYEP	AY	C13
N	N	ODP	ODP	ODP	AYEP	AY	C14
ODP	ODP	AYEP	AYEP	AY	AY	AY	C15
ODP	ODP	ODP	ODP	AY	AY	AY	C16
N	N	N	N	ODP	AYEP	AY	D1
AY	AY	AY	AY	AY	AY	AY	D2
AY	AY	AY	AY	AY	AY	AY	D3
N	N	N	N	ODP	AY	AY	E1
N	N	N	ODP	ODP	AY	AY	E2
AYEP	AYEP	AYEP	AYEP	AYEP	AY	AY	E3
N	N	N	ODP	AY	AY	AY	E4

Table A. 4. Continued.

Load Shedding Possible for Hours							
10-12	8-10	6-8	4-6	2-4	$\frac{1}{2}$-2	0-$\frac{1}{2}$	S/S
N	N	N	ODP	ODP	AY	AY	E5
N	ODP	ODP	ODP	AY	AY	AY	E6
AYEP	AYEP	AYEP	AYEP	AY	AY	AY	E7
AYEP	AYEP	AYEP	AYEP	AY	AY	AY	E8
N	N	N	ODP	ODP	AY	AY	E9
ODP	ODP	ODP	AY	AY	AY	AY	E10
ODP	ODP	ODP	AY	AY	AY	AY	E11
N	N	ODP	ODP	ODP	AY	AY	F1
N	N	N	AYEP	AYEP	AYEP	AY	F2
AYEP	AYEP	AYEP	AYEP	AY	AY	AY	F3
N	N	N	N	N	N	N	GM
AYEP	AYEP	AYEP	AYEP	AYEP	AYEP	AYEP	G1
N	N	ODP	ODP	ODP	AY	AY	G2
N	N	ODP	ODP	ODP	AY	AY	G3
NIP	NIP	NIP	NIP	NIP	NIP	NIP	G4
NIP	NIP	NIP	NIP	NIP	NIP	NIP	G5
NIP	NIP	NIP	NIP	NIP	NIP	NIP	G6
ODP	ODP	ODP	ODP	AY	AY	AY	G7
NIP	NIP	NIP	NIP	NIP	NIP	NIP	G8
AYEP	AYEP	AYEP	AYEP	AYEP	AYEP	AY	G9
NIP	NIP	NIP	NIP	NIP	NIP	NIP	G10
N	N	N	N	NIP	NIP	AY	G11
NIP	NIP	NIP	NIP	NIP	NIP	NIP	G12
N	N	N	N	ODP	AY	AY	J1
N	N	NIP	NIP	NIP	AYEP	AY	J2

N means Never except in real emergency.
NIP means Never in pilgrimmage.
ODP means Only during pilgrimmage.
AYEP means All year round except pilgrimmage.
AY means All year round.

Table A.5. Normal operation of feeders.

Feeder No.	Size sq. in.	Type	S/S Served
1	3 x 0.2 Throughout	Loop	A1, A3, A4, A5, A8, A9, A10, A11, C5
2	3 x 0.2 Throughout	Loop	B1, B5, B6, D1, D2, G5, G6, G8, G10, G11, G12
3	3 x 0.2 Throughout	Loop	B2, F1, F2, F3, G1, G2, G3, G4, G7, G9
4	3 x 0.2 Change of section to 3 x 0.1 between stations. See Figure A.5	Loop	A2, A6, A7, E1, E2, E3, E4, E5, E6, E7, E8, E9
5	3 x 0.2 See Figure A.5	Radial	J1, J2
6	3 x 0.2 Change of section to 3 x 0.1. See Figure A.5	Loop	GM, C1, C3, C9, C10, C15
7	3 x 0.3 Change of section to 3 x 0.2. See Figure A.5	Loop	C7, C14
8	3 x 0.3 Change of section to 3 x 0.2. See Figure A.5	Loop	B4, C2, C6, C8, C11, C12, C13

In Table A.6 we give an account of the feeder assigned ampacities and normal load in off pilgrimmage season.

An examination of Table A.6 shows that feeder 5 is the most lightly loaded feeder. Feeder 5 is a radial feeder and it has two branch outs from the circuit breaker in the power house. One branch is used to supply a 300 kva load of Nadwa press and the other branch feeds the 107 kva load of Television Repeater Station. Please see Figure A.5. The TV station is located on the top of a hill northeast of PH and there are no chances of any further load development here, in the next 20 years. Nadwa press is also in the outskirts of the city limit and is located North of the power house on a level ground. Since the surrounding area here is plain and the highway is within a furlong there are chances of load development of the area in the next 10-15 years. Even if the Nadwa press expands or builds facilities for its employees, feeder No. 5 may be satisfactory to supply sufficient power for quite a time.

Table A.6. Capacities and normal load on feeders.

Feeder No.	Size from Power House	Assigned Ampacity	Maximum Assigned 3-Ph kva Capacity	Maximum Expected kva on Feeder when Diversity and Load Factors are = 1.0
1	3 x 0.2	250	4750	6000
2	3 x 0.2	250	4750	8500
3	3 x 0.2	250	4750	6871
4	3 x 0.2	250	4750	6007
5	3 x 0.2	250	4750	407
6	3 x 0.2	250	4750	4500
7	3 x 0.3	355	6750	2000
8	3 x 0.3	355	6750	4800

Assigned ampacities for 3 x 0.0225 sq in. PILCDSTA & S cable is 70A
3 x 0.06 sq in. PILCDSTA & S cable is 60A
3 x 0.1 sq in. PILCDSTA & S cable is 160A

Although Table A.6 shows feeders No. 2, 3 and 4 to be overloaded during normal operation, yet the situation is rather different. Because of a high diversity the S/S are generally not loaded to capacity even, during normal operation. A lot of buildings which are served by these feeders remain unoccupied for about 10 months every year. Secondly, during summer a sizeable population of Mecca shifts to Taif.[50] However, if the pilgrimmage falls in summer[51] the situation is different. In that case there is a lot more influx in the city and the per capita consumption of power rises quite high.

Feeders 2, 3 and 4 are relatively old feeders and feeders 6, 7 and 8 have been laid not much time ago. In fact feeders 7 and 8 were laid in 1968.

These newer feeders are laid not only to cope with the emergencies by open and closed loop operations at conspicuous places, but also to keep abreast with the changing environs--easier and convenient living with electricity. The maximum demand noted in the power house was about 5672 kw in 1384 AH.[52] This jumped to about 17,000 kw in 1388 AH;[53] which shows a rapid development of load and a high load factor.

