Batteries are permanently connected to a dc source usually supplied through small copper oxide or selenium rectifiers from an ac supply, and connected as shown in Fig. 13-6.

MEASURING INSTRUMENTS

Measuring instruments usually include ammeters, voltmeters, watthour meters, and kilowatt demand meters; wattmeters, reactive volt-ampere, and power factor meters may also be found in some installations. These have been generally discussed in Chap. 8, and as they are universal types of instruments they will not be described further. Associated current and potential transformers have been described elsewhere.

CAPACITORS AND STREET LIGHTING EQUIPMENT

Capacitors and lighting equipment have been described in Chaps. 4, 5, and 12 and need no further discussion.

BUSES AND BUS SUPPORTS

Buses and their supports have been discussed in Chap. 7 and need no further discussion.

ALL SUBSTATION EQUIPMENT

For current information and further details on substation equipment, reference should be made to manufacturers' instruction books and catalogs. Consultation with manufacturers' and suppliers' representatives and engineers will prove most valuable.

PART FOUR

OTHER DESIGN CONSIDERATIONS

USE OF THE URD-LOOP PRIMARY CONDUCTOR SIZE-SELECTOR CHART

1. Lay out a tentative URD loop to serve the URD area. Defer the choice of transformer locations and required ratings.
2. Determine the total length of the proposed loop.
3. Determine the normal peak demand (kVA) for the total number of consumers to be supplied from the proposed loop. Refer to the group load-estimating guides in Table 6-12.
4. Enter the chart at the bottom axis at a point corresponding to the total length determined in step 2 and project a vertical line upward from this point (to the length in thousands of feet).
5. Enter the chart at the left-hand axis at a point corresponding to the kVA demand determined in step 3 and extend a horizontal line to the right to the point of intersection with the vertical line drawn in step 4.
6. a. If the intersection falls within the zone labeled no. 2, select no. 2 aluminum as the primary conductor and design the loop as proposed in step 1.
   b. If the intersection falls within the no. 1/0 zone, select no. 1/0 aluminum conductor and design the loop as proposed in step 1.
   c. If the intersection point does not fall within either the no. 2 or the no. 1/0 zone, the loop layout proposed in step 1 cannot be used. Try another layout dividing the area load between the two loops, then repeat steps 1 to 6 for each loop. Depending on the total area load and size, it may be necessary to repeat this procedure using three loops, etc., until the number of loops is adequate to supply the area load level.

Example 6-2 Refer to Fig. 6-21a.

1. The loop length is 6500 ft, and the total loop demand is 350 kVA. The intersection point falls in the no. 2 zone. The loop may be designed as proposed, using no. 2 aluminum.
2. The loop length is 5500 ft, and total loop demand is 1200 kVA. The intersection point falls in the no. 1/0 zone. The loop may be designed as proposed, using no. 1/0 aluminum.
3. The loop length is 8000 ft, and total loop demand is 1300 kVA. The intersection point falls outside the no. 2 and no. 1/0 zones. Redesign the layout for two loops, dividing the area load between the two loops. (In this example, assume the subsequent layout consists of two loops as follows:

   Loop a—6500 ft, 800 kVA
   Loop b—7500 ft, 500 kVA

   The proposed loops are both acceptable designs, using no. 2 aluminum.)

CHAPTER 7

DISTRIBUTION SUBSTATIONS

The design of a distribution system is affected by the location and design of its supply substation. Indeed, the distribution substation is an integral part of the electrical distribution system.

SITE SELECTION

The availability of land, annual costs, taxes, zoning laws, and environmental and public relations considerations are some of the factors that determine the ultimate location.

The number and locations of the substations may affect the voltage selected for the primary distribution system. The fewer and farther apart the substations, the higher the primary voltage selected and the larger the loads supplied. Also, the length of distribution feeders (and the distance of consumers from the substation) and the number of consumers supplied from a feeder are reflected in the size of conductors, voltage-regulation measures, and, equally important, the losses that may be incurred. Hence, the study of the most economical design of a distribution system must include substation and transmission supply costs as well as the effect of primary voltage on feeders, transformers, equipment, and methods of maintenance and operation.

In addition to the factors cited, other considerations should be taken into account in choosing a site for a substation:

1. It should be located as near as practical to the centers of the loads to be served; the summation of the loads (which are assumed to be concentrated at some points) multiplied by their distances from the proposed substation site should be at a minimum.

2. It should be possible to supply the loads without undue voltage regulation and with available standard equipment.
3. Access for incoming transmission lines and outgoing distribution feeders should be available with a minimum of inconvenience, and should allow for future expansion of such facilities.
4. A shutdown of the substation should not affect an undue number of consumers; the substation location in relation to other, adjacent substations, both present and future, should permit ties to them in event of emergency.

GENERAL DESIGN FEATURES

Since the substation is the link between the transmission and distribution systems, its continuous and uninterrupted operation is of prime importance. For this reason, multiple incoming supply feeders are provided, relays are installed to operate switches and circuit breakers automatically to disconnect faulted feeders and equipment, and spare equipment may be provided for rapid restoration of service in the event of failure.

Equipment Installation

Arrangement Equipment may be connected in various arrangements by means of buses, switches, and circuit breakers as described in Chap. 4. The arrangements are usually such as to insure safety to workers and reliability of operation, the usual arrangement in many substations permitting work on almost any piece of equipment without interruption to the incoming or outgoing feeders. The choice of arrangement is based on economics and the degree of reliability desired; see Fig. 7-1.

Insulation Coordination (BIL)

The feature of coordination of insulation, associated with the reliability of the substation, has been detailed in Chap. 4. The impulse values of the insulation of transformers, circuit breakers, switches, lightning or surge arresters, regulators, bus supports, and other elements are chosen at different levels, determined from a minimum basic insulation level (BIL), usually based on the minimum line-to-ground voltage rating of the surge arresters. Such design assures that potential failures of insulation from overvoltages can be made to occur at the least destructive and most accessible points, where they can be readily found and repairs or replacement of damaged equipment can be made.

Coordination of Protective Devices

The coordination of protective devices, both within the same substation and with devices on the associated transmission and distribution feeders, has been discussed in Chap. 4. Such coordination is essential to ensure that the operation of a particular device does not unnecessarily deenergize remaining unfaulted portions of the distribution system.