General Operations of HT During Pilgrimmage

Basically there are three major operations during pilgrimmage. Operations to cope with the:

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[50] Taif is the summer capital of the kingdom. Height above sea level is 8415'. Distance from Mecca is 55 miles southeast.

[51] Almost every consecutive 12 years.

[52] Maximum demand noted in PH in Haj of 1384 AH, April 1965. National Geographic, Jan. 1966 has colored pictures of this Haj.

[53] Maximum demand noted in PH in Haj of 1388 AH, Feb. 1969.

1. rising load in the Harem adjoining areas (see Table A. 2), from 1st, Zil Haj to 7th Zil Haj.
2. shifting loads of pilgrims in the Mona area on S/S G4, G5, G6, G8, G10, G12 during 8th Zil Haj to 12th Zil Haj.
3. returning load of pilgrims to Mecca from Mona, on S/S lying in the Harem adjoining areas (see Table A. 2), from 13th Zil Haj to 30th Zil Haj.

Depending upon the maximum demand on the power house in a preceding year operations are planned for an increased demand for the present year. As such these operations are different for different years and can not be standardized. However, all endeavors are made to provide more than one feeder in all important S/S, to improve the reliability of the system. For improved reliability of the network, the HT system is in constant adjustments.

Present Situation of LT Distribution

Whereas HT network is in constant improvement, not so much has been done on LT. There are quite a few reasons for this. A few of these are:

1. HT network is relatively small; 6 feeders and 61 sub-stations.
2. LT system is much bigger, with generally 7 feeders from a sub-station and about 30, 000 consumers.[54]

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[54] 1389 AH statistics. The number of consumers in 1384 AH were 14, 000. A good load development and rapid expansion.

3. HT system, including feeder, S/S building, transformer, connections, labor and sundries are generally at the cost of company.
4. LT system, including LT feeders, distribution cabinets, sub-feeders, service mains, extension, trenching, labor and sundries are at the cost of consumer or consumers.
5. Job on HT system are generally planned ahead in time as there is no problem of cost.
6. Job on LT system are not planned ahead in time and can not be done so, because of the disbursement of cost from consumers.
7. Generally one man is responsible for HT operations and adjustments etc., and so in case of difficulties he consults the head office,[55] and avoids any possible hue and cry from public or local management.[56]
8. In case of LT, situation is just the reverse. Since the Company's philosophy is different in case of LT extensions and adjustments, it makes the situation tricky and difficult for the engineer. Mostly, the local management has a lot more concern with LT than HT and all situations in which the

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[55] From Chief Engineer or Managing Director in Jeddah. Jeddah is an international air port and is situated 44 miles west of Mecca.

[56] Management in Mecca.

Company has to invest are avoided if not totally refused. So much so, a few old and senior electricians and jointers who are in service of the Company since the Company established take undue advantage of their seniority. They not only consider them authority on Mecca LT distribution, but also blemish any new idea propagated by their engineer, and confuse the management. This way the progress retards, and the management takes some time to develop confidence in the LT engineers. By the time the Company has confidence in the engineer, the engineer gets so disheartened by the local politics that he prefers to change than to continue. As such it is more harmful to the organization and to the LT system than it is to the engineer. A new engineer who comes to work in the place of the previous one takes time to study and understand the system and then when he tries to improve the system faces the same troubles.

9. The organization is quite attentive to the material requirements and stores for its HT system. In case of shortage of HT material special arrangements are made. Secondly, while planning for HT the stores are checked and a material requisition is immediately sent to the head office. It then becomes the responsibility of the head office to provide for the material.

10. In case of LT the material requisition is made for one year requirements in advance. In listing annual requirements, a statistical analysis is never made, because of rush of work, lack of organization and training. As such the list is never complete and open to objection from HO. This back and forth process consumes a lot of useful time and some of the important items are dropped from the list. Non existence of enough or proper material at the time of need especially during Haj creates a lot of technical and administrative problems.[57]

11. The HT staff of jointers is better educated and well trained. They have a sound knowledge, clear understanding and a long experience and have a beautiful craft. They understand the HT operations and have much better co-operation. They work in as a good team with the HT engineer and are willing to improve methods and procedures.

12. Not all the LT staff is educated or trained well. Some of them can not read or write Arabic even. Most of them who are doing the job for even more than 10 years still do not understand the necessity and philosophy of fuse protection. Few of them have good craft but no understanding of their

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[57] As temporary connection. Who will be responsible for this adjustment, who will pay and how the accounts will be adjusted etc.

job. They were generally trained and work under the senior electrician and jointers referred in No. 8 above. Since these people come in direct contact with the customer and the public all the more it is important that they should have been trained in public relations and have reading and writing capability.

Scarcity of proper facilities for work, inadequacy of proper tools and material, scorching heat, blazing sun, mountainous rough terrain, rush of work, undue pressures and lack of training boils their tempers at times and deteriorates company-customer relations. Since some of them have a long although not very creditable experience behind, it becomes difficult to teach them new methods, techniques and ways.

Situation of LT during Pilgrimmage

Whereas the situation of HT improves as the Haj approaches the situation of LT worsens. With Haj approaching the prospective consumers get more impatient, the supply of labor[58] shortens and becomes more expensive. Pressure for extension and reinforcement in the Mona area increases. Supply and movement of material

[58]Since most of the trenching is done manually, labor is hired on a daily wages basis. With Haj approaching rates of laborers get higher and they find jobs outside the Company easily and are better paid.

becomes much more difficult. Sometimes S/S plots get available only during Haj and LT staff also has to devote its time and effort for the new S/S and necessary changes due to new S/S.[59]

In such a rush, a lot of temporary connections are given with the pretext that regular connections will be provided after Haj. Not all times these connections are regularized due to the slackness of consumer, consumer section or LT engineering personnel. The influx of pilgrims reminds the consumer of his temporary connection, which had been lying unattended for one year by the company, and as such the LT staff have few more temporary connections to replace each year.

Almost from all corners of the city demands for new connections are "urgent" and "immediate." The consumers can not be blamed for these demands. Haj is their major economy. It provides them for the entire year. It is the Company's policy which should be adjusted.

Existing Procedure for a New Connection

For a new connection or reinforcement the following procedure is in use.[60]

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[59] A S/S in such a situation has been scheduled by CPM and PERT techniques. Please see Appendix III for details.

[60] As of December 1969.