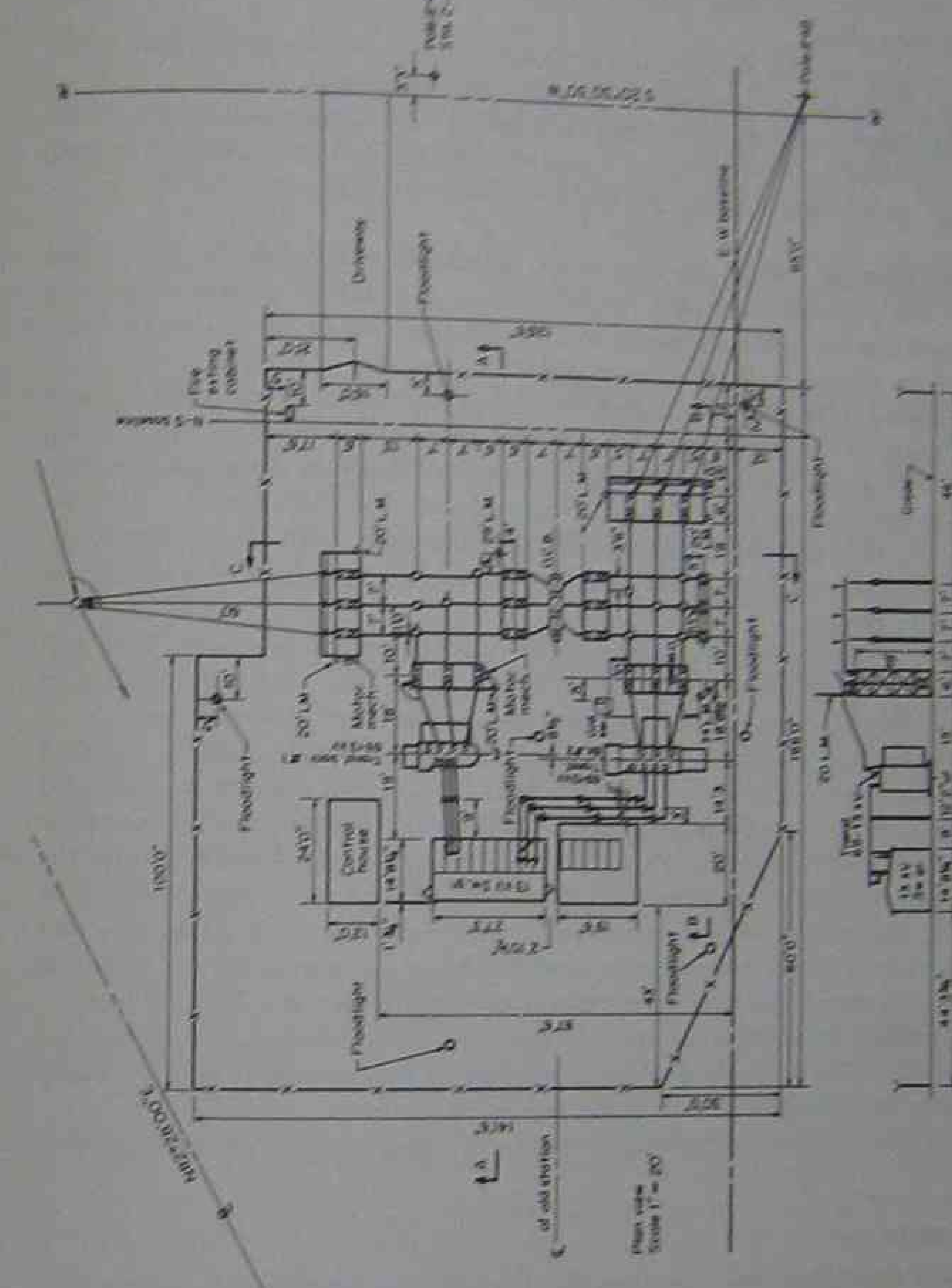


FIG. 7-1 Typical substation arrangement. (Courtesy *Long Island Lighting Co.*)

Protection Control

Instrument Transformers The circuit breakers that serve to deenergize equipment require two sources of power for their proper operation: that which actuates the relays, and that which causes the mechanical operation of the equipment to take place.

The relays receive their actuating power (usually) from instrument transformers which measure the electrical quantities associated with the circuits or equipment they are to protect. These include current transformers, with a standard secondary current rating of 5 A, and, where a voltage input is required, potential transformers, with a standard secondary voltage rating of 120 V.

Auxiliary Circuits While the instrument transformers furnish the power that actuates the protective relays, a separate source of auxiliary power is provided to operate the trip coils, solenoids, and motors that may be involved. This separate source of power must be as reliable as practical.

In substations in which the power supply bus is sectionalized into two or more parts, transformers supplying station power may be connected to two sections separated from each other, with the transformer supplying the auxiliaries connected to one section and the equipment connected to the other. In other instances, the station transformer may be equipped with a throwover switch, operated manually or automatically, in order to improve the reliability of the supply of auxiliary power.

Where reliability must be of the highest order, storage batteries, "floating" on the line, connected to an ac supply through rectifiers, are also installed to complement other power sources; here, the auxiliary circuit is a dc one.

In almost every instance, one or more of the distribution feeders supplied by the substation are so arranged in the field as to permit them to be energized from adjacent feeders emanating from a different substation. Should the entire substation become deenergized, such feeders may be utilized to reenergize the station power supply, enabling the circuit breakers and other equipment to be operated electrically. Where the substations involved are fed from different transmission or generating sources, care should be taken to avoid the interconnection of transmission and generating sources through the substation buses.

As a further precaution, control and auxiliary wiring systems are ungrounded and are provided with ground-detecting devices that actuate a light or alarm indicating the presence of a fault on the circuit involved.

The auxiliary power supply may also supply some emergency station lighting.

Bus Design

Electrical Considerations The design of buses in a substation must take into account not only the current-carrying requirements under both normal and short-circuit conditions, but also voltage drops, power losses, and temperature rises (usually a maximum of 30°C above a 40°C ambient). The current-carrying ability of buses, especially for the higher-capacity and higher-voltage circuits, must also take into account the skin effect of the ac flowing through them. Also, where buses are very closely situated (between phases or between circuits), a proximity effect must also be considered which may further distort the distribution of the current flowing in the conductor and may affect the current-carrying ability of the bus.

Voltage drops must also take into account the reactance of the buses, including the self-reactance of the buses themselves (which may be affected by their shapes and composition) as well as the mutual reactance from adjacent buses.

The enclosure of buses, for fire or mechanical protection, may lower the current rating, since the heat generated by the I^2R losses is not as freely dissipated. Further, if the enclosures are metallic, or cause the buses to be spaced farther apart, reactance values may be changed, in turn affecting the voltage drop in the buses. Where individual-phase buses are separately enclosed, no part of the enclosure or any phase may form a loop of conductive material, since such a loop would form a short-circuited turn and would overheat under normal and fault-current flow in the bus.

Mechanical Considerations Buses are usually made of copper or aluminum. Their cross-sectional shapes may include flat bars (single, or several in parallel), tubing, channels, or hollow squares. Sections may be joined together by means of bolts or clamps, or may be brazed or welded together; at intervals, however, expansion-type joints are employed to take care of the expansion and contraction due to load cycles.

The buses must also take into account the forces set up by short-circuit or fault currents that may flow through them (or in adjacent buses), as well as the voltage surges that may result from switching or lightning. The shape of the bus may provide sufficient rigidity and strength. They must also be supported on insulators capable of meeting both the electrical and mechanical requirements. Bus supports specified, therefore, usually include a fairly large safety factor, between 2 and 4.

Current transformers that are connected in these circuits must also withstand both the electrical and mechanical forces imposed on them.

Substation Electrical Grounds

Grounding at a substation is of the greatest importance. Because of the strong alternating magnetic fields set up by the heavy short-circuit currents that may flow in the several elements, voltages of appreciable values may be induced in the metallic structural members, in the equipment tanks and their supporting frames, in metal conduits for power and communication circuits, in metal fences, etc. All of these must be grounded, preferably to a common ground. The ground connections of the surge arresters, as well as the neutral conductors of the feeders, both incoming and outgoing, and of the grounded wye-connected transformers (if any), should also be connected to the common ground.

Draining of the induced voltages to ground prevents dangerously high voltage rises from forming, especially in the vicinity of the substation during fault conditions.

Grounds may consist of a multitude of metal rods driven into the ground at frequent locations and connected together, or of a mesh buried (usually) beneath the substation. The number, spacing, size, and depth of burial of the conductors making up the mesh will depend on the nature of the soil and the ground resistance desired. Both rods and mesh may be installed and connected together.

SUBSTATION CONSTRUCTION

Distribution substations may be constructed entirely indoors, entirely outdoors, or in a combination of the two ways.

Indoor

In purely indoor construction, all the equipment is completely enclosed within a structure, protected from the weather. Measures are taken to ensure that the failure of a piece of equipment does not spread and involve other units. Reinforced concrete fire- and explosion-resistant walls or barriers are installed between major pieces of equipment, such as transformers, circuit breakers, and regulators. Sumps are usually provided beneath oil-filled equipment and connected to waste lines where they exist. The sumps should be of ample size to contain all of the oil in the equipment should its failure result in an oil spill. Control equipment, switchboards, batteries (if any), and other communication facilities may be located in separate fireproof compartments.

Automatic fire-extinguishing systems may be installed to smother any oil fire that may ensue; foam, carbon dioxide, a high-pressure fine spray of water, and other materials may be specified.

Ventilation may be by natural circulation of air, or by means of fans that may operate at peak load periods or when the internal ambient temperature exceeds a predetermined value.

In general, the rating and capacity of the equipment, particularly transformers and circuit breakers, may be lower than for similar units installed outdoors. On the other hand, the units need not provide for inclement weather conditions (e.g., bushings may have shorter creepage distances, tanks need not be watertight, etc.).

Provision, in the form of rails, rollers, or other devices, is made to permit the replacement of the several pieces of equipment. Space around each unit is provided to permit safe access for the maintenance, repair, or replacement of the unit.

The architecture of the exterior should blend with the surroundings, as should the associated landscaping, lawns, or other environmental prerequisites. Incoming and outgoing feeders are installed underground, out of sight.

Outdoor

Outdoor substations have all of the equipment located outdoors within a securely fenced off area. Here, too, provisions are made for the maintenance, repair, and replacement of the pieces of equipment. Sumps may be constructed beneath a unit, in the form of dikes or pits containing coarse gravel or crushed stone, of a sufficient volume to hold possible oil spillage from the unit. Depending on the availability of land and the spacing between units, fire walls between major units may be found desirable.

Transformers, circuit breakers, and other outdoor equipment are designed to operate in all kinds of weather. Tanks are usually hermetically sealed or are equipped with "breathing" devices; bushings and insulators have creepage paths sufficiently long to prevent flashover. Control facilities may be located in sealed compartments either associated with each unit or grouped together in an outdoor-type housing. Small strip heaters may be required to keep condensation from forming in the compartments.

The location of the outdoor substation may present serious environmental problems. These include appearance; sometimes extensive and expensive landscaping is required to conceal the substation partially or entirely from neighboring observers. Another source of objection may be the sound emanating from the transformers; sound barriers then have to be erected around those units to deflect or mitigate the sound emissions in a particular direction.

Combination Indoor and Outdoor

In the combined indoor and outdoor arrangement, the major units, usually the transformers only (with their associated surge arresters), but sometimes circuit breakers also, are located outdoors, and the remaining equipment is housed in a building of some kind. The requirements already outlined should be followed in connection with each portion of the substation. Such substations are located in areas where appearances may not be a major consideration and some equipment, sometimes concealed by landscaping, may be found acceptable.

Unit Substations

Unit substations are small, self-contained, metal-clad units, usually installed in residential areas where larger sites are unobtainable. They are usually well landscaped, and their incoming and outgoing feeders are placed underground. Primary feeders from one unit substation extend to meet those from other, adjacent unit substations so that, when one unit substation is out of service, its load can be picked up by the feeders from the adjacent unit substations. Each unit substation, therefore, must be designed with spare capacity to enable this transfer of load to be made during contingency conditions.

Mobile Substations

Mobile substations, which may be considered portable outdoor-type substations, have been discussed in Chap. 4. Provisions are generally made at the several types of substations to permit a mobile substation to be connected to pick up all or part of the load should a substation be out of service for a prolonged period of time.