The consumer:

1. Writes an informal letter of intent for connection.
2. Declares his LPF, D/C & A/C requirements and signs a form agreeing to the stipulated conditions if connection is granted.
3. Deposits an inspection fee of SR 10/-[61] and returns to LT department for a schedule of inspection with the engineer estimation.
4. Reports on the appointed time and date for an estimate.
5. Returns to the consumer section for finding the cost for this connection.
6. Pays off the dues if agreed and waits for connection.

In office:

7. After proper signatures papers go to the materials requisition clerk. The clerk prepares the material requisition list, work order, takes off one copy of estimate, gets the proper signatures and returns these papers to HT engineer.
8. The HT engineer initials and sends these papers to LT engineer.
9. The LT engineer collects the meters and the sundries from store for the work orders and stores them in his office.

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[61] $1.00 = Saudi Riyals 4.5.

10. LT engineer distributes the meters and the sundries to electricians for installation of meters and in case of an O/H connection also helps in shifting the O/H electrician's tools and material to the work site.
11. LT engineer gives work order for cable jointing to jointer and helps in their transportation and provision of cable to them from stores.
12. After the job is completed, the details are entered on the work order and work completion is signed and returned back to consumer section for preparation of meter card etc. In case the material was expended in excess of the estimated quantity, the fuse is taken out of the fuse holder and returned to the consumer section. The consumer pays the difference to get the fuse back. In case the estimated material was in excess of the material expended, the fuse is not taken out. LT engineer informs the consumer section and the consumer is reimbursed of the difference.

Discrepancies and Loopholes in Procedure

As mentioned earlier all the population of Mecca is not learned and so generally the consumer signs a contract without understanding what he is signing. Lack of understanding of the company contract is injurious for the company operation and result in complications many a time.

The fee of SR 10/- charged from the consumer is not deductable from the cost of the connection and a lot of grumbling is heard on this issue.

It is unnecessary to send the papers for initials to HT engineer on material requisition. HT engineer does not have much concern with LT material and it unnecessarily causes delay due to red-tapism.

It is wasteful of LT engineer's time to expect him to fetch and disburse the stores. Storing the meters and sundries in the LT engineer's office is not only ugly but open to pilferage. Administrative problems may be caused when a wrong meter is installed.

The pick-up allotted to LT engineer is busy in material transportation and it is wasteful of the engineer's time. The consumer takes advantage of this situation and offers to transfer the material at his cost. Since there is no provision of such an action in the contract it not only jeopardizes company customer relation, but also causes administrative problems.

It is an obnoxious act to deprive the consumer of the fuse when an excessive material is used than expected. It deteriorates the company customer relations.

LT Distribution Equipment and Material

The thumb rule of providing a consumer through a tee joint prevailed for a long time in the city. Until recently[62] this system was discouraged and new systems were introduced. The new system comprised using:

1) Feeder cabinets of 6 x 400 A outside S/S at conspicuous places in the area served by S/S.
2) Bus chamber boxes of 4 x 200 A on the site of consumer wall or mounted on angle iron frame.
3) Service tappings to be taken out directly from bus chamber boxes, or through fuses from feeder cabinets.

Figures A. 6, A. 7 and A. 8 show the electrical details and arrangement of these cabinets in the system.

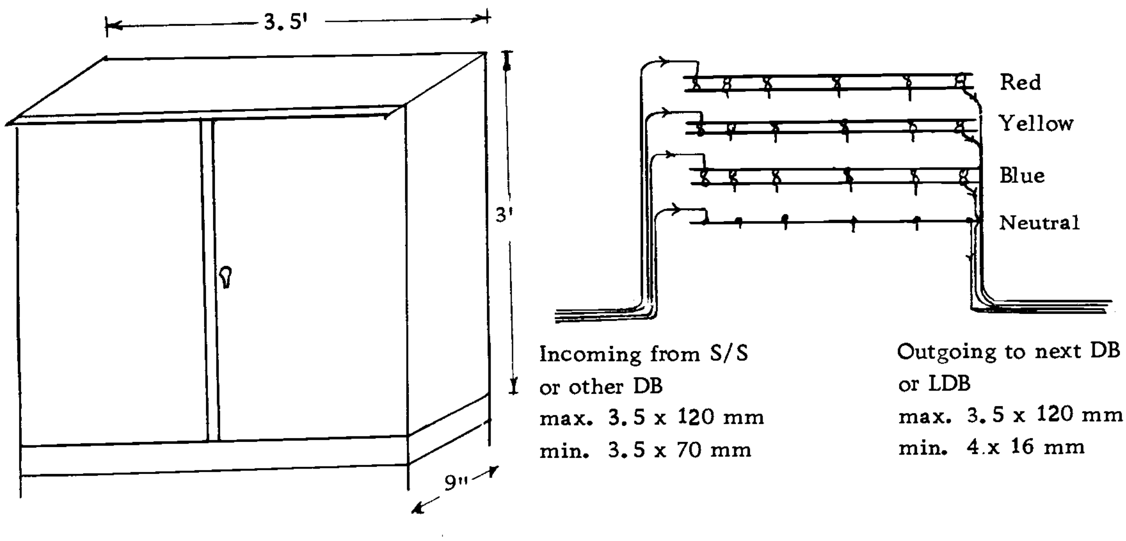

Figure A. 6. DB, Siemens distribution box.

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[62] Since June 1965.

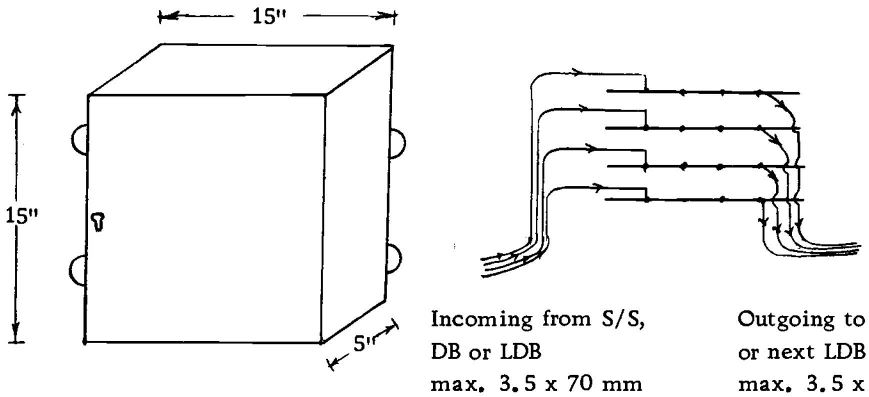

Figure A. 7. LDB, BICC bus chamber.