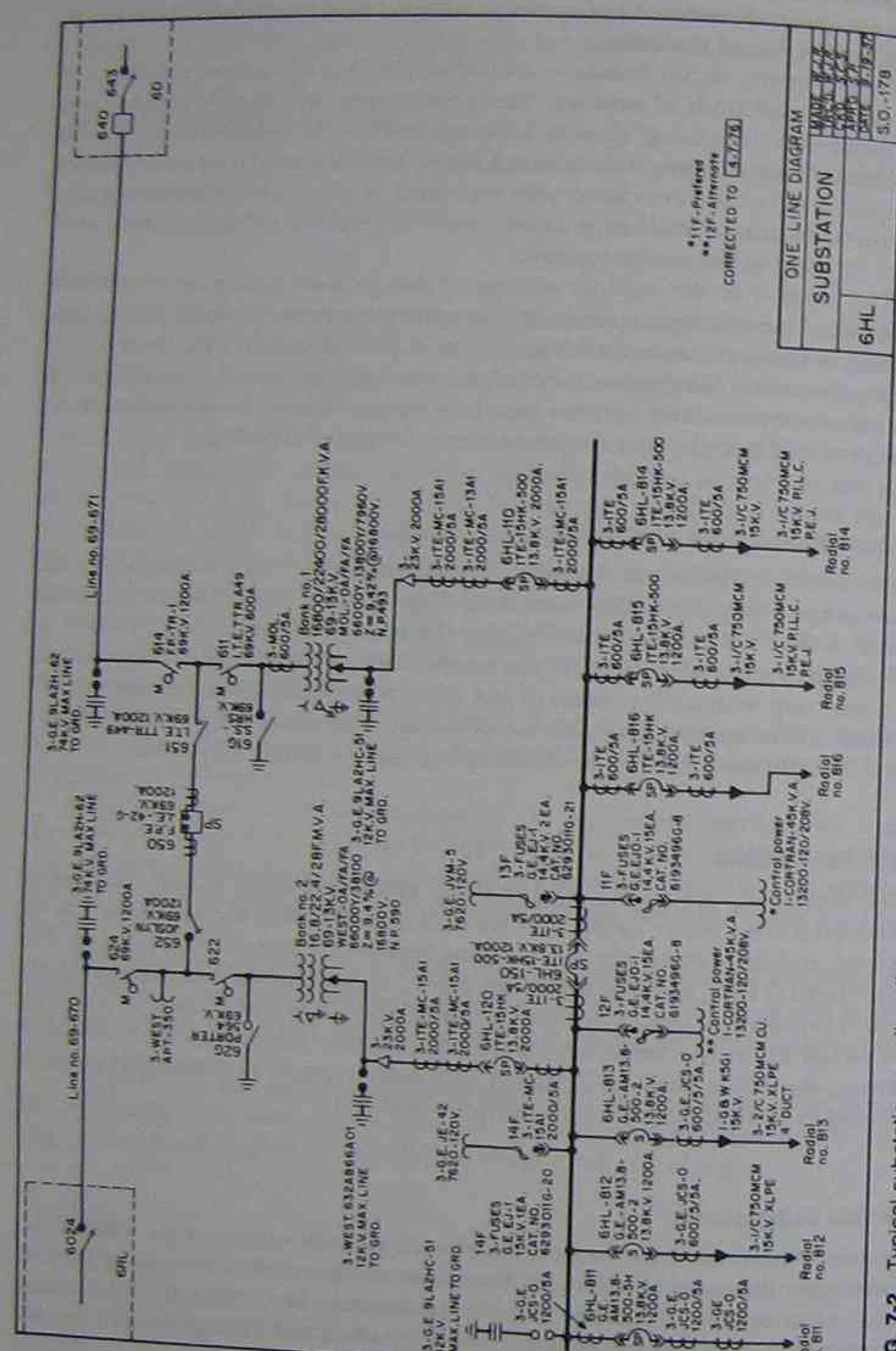


FIG. 7-2 Typical substation one-line diagram. *(Courtesy Long Island Lighting Co.)*

Operation

When an operator is in attendance, the speed and smoothness of restoration of service at times of interruption very often depend on the efficient performance of the operator.

Unattended substations may be designed in which some or all of the equipment is to function automatically. They may be operated by remote control from other substations, or from a central dispatching point, or they may be serviced by a "roving" or multistation operator. Automatic stations may, in many instances, shorten the time of interruption occurring from temporary abnormal conditions.

ONE-LINE DIAGRAMS OF CONNECTIONS

The connection of apparatus in a substation is usually drawn in the form of a "one-line diagram" for convenience and simplicity. Inasmuch as all the phase connections in a polyphase system are alike, it is only necessary to show the connections for one phase to indicate the simultaneous operation (as nearly as practical) of all the phases.

There are two types of one-line diagrams. The first, usually referred to as an operating diagram, merely indicates all the major equipment and connections, with such pertinent information as will enable the engineer, field supervisor, and operator to call for and complete the desired switching.

The second type is an elaboration of the first and includes additional information, such as fusing, relaying, and location and rating of instrument transformers and other auxiliary equipment. Such a diagram lends itself to rapid analysis in the event of improper operation of equipment. See Fig. 7-2.

CHAPTER 8

METERING

SCOPE

There are two broad classes of metering that interest the distribution engineer: that used to operate or monitor the several elements of the distribution system, and that mainly used for revenue purposes. With the advent of the digital computer (used for billing, among other applications), the latter may also be employed in furthering the purposes of the first class of metering. Further, the development of microelectronic technology has made possible operations of the electric system heretofore thought impractical if not impossible.

The principle of operation of most meters is that of the interaction of two (or more) magnetic fields tending to produce rotation of one of the elements. They may, however, be thought of as small but accurate motors, with their rotation restrained by springs or other magnetic fields.

Basic electric meters include the ammeter for measuring current in amperes, the voltmeter for measuring electrical pressure in volts, and the wattmeter for measuring power in watts. The ammeter operates on the interaction of a magnetic field, set up by the current to be measured, with the field of a permanent magnet. The voltmeter is essentially an ammeter connected in series with a fixed resistance. A wattmeter is a combination of both the ammeter and voltmeter elements.

OPERATION-MONITORING METERS

Applications

Ammeters are used for measuring loads on substation transformers, distribution feeders and transformers, secondary mains, and services. Voltmeters are used for measuring bus voltages at substations, both on the supply side of power transformers and on outgoing distribution feeders and regulators, at distribution transformers, secondary terminals, and consumer services. In a modified form they serve as control relays for voltage regulators. Both kinds of meters are also used in the setting and maintenance of protective relays and in determining the volt-ampere loads on equipment. Wattmeters measure the power input and output at substations, and at other points where such measurements are desirable.

The three basic meters used in association with each other can determine the power factor of circuits and loads; the three elements may be combined in one instrument to read power factor directly. Likewise, resistance, reactance, and impedance measurements may be obtained from the ammeters and voltmeters used in association with each other, or in one instrument that is made to read such quantities directly.

Extending Ranges

The range of these meters may be extended by means of auxiliary equipment. Ammeters for dc measurements may use a shunt calibrated so that only a predetermined proportion of the current flowing through it is measured by the ammeter; for ac measurements, a current transformer of a predetermined ratio achieves the same results. A voltmeter for dc measurements may use a potentiometer calibrated so that a predetermined proportion of the voltage across the entire potentiometer coil is measured by the meter; for ac measurements, a potential transformer of a predetermined ratio achieves the same results. Shunts and potentiometers are used to extend the range of dc wattmeters, and current and potential transformers are used to extend that of ac wattmeters.

Types

These meters may be of the indicating type or of the recording type; they may also be of the portable or of the station or switchboard type. Indicating ammeters may also be constructed to retain maximum values of current readings; they are sometimes referred to as maximeters.

In ac systems, separate current and voltage measurements are made for each phase of a polyphase circuit, but power and volt-ampere measurements for the sum of all of the phases may be made with one polyphase meter, or may be made using two or more single-phase wattmeters.

Polyphase Power Measurements

Power in a polyphase circuit may be measured by connecting a separate wattmeter in each of the phases and algebraically adding the values obtained. Equal accuracy, however, may be obtained by using one less wattmeter, the remaining ones being properly connected among the phases of the polyphase circuit. This is known as Blondel's theorem for the measurement of power in a polyphase

system of any number of wires without regard to any unbalance of currents and voltages that may exist among the phases.

Blondel's Theorem The theorem may be stated as follows: In any system of N wires, the true power may be measured by connecting a wattmeter in each line but one ($N - 1$ wattmeters), the current coil being connected in series in the line and the potential coil being connected between that line and the line that has no current coil connected in it; the total power is the algebraic sum of all the readings of the wattmeters so connected.

According to the theorem, then, the total power in a three-phase three-wire circuit, either wye- or delta-connected, may be measured by two wattmeters; a three-phase four-wire circuit would require three wattmeters.

If the power factor of the circuit falls below approximately 50 percent, it is likely that the reading of one of the wattmeters may be negative, and it may be necessary to reverse the terminals of the current or potential coil; this change should be noted in connection with any later measurement when the power factor may be greater than 50 percent.

REVENUE METERING

Metering for revenue purposes, in itself, is not the responsibility of the distribution engineer, but the data accumulated by meters so used can serve in optimizing the planning and design as well as the operation of distribution systems. The same computer that translates meter readings into consumers' bills can also be programmed to make selective summaries of such data, simultaneously converting such consumption data into loads and demands on the several elements of the distribution system. The grid coordinate system of mapping is extremely useful in such instances; it is described in Appendix C at the end of this book.

Meters for revenue purposes measure energy in kilowatthours and power demand in kilowatts. Although constructed differently, they are connected in circuits in the same manner as wattmeters, and have both current and potential coils.

Watthour Meters

The watthour meter is essentially a small motor whose rotor, usually a metallic disk, is caused to turn by the torque produced by the reaction of the magnetic fields set up by the current and voltage coils with a magnetic field of the disk resulting from the eddy currents set up in it by those magnetic fields. Its speed of rotation can be made to be proportional to the power flowing in the coils of the meter; a magnetic brake regulates this speed to obtain the desired accuracy. A register which counts the revolutions of the disk acts to integrate the instantaneous values of power over a period of time; the integral is the expression for energy.

Watthour meters may be single-phase or polyphase, although the single-phase units constitute the greatest number in use, measuring the energy consumption of residential consumers.

Transformer Load Monitoring

The consumptions of each of the consumers supplied from one distribution transformer can be totaled to obtain the energy supplied through that transformer over the billing period of time, usually approximately a month. Factors can be applied to this total to convert it into an approximate demand in kW or kVA. In this manner, the loading of that transformer can be monitored. The computer which compiles the consumers' bills for that period of days can be programmed to perform this function. Conversion factors are obtained and kept current by sample testing of small groups of representative consumers.

Similarly, the consumption supplied from each distribution transformer can be summarized for the transformers on each phase of an entire feeder or portions of that feeder. Carrying it a step further, these consumptions can be summarized for all the feeders on a substation bus or on the supply transformers. These values can also be converted to approximate kilowatt demands on the several elements of the distribution system. Comparison of the sum of the individual consumptions on a feeder to such readings on the feeder at the substation (making correction for differences in the time of the readings, if any) can give a rough indication of actual losses on the feeder.

The computer can be programmed to produce periodic readouts of these data together with average demands per consumer, and to identify distribution transformers and other elements that exceed values predetermined to indicate overloads and potential sources of troubles.

The distribution engineer is thus able to initiate actions not only to prevent inconveniences to consumers, but also to avert damage or destruction of equipment and other facilities that could cause long and costly interruptions affecting the safety and well-being of the public. Moreover, the updated values of consumer demands and circuit loadings enable the engineer to do a more effective and economical job of planning and design of the electric distribution system.

Power Factor Correction

For some larger (usually industrial) consumers, the reactive kVA load is also measured in kVA-hours (by shifting the voltage 90° by means of reactors) along with kilowatthour consumption. By properly interrelating these quantities for the period of time covered, a value of average power factor of the consumer's load is obtained. With rate schedules tailored to reflect rewards (or penalties) for power factor, the installation of power factor-corrective measures at the consumer's expense is encouraged; these may be banks of capacitors, synchronous motors, or both. Such power factor improvement enables the distribution engineer to design more economical distribution systems affecting costs to all consumers.

Demand Meters

The measurement of maximum demand for a consumer may be obtained by adding another dial and set of gears to the registers of the watthour meters. Kilowatt demands for consumer billing purposes are obtained basically by meas-

uring the kilowatthour consumption over a 15-min period, multiplying this by 4 to obtain an hourly demand. In some instances, a period of 30 or 60 min is used and the multiplier adjusted accordingly. This is accomplished essentially by a "floating" hand that is pushed by the watthour element that returns to zero every period, after which the action is repeated.