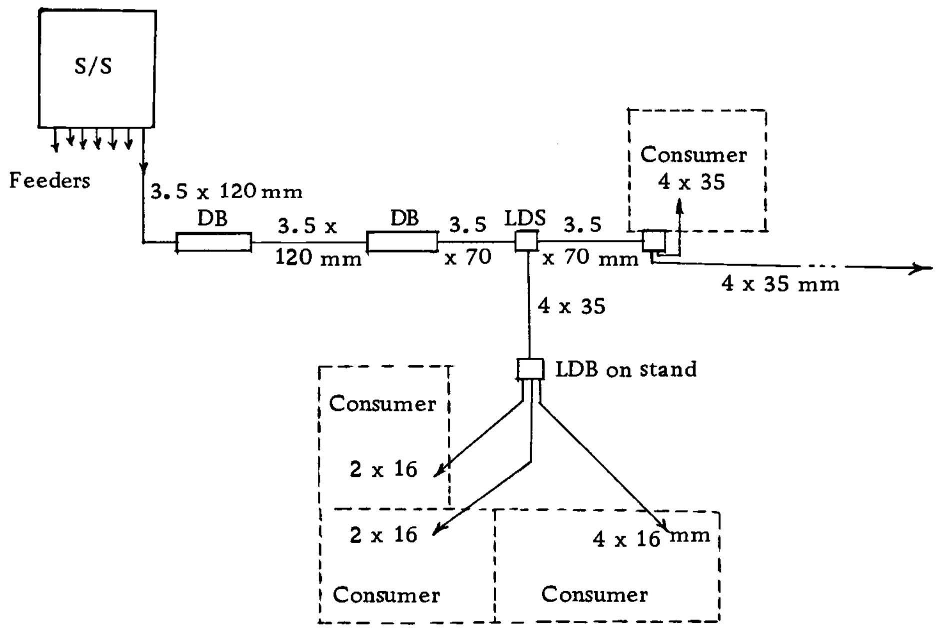

Figure A. 8. Arrangement of DB and LDB in the system.

The arrangement shown in Figure A. 8 was definitely much better and more flexible than that shown in Figure A. 1. However, the use of bus bar chamber was not effective and caused problems of service protection. In case it was desired to change or manipulate the house service it was necessary to:

1) Work on the live service main or

2) Pull out the fuses from the DB.

None of the above two procedures was adequate. The first was unsafe for the electrician and the second was annoying for the public.

The company had purchased several thousands of such bus chambers and they were to be used in the LT distribution.[63] However, the second development was the use of fused distribution box for a single outlet or the so called double entry cut-out. We may use the term double entry cut out[64] hence. Instead of ordering the DE cutouts of one capacity only, two different capacity cutouts were ordered. These cutouts had replaceable fuses housed in screwed cap and were more neat, safe and efficient than bus-chambers. Figures A. 9, A. 10 and A. 11 show their electrical details and use in the system. The arrangement shown in Figure A. 11 is better and more flexible than that shown in Figure A. 1 or Figure A. 8.

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[63] Since late 1968.

[64] DE cutout, because incoming cable enters the fuse links and the outgoing cable can be taken out across the fuses or along the fuses.

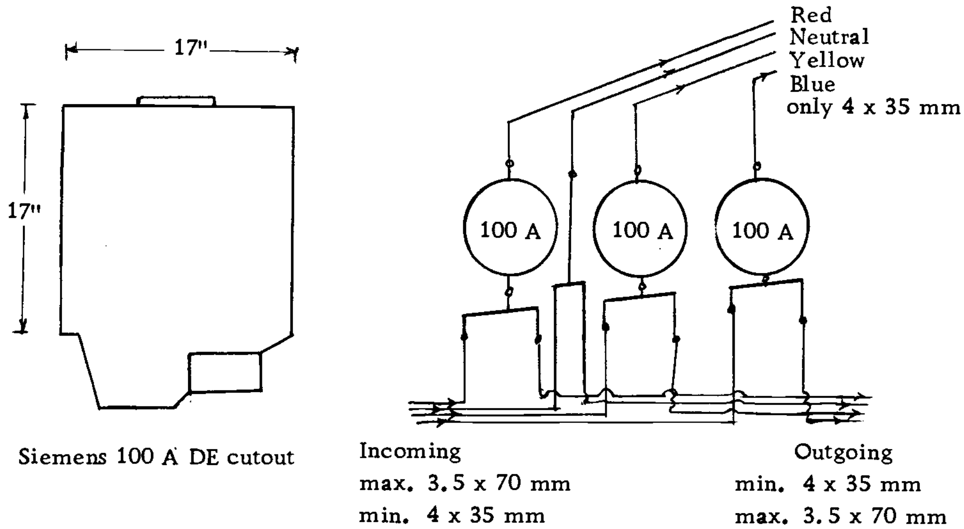

Figure A. 9. DE 100 A cutout and its connections.

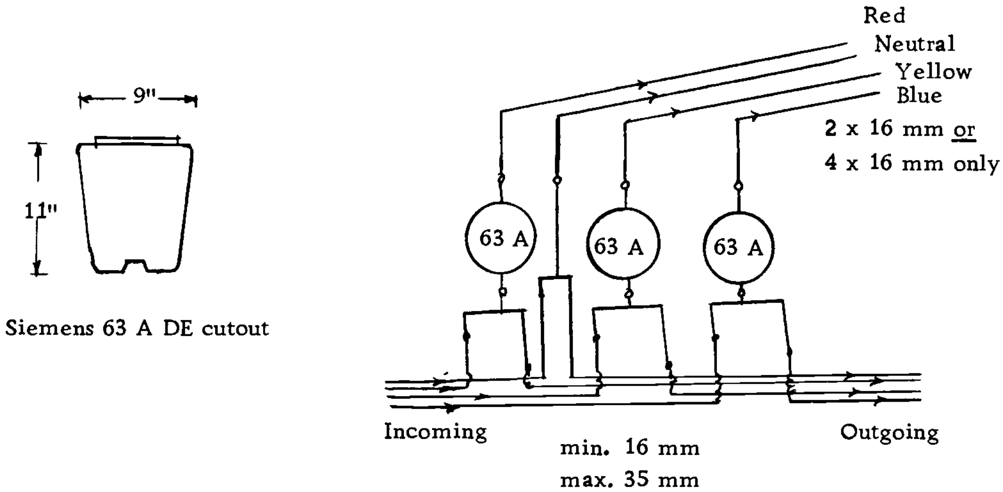

Figure A. 10. DE 63 A cutout and its connections.

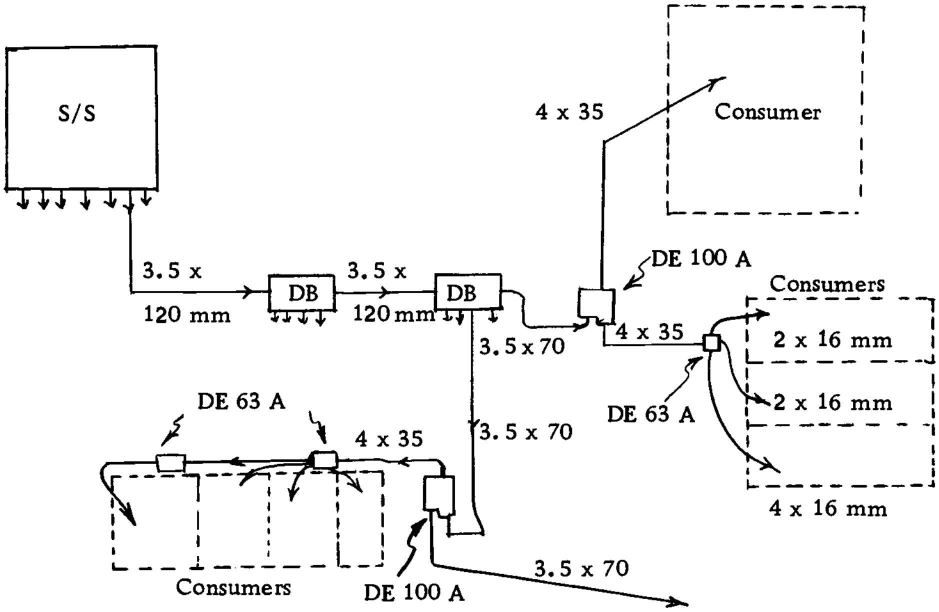

Figure A. 11. Arrangement of DE 100 A and DE 63 A cutouts in the system.

There is some O/H distribution as well, on the hills in the Harem adjoining and Mona areas. This distribution is radial feeder system and uses PVC covered conductors. The poles are 30' steel tubular with 5", maximum-diameter at bottom and 3" at top. The poles are designed for vertical configuration and reel type insulators. The old O/H distribution has O/H draw out type fuses or fused switches for line protection and relatively new[65] lines have protection by grip out fuses installed in the distribution boxes.

We give in Table A. 7, a break up of the LT O/H conductors and underground cables in use along with their adjusted ampacities for

[65] Since after Nov. 1965.

Table A.7. Size and ampacities of LT U/G and O/H cables.

Size and Type	Adjusted Rating for Mecca, amps	Maximum Allowable Load in amps	How Used	Conditions of Use	Remarks
3.5 x 0.2 sq in or 3.5 x 120 mm PIICDSTA & S or PVC	300	355	U/G	Buried at 70 cm in ground	As feeders from S/S to DB, between DB, to big consumers direct from DB or S/S
3.5 x 0.1 sq in or 3.5 x 70 mm PILCDSTA & S or PVC	160	200	U/G	Buried at 70 cm in ground	As subfeeders between DB & LDB, LDB & LDB, DB & DE 100 A cutout, to bigger consumers direct from DB, LDB, S/S or DE 100 A cutout
4 x 0.06 sq in or 4 x 35 mm PIICDSTA & S or PVC	100	125	U/G	Buried at 70 cm in ground	To consumer direct from LDB, DE 100 A or DB. Between LDB and DE cutouts
2 or 4 x 0.0225 sq in or 2 or 4 x 16 mm PILCDSTA & S or PVC	60	63	U/G	Buried at 70 cm in ground	To consumer direct from DE 63 A or LDB
19/.064 VIR or PVC	100	125	O/H	In air or M.C	VIR stores are finished first
7/.064 VIR or PVC	60	63	O/H	In air or M.C	VIR stores are finished first
7/.044 VIR or PVC	40	45	O/H	In air or M.C	The use is highly discouraged in favor of 7/.064
7/.029 VIR or PVC	25	25	M.C	M.C	The use is highly discouraged in favor of 7/.064.

Mecca. The company does not use a maximum demand tariff. The energy meters are generally Siemens, Danubia and are rated 10(30)A single phase and 15(45), 25(75) and 50(150)A three phase. There is hardly any need for a meter bigger than 50(150)A and in case there is, metering is done in the S/S on the LT panel using CTS. Other sundries do not affect the LT distribution system and as such we leave their details for brevity.

Material Handling and Transportation

The distribution stores has a 7 ton mobile crane and 2 heavy duty trucks. There is also one cable drum carrier which can be coupled to the truck and rolled with the drum.

A trained crane driver is not always available. Quite a mis-handling happens because of untrained staff and slack methods[66] and a lot of useful time is wasted in these elementary applications.

Energy meters are transferred from stores to office in bulk in ordinary pickups without hook or meter hanging arrangement. To transfer these meters to site, the electrician's helpers have to carry them on their heads and shoulders. These helpers are generally young boys, untrained and irresponsible. Many a time meters have been damaged by sliding and loose handling. A damaged meter even

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[66] One 500 kva transformer dropped down to ground from a crane, and got damaged in 1968.

though in shape only, destroys customer-company relations and the customers get doubtful as to the soundness of meter working.

The transportation of U/G or O/H cable to hills is highly pathetic. It is miserable to see 2 or 3 young laborers pulling on their backs hundreds of pounds of this dead mass. This not only exhausts the man, but deteriorates the cable much more.

The cable must be laid in the trench by hand and no mechanical aids are available. Whereas this produces bad laying, it has crushed the feet of lots of laborers as well.

Withdrawal from Store and Wastage of LT Cables

Red tapism, inconsistent stores, and non synchronizing stores timing with distribution department causes problems of having the required material at required time and place.

Since the LT maps are neither complete nor reliable a lot of estimates for new connections are a result of the personal knowledge or good engineering guess of the estimating engineer. At times, before the estimating engineer even decides to approve the estimate, the guess estimate is asked by the consumer section and payment is received for the connection. At the time of connection the guess would be found wrong; whereas before the trench was prepared, material for final construction was already issued for connection. Keeping aside the administrative difficulties it causes cabel wastage.

The LT jointers or electricians do not have a transport at their disposal. For them it is wasteful of their time and energy to report for the cable requirement and wait till they get the piece. So they prefer to work with cable at hand and at times it is wasteful.