At the billing period, the meter reader reads this floating hand and returns it to zero, eliminating any record of that demand reading. Another system does the same thing, but records the demand on a separate register, the actuating element returning to zero every period; the action is repeated, but the demand value is added to the previous reading. At the billing period, the reader reads the second register, which has "accumulated" the maximum demands, and resets the actuating element to zero. The maximum demand for the period is the difference between the last reading and the previous one on the demand register; hence, a record of the maximum demands for each billing period is maintained.

Demand Control

Rate schedules are designed to encourage the consumer to arrange the operation of loads so as to hold down maximum demand.

Many of the relatively smaller consumers arrange the operation of major pieces of equipment on a predetermined schedule in an effort to hold down their overall maximum demand, usually concentrating on reducing or eliminating short-term peaks.

In large industrial and commercial installations, the demand is continuously monitored by the consumer using impulses generated by the utility's demand meter (impulses that trigger the demand meter's 15-min periodic return to zero). These impulses are fed into the computer that supervises the operation of the consumer's equipment; in some programs, actual shedding of less critical loads within the billing (15-min) interval is done so as not to exceed a predetermined value; see Fig. 8-1.

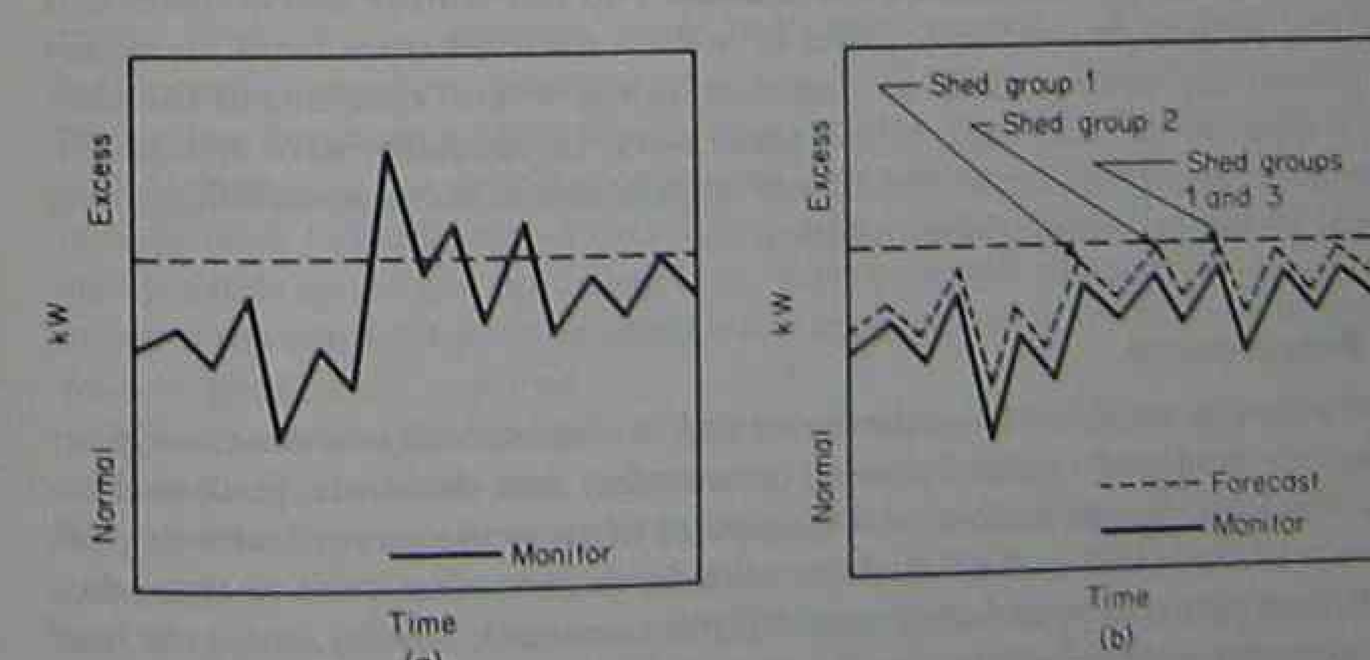


FIG. 8-1 Continuously monitored demand control (*a*) without demand limit and (*b*) with demand limit. *(Courtesy Johnson Controls, Inc.)*

In general, the goal is to improve the consumer's load factor, and the first step usually is to obtain the consumer's load profile. If the profile shows only a few 15-min intervals where sharp peaks occur, it is a relatively easy matter to identify the equipment causing those demand peaks and take remedial measures. In most cases, however, a more detailed approach is followed to determine what, if any, demands can be reduced or eliminated. This generally calls for classifying the consumer's major loads into four categories: those which (1) can be rescheduled, (2) can be deferred, (3) can be curtailed or eliminated, and (4) are essential base loads.

Often, this control of consumers' demands is a cooperative effort between the consumers and the utility's distribution engineer. Success of such efforts is beneficial to both the consumer and the utility. While this may reduce the consumer's demand payments and reduce the utility's revenue, the loss in revenue is almost always overshadowed by the utility's reduced carrying charges from the improved usage of fewer facilities and reduced energy costs from the reduction in losses that accompany the reduction of peaks. The reduction of these costs is of increasing concern to the distribution engineer.

WIRING DIAGRAMS

Wiring diagrams for the various meter connections for different types of distribution systems are shown in Fig. 8-2.

ELECTRONIC METERING

The development of so-called microelectronic processing (including solid-state) techniques is making the kilowatthour meter more than just a device for billing purposes; it also provides another tool for use by the distribution engineer and operator. By adding memory and other circuitry to the register of the meter, its functions can be expanded to provide additional data valuable to the distribution engineer. Further, microprocessors can be programmed to process the data and execute predetermined commands. This last feature can be extended to control individual consumer loads in order to restrict consumers' demands and, collectively, reduce the peak demands on the several elements of the electrical system all the way back to the generators. Incidentally, such systems facilitate the remote reading of consumers' meters and instantaneous billing, long the goal of the accounting departments.

Data Procurement

Data that can be obtained from the meter and its electronically enhanced register can include real and reactive power consumption and demands, peak and average demands, power factors, and such other items as the power factor at peak demands of both kW and kVA. Also, calendar information such as time, day, month, and year can be included, and different seasonal, holiday, leap year, and other complex rate schedules can be stored; when such data are employed at predetermined times and conditions, the price in effect and the rate-of-usage information can be readily obtained.