Mishandling of Left Over Pieces

The general tendency of the jointers and electricians is to have the cable in excess instead of falling short. With this provision, instead of being careful they become more careless. Not only do they not do the splicing properly, but also bury the left over pieces or leave them at sites. At many instances the consumer has complained of the left over cable pieces in their premesis which have not been picked up since. Whereas 8 to 10 meter pieces have been quite common, ocassionally cable as long as 30 meters have been recovered.

This mishandling also creates problems many times as the consumer feels that he has paid for a much longer length of cable than was actually used for his connection.

Policy and Philosophy for Wastage

There are no clear defined rules and regulations to deal with such wasteful employees and stop this scrap.

The jointers and electricians feel that it is not worth the trouble to shift these left over pieces to office and then to stores and reply to the questions, what, how, where and why. The management feels the cable was already paid for and this way the company does not lose much.

Inconsistent Position of Contract Employees

As mentioned earlier that the LT splicers and electricians are generally local, whereas engineers are generally foreigners; serving the company on a contract of 2 years.

Not knowing the language, customs, the distribution system and with incomplete and disorganized records and data, indifference of the fellow and subordinate employees, the demand of management for some constructive and substantial work, the new engineer get puzzled. He feels inconsistent because his duties and powers are not well defined for a long time. Sometimes he does not know his exact job till the expiring of his first contract. Perhaps the organization tries him for his capability in different phases to find which work he can do best. However, this method of hide and seek is very injurious to both the employee and the company.

What Next

We have tried to present a brief survey of Mecca and its distribution for our readers before we can possibly proceed to suggest improvements and tentatively renovate the entire distribution system.

Without the present survey it should have been difficult for our reader to visualize the situation and the proposed improvements.

Someone has said that all change does not result in progress. However, one who dedicates himself to the principle of service will not fall into the trap of recommending a change for the change's sake--he will be able to back up his opinions with carefully collected facts and sound analysis of the results of his studies (2).

Prologue

We trust that by now our reader had a peep in Mecca, its distribution and its problems. Keeping in mind the above survey as our basic data, we will suggest renovation procedures and methods and as such would refer our readter back to Chapter 2 in the main text.

APPENDIX III: BUILDING AND COMMISSIONING A SUB-STATION

Description of the Problem

Placed herewith is a project for building and commissioning a sub-station in the electric power distribution system for the city of holy Mecca, in Saudi Arabia.

The project is a true picture of the work and its progress in the crucial state of the pilgrimmage season in the holy city.

A sub-station was badly needed in the Grand Mosque adjoining area and the matter was reported to management many a time. It was requested that a plot be acquired at some conspicuous place for building a S/S. Due to other preoccupations, the action on this issue was kept pending by the management, till the fasting season began. With the fasting season, pilgrims start pouring into the holy city, and the electric consumption increases with an ultimate increase of load on sub-stations. One of the S/S was developing load at a high rate and depending on last year's (1388 AH, i.e., 1968 AD) records it was anticipated that this S/S will be overloaded beyond capacity within a month. Under such situations the company may be constrained to shed load in the pilgrimmage season--a very undesirable situation for the general public--a situation which could injur company goodwill with the public and the government. It was expected that if a plot was acquired immediately we could finish everything starting ab initio within 70-75 days. The pilgrimmage season was 100 days ahead--the mobility and the availability of labor was diminishing fastly in the city. The matter was reported to management and an earnest request for S/S plot was made. Whereas the management agreed to the immediate need of a S/S, they were rather reluctant to acquire a S/S plot before a month. The management had the notion that with the present available resources it was possible to construct and commission the S/S in two months and as such we could still cope with the incoming increased demand during pilgrimmage which was exactly 100 days ahead. The engineer was of the opinion that he needed about 14 weeks to complete the project, and as such stressed that the plot be acquired before a month had elapsed.

As may be appreciated the situation is quite crucial. The enclosed Project is an attempt to analyze this situation by CPM techniques. A best solution on optimum time-cost basis is required for presentation to the management.

It may be noted that:

1) the durations for activities are deterministic depending upon past experience on the job.
2) most of the jobs will be carried out by the company employees due to the scarcity of skilled labor.
3) cost of material will not be taken into account.

4) not all but few activities can be crashed at additional cost and follow a linear cost time relationship.

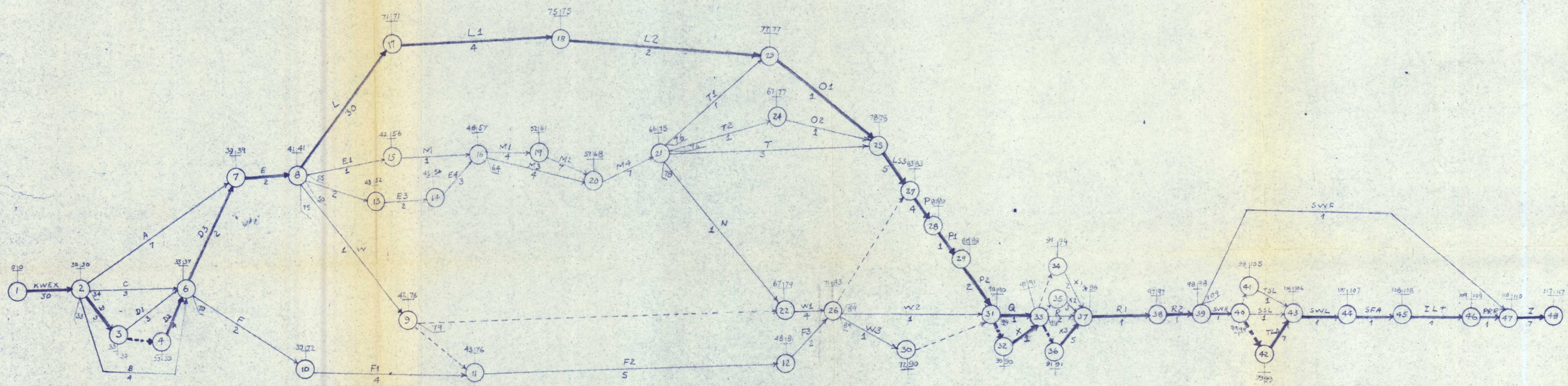
5) the indirect costs of $50/- per day includes wages, salaries, and rentals etc.

Table A. 8. CPM project restrictions list and activities durations.

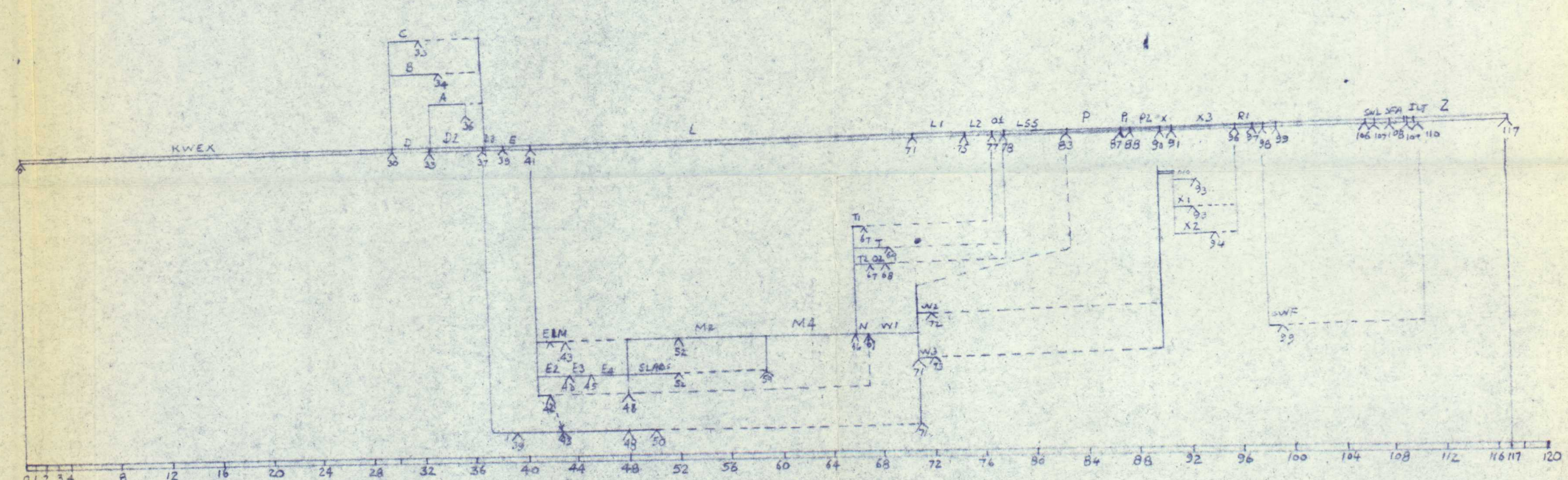
Activity		Duration, Days	Restriction to
KWEX	Demand exceeds more than capacity	30	A, B, C, D,
A	Managing Director's Approval	7	E
B	Chief Engineer's Approval	4	D3, F
C	Manager's Approval	3	D3, E, F
D	Collection of Data	3	D1, D2
D1	Complete the design	3	De, F
D2	Inspect the sites	4	D3, F
D3	Select the site	2	E
E	Award job to Engineer in Charge	2	E1, E2, W, L
E1	Mark the S/S plan on site	1	M
E2	Prepare materials requisition list	2	E3
E3	Check material from stores and market	2	E4
E4	Get material from market and stores	3	M1, M3
F	Tender fire alarm	2	F1
F1	Collect bids and compare specifications	4	F2
F2	Select and acquire firm alarm	5	F3
F3	Install the fire alarm in S/S	2	P, W2, W3
L	Complete cable laying for the feeder	30	L1
L1	Complete intermittent cable joints	4	L2
L2	Complete cable ends for the feeder and hook up in the new S/S and in the ring S/S	2	O1
M	Move construction crew on to the site	1	M1, M3
M1	Complete the trenches	4	M2
M2	Complete iron frames and walls	7	M4
M3	Complete the slabs	4	M4
M4	Complete roof and plaster the interior	7	T, T1, T2, N
N	Move the electrician to site	1	W1
O1	Open HT Ringmain Switch	1	LSS
O2	Open LT Switch	1	LSS
P	Paint walls	4	P1
P1	Paint windows	1	P2
P2	Paint S/S main doors	2	Q, X
Q	Lock S/S door. Move out and clean up	1	R, X1, X2, X3
R	Move to ring-main S/S	2	R1
R1	Close ring-main switch after completing ring joint	1	S
S	Return to new S/S after checking feeders loads	1	SWF, SWH

Table A.8. Continued.

Activity		Duration, Days	Restriction to
T	Move transformer in the S/S	3	LSS
T1	Move HT Panel in the S/S	1	O1
T2	Move LT Panel in the S/S	1	O2
W	Complete S/S wiring diagram	1	W1, F2
W1	Complete S/S wiring	4	W2, W3, P
W2	Install fittings	1	Q, X
W3	Connect S/S wiring to LT Panel	1	Q, X
X	Inspection by Engineer in Charge	1	R, X1, X2, X3
X1	Inspection by Manager	2	R1
X2	Inspection by Chief Engineer	3	R1
X3	Inspection by Managing Director	5	R1
LSS	Complete S/S inside cable joints	5	P
SWF	Open outgoing HT feeder from S/S	1	Z
SWH	Close S/S HT switch	1	TOL, SSL, TLD
SSL	Check S/S lighting and fixtures	1	SWL
TOL	Check transformer oil level and relays	1	SWL
TLD	Transfer the loads to new S/S	7	SWL
SWL	Close LT Switch and record the loads	1	SFA
SFA	Set Fire alarm	1	ILT
ILT	Inform management of load test	1	PRR
PRR	Perform load test and set all relays for overload tripping	1	Z
Z	Report S/S commissioning in writing to Managing Director, Chief Engineer and Manager	7	---



ARROW NETWORK



TIME CHART

Table A. 9. Boundary time table.

Activity	Nodes i	j	ET	Start ES	LS	Finish EF	LF	Float TF	FF
KW	1	2	30	0	0	30	30	0	0
D	2	3	3	30	30	33	33	0	0
B	2	6	4	30	33	34	37	3	3
A	2	7	7	30	32	37	39	2	2
F	6	10	2	37	70	39	72	33	0
D3	6	7	2	37	37	39	39	0	0
F1	10	11	4	39	72	43	76	33	0
E	7	8	2	39	39	41	41	0	0
W	8	9	1	41	75	42	76	34	0
F2	11	12	5	43	76	48	81	33	0
Dummy	9	22	0						
F3	12	26	2	48	81	50	83	33	20
E1	8	15	1	41	55	42	56	14	0
M	15	16	1	42	57	43	58	15	5
E2	8	13	2	41	50	43	52	9	0
E3	13	14	2	43	52	45	54	9	0
E4	14	16	3	45	54	48	57	9	0
M1	16	19	4	48	57	52	61	9	0
M2	19	20	7	52	61	59	69	8	0
M3	16	20	4	48	64	52	68	16	7
M4	20	21	7	59	68	66	75	9	0
TOL	40	41	1	99	105	100	106	6	0
Dummy	41	43	0						
TLD	40	42	7	99	99	106	106	0	0
Dummy	42	43	0	106	106	106	106	0	0
SWL	43	44	1	106	106	107	107	0	0
SFA	44	45	1	107	107	108	108	0	0
ILT	45	46	1	108	108	109	109	0	0
PPR	46	47	1	109	109	110	110	0	0
Z	47	48	7	110	110	117	117	0	0
D1	3	6	3						
D2	4	6	4						
Dummy	3	4	0						
N	21	22	1	66	76	67	78	11	0
L	8	17	30	41	41	71	71	0	0
L1	17	18	4	71	71	75	75	0	0
L2	18	23	2	75	75	77	77	0	0
T	21	25	3	66	75	69	78	9	9
T1	21	23	1	66	76	67	77	10	10

Table A. 9. Continued.