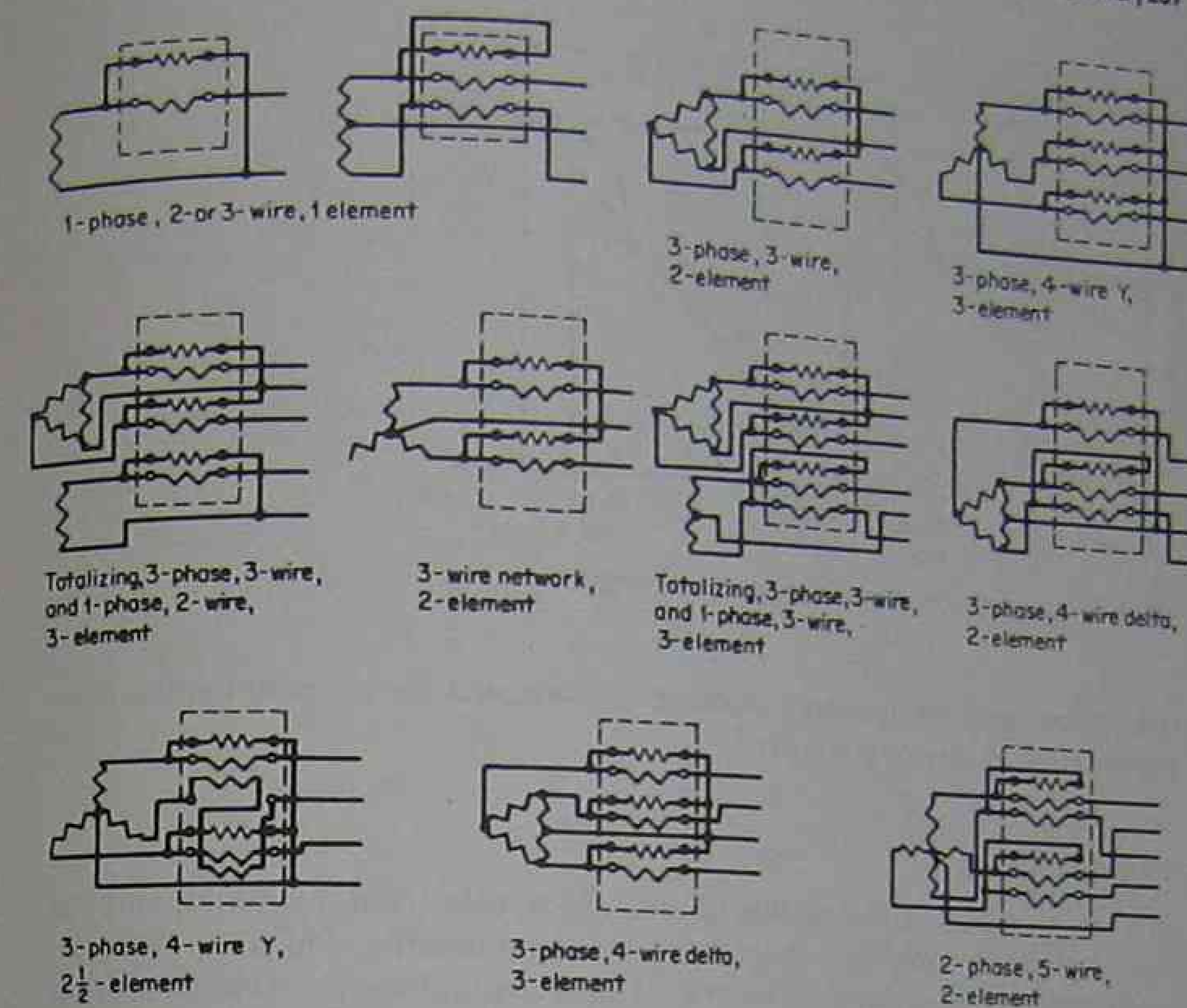


FIG. 8-2 Schematic diagrams of meter applications for different types of distribution systems. *(Courtesy Westinghouse Electric Co.)*

Operating Functions

By coupling this electronic metering with its sophisticated registers to a communications network (microwave, radio, telephone, carrier, or combinations of these), control of consumers' loads (with prearranged and contractual assent) by the utility operator becomes practical. Such control is directed primarily at restricting demands on the several parts of the *entire* electrical system, starting with elements of the distribution system. Not only is it possible to reduce capital outlays (and related annual carrying charges) for additional facilities, but it is also possible to reduce operating (e.g., fuel) expenses through the reduction of losses in the transmission and distribution systems and in the amount of spinning reserve generation required.

There are several methods which may be used to shift or reduce electrical demands. One simple and "minimum" system limits a consumer's maximum demand during peak periods from a signal actuated by the utility operator. The metering circuit monitors the load automatically with a signal light at the meter and an alarm of some kind on the consumer's premises. Exceeding the limit (after actuating by the operator) triggers the alarm and starts a programmable time delay of (say) 14 min (of the 15-min demand cycle), allowing the consumer time to reduce the demand before service is interrupted; see Fig. 8-3. A second

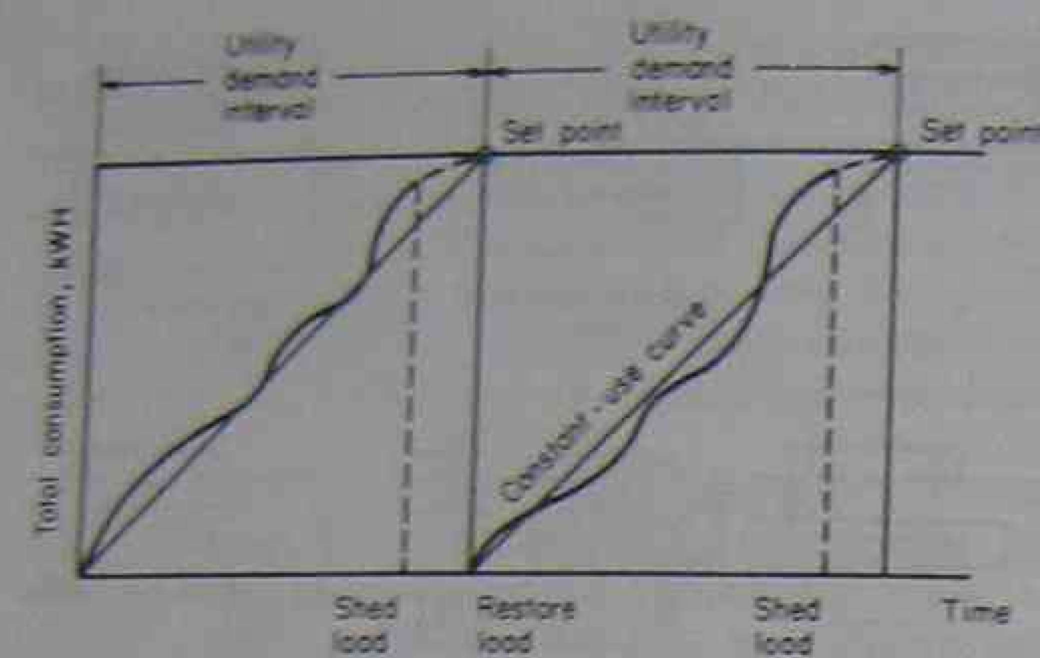


FIG. 8-3 Last-moment method of demand control.

time delay prevents appliance damage to loads such as air-conditioning compressors, when service is restored.