Activity	Nodes i	j	ET	Start ES	LS	Finish EF	LF	Float TF	FF
T2	21	24	1	66	76	67	77	10	10
O1	23	25	1	77	77	78	78	0	0
O2	24	25	1	67	77	68	78	10	10
W1	22	26	4	67	79	71	83	12	0
W2	26	31	1	71	89	72	90	18	18
Dummy	26	30	0						
W3	30	31	1	71	89	72	90	18	18
LSS	25	27	5	78	78	83	83	0	0
P	27	28	4	83	83	87	87	0	0
P1	28	29	1	87	87	88	88	0	0
P2	29	31	2	88	88	90	90	0	0
Dummy	31	32	0	90	90	90	90	0	0
Q	31	33	1	90	90	91	91	0	0
X	32	33	1	90	90	91	91	0	0
X1	33	34	2	91	94	93	96	3	0
Dummy	34	37	0						
Dummy	33	35	0						
X2	35	37	3	91	93	94	96	2	2
R	33	37	2	91	94	93	96	3	3
Dummy	33	36	0	91	91	91	91	0	0
X3	36	37	5	91	91	96	96	0	0
R1	37	38	1	96	96	97	97	0	0
S	38	39	1	97	97	98	98	0	0
SWF	39	47	1	98	109	99	110	11	11
SWH	39	40	1	98	98	99	99	0	0
SSL	40	43	1	99	105	100	106	6	6

Table A. 10. CPM project cost analysis.

Activity	Normal Cost	Normal Duration	Crashed Cost	Crashed Duration	Slope
KWEX	$ 0	30	$ 0	30	0
A	0	7	20	5	+10
B	0	4	15	3	15
C	0	3	0	3	0
D	50	3	60	2	10
D1	0	3	15	2	15
D2	20	4	20	4	0
D3	20	2	20	2	0
E	0	2	0	2	0
E1	20	1	20	1	0
E2	20	2	30	1	10
E3	10	2	15	1	5
E4	15	3	25	2	10
F	0	2	0	2	0
F1	0	4	0	4	0
F2	0	5	25	4	25
F3	0	2	0	2	0
L	700	30	1375	15	45
L1	0	4	60	3	60
L2	0	2	0	2	0
M	0	1	0	1	0
M1	0	4	0	4	0
M2	100	7	150	5	25
M3	0	4	0	4	0
M4	0	7	25	6	25
N	0	1	0	1	0
O1	0	1	0	1	0
O2	0	1	0	1	0
P	0	4	0	4	0
P1	0	1	0	1	0
P2	0	2	0	2	0
Q	0	1	0	1	0
R	0	2	0	2	0
R1	0	1	0	1	0
S	0	1	0	1	0
T	50	3	70	2	20
T1	0	1	0	1	0
T2	0	1	0	1	0

Table A. 10. Continued.

Activity	Normal Cost	Normal Duration	Crashed Cost	Crashed Duration	Slope
W	0	1	0	1	0
W1	0	4	30	2	15
W2	0	1	0	1	0
X	0	1	0	1	0
X1	0	2	0	2	0
X2	0	3	0	3	0
X3	0	5	60	3	30
LSS	0	5	0	5	0
SWF	0	1	0	1	0
SWH	0	1	0	1	0
SSL	0	1	0	1	0
TOL	0	1	0	1	0
TLD	0	7	70	5	35
SWL	0	1	0	1	0
SFA	0	1	0	1	0
ILT	0	1	0	1	0
PPR	0	1	0	1	0
Z	0	7	30	5	15

Cumulative normal direct costs = $1,005

Cumulative normal indirect costs = $5,850

Total normal cost of the project = $6,855

Table A. 11. Cost time relation for the project.

Cut No.	Activity Cut	Project Duration	Cum. Ind. Costs @ $50/day	Cost of Cut	Dir. Cost	Total Cost
0	Nil	117	$5, 850	$00	$1, 005	$6, 855
1	D	116	5, 800	10	1, 015	6, 815
2	Z	115	5, 750	15	1, 030	6, 780
3	Z	114	5, 700	15	1, 045	6, 745
4	X3	113	5, 650	30	1, 075	6, 725
5	X3	112	5, 600	30	1, 105	6, 705
6	TLD	111	5, 550	35	1, 140	6, 690
7	TLD	110	5, 500	35	1, 175	6, 675
8	L	109	5, 450	45	1, 220	6, 670
9	L	108	5, 400	45	1, 265	6, 665
10	L	107	5, 350	45	1, 310	6, 660
11	L	106	5, 300	45	1, 355	6, 655
12	L	105	5, 250	45	1, 400	6, 650
13	L	104	5, 200	45	1, 445	6, 645
14	L	103	5, 150	45	1, 490	6, 640
15	L	102	5, 100	45	1, 535	6, 635
16*	L	101**	5, 050*	45*	1, 580*	6, 630**
17	L+T	100	5, 000	65	1, 645	6, 645
18	L+M4	99	4, 950	70	1, 715	6, 665
19	L+M2	98	4, 900	70	1, 785	6, 685
20	L+M2	97	4, 850	70	1, 855	6, 705
21	L+E3	96	4, 800	95	1, 950	6, 750
22	L+E4	95	4, 750	55	2, 005	6, 755
23	L1+E2	94	4, 700	70	2, 075	6, 775
24	**Not possible to cut any more activity.	93	**Not possible to finish the project in 93 days.			

Results:

1) Cheapest possible schedule.

Cost of project = $6, 630
Total duration of the project = 101 days
Construction time = 71 days

2) Shortest possible schedule.

Cost of project = $6, 775
Total duration of the project = 94 days
Construction time = 64 days