TRANSDUCERS

In many instances, it is desirable to measure nonelectrical quantities, and this may be done by converting them into electrical quantities, which are then metered or measured in the usual manner. This is accomplished by a class of devices generally called *transducers*. Thermocouples, photocells, and microphones are examples of devices which convert heat, light, or sound into electrical quantities; when these quantities exceed predetermined limits, they act to control the equipment with which they are associated. Other devices convert pressure or pressure differences into variations of electrical quantities, which again serve to actuate or control the equipment with which they may be associated.

Transducers may also be applied to convert electrical quantities into nonelectrical quantities.

PART THREE

MATERIALS AND EQUIPMENT

CHAPTER 9

CONDUCTORS

INTRODUCTION

Conductors, as carriers of the electrical energy, are perhaps the most important element of an electric circuit; often they are called wires, and the terms are used interchangeably. They may be installed overhead as bare, covered, or insulated conductors; and, in cable form, they may be installed underground in ducts or buried directly in the ground. Cables are also sometimes installed in trays in substation or industrial installations where immediate access to them is of relatively great importance.

Since a failure of a conductor results in a complete interruption to a circuit, it is imperative that the causes of such failure be minimized. The failure may occur from mechanical causes where the stresses and strains imposed are simply too great and the conductors literally tear apart. More often, however, the cause may initially be an electrical failure which then affects the conductors mechanically. Overloads or short-circuit currents, for example, may cause heating of the conductors to the point where they begin to liquefy (or melt) and ordinary mechanical stresses can no longer be sustained and the conductors pull apart, perhaps vaporizing in the process.

MATERIALS

It is evident, therefore, that both the mechanical and electrical characteristics must be considered in the choice of conductors. In addition, the all-important element of cost limits the number of economically available materials suited for conductors. A brief discussion will highlight the properties of those most commonly used: copper; aluminum; aluminum conductor, steel-reinforced (ACSR);

TABLE 9-1 CHARACTERISTICS OF CONDUCTOR MATERIALS (COMMERCIAL GRADES)

Material	Conductivity, % (pure Cu = 100%)	Weight		Ultimate strength, lb/in² (× 1000)	Elastic limit, lb/in² (× 1000)	Modulus of elasticity (× 10⁶)	Temperature coefficient of linear expansion per degree (× 10⁻⁶)	
		lb/in³	lb/1000 ft per 1000 cmil				°C	°F
Copper—SD	99–100	0.320	3.027	36 to 40	18 to 20	12	17.1	9.5
MHD	98.5–99.5	0.320	3.027	42 to 60	23 to 33	14	17.1	9.5
HD	97–99	0.320	3.027	49 to 67	30 to 35	16	17.1	9.5
Aluminum, plain	61	0.0967	0.920	23 to 27	14 to 16	9	23.0	12.8
Aluminum, steel-reinforced	61	0.147	1.390	44	31	—	19.1	10.6
Steel	8.7	0.283	2.671	45 to 189	23 to 112	29	11.9	6.6
Copper-clad steel—30%	29.25	0.298	2.810	60 to 100	—	16 to 20	13.0	7.2
40%	39	0.298	2.810	60 to 100	—	16 to 20	13.0	7.2

To convert to metric system:
lb/in³ × 0.0277 = kg/cm³
lb/1000 ft × 0.1488 = kg/km
lb/in² × 0.0703 = kg/cm²

Courtesy The Anaconda Co., Wire and Cable Div.

steel; and copper-clad steel. The chief characteristics of these conductor materials are compared in Table 9-1.

Copper

For many years, copper has been the most satisfactory conductor for electrical purposes. Its electrical and mechanical properties, coupled with comparative cost benefits, made it almost exclusively used universally.

Its conductivity is high, surpassed only by that of silver and some other rare metals; indeed, its conductivity is used as a reference for that of other materials.

Degrees of Hardness Although basically soft enough to be handled easily, copper can be increased in strength through annealing processes. It is available in three standard degrees of strength and hardness: hard-drawn, medium-hard-drawn, and soft-drawn. Hard-drawn copper results from the repeated drawing of the wire down to the desired size without annealing, i.e., without deliberate after-heating and cooling. Medium-hard-drawn copper results from drawing the wire down to the desired size; annealing must be made under controlled conditions or the degree of hardness will not be consistent enough to be considered constant for design purposes. Soft-drawn copper results from annealing after drawing is complete; here, too, annealing must be controlled to result in constant values of hardness.

As the names imply, the difficulty in handling copper wire depends on its hardness, as does its strength. Hence, for overhead lines, hard-drawn copper finds greatest application for long spans, medium-hard-drawn for intermediate-length spans, and soft-drawn for short spans and for such other uses as connecting leads, tie wires, and other applications where strength is not a major requirement and flexibility is highly desirable.

For cables, interior wiring, and other uses where mechanical strength is not of paramount importance, soft-drawn copper is almost always preferred because of its flexibility.

Flexibility To obtain additional flexibility, particularly where hard-drawn and medium-hard-drawn copper are involved, conductors are sometimes stranded; i.e., a conductor of a specific size may be made up of a number of smaller-cross-section conductors whose sum is equal to the cross section of the specific conductor. While this makes the conductor more flexible, it does increase the overall diameter of the conductor.

Aluminum

Although the conductivity of aluminum is only some 61 percent that of copper, the weight of aluminum is only about one-third that of copper. For the same conductivity, therefore, an aluminum conductor would weigh only about half as much as copper, although somewhat larger in diameter. The breaking strengths of aluminum and soft-drawn copper are also about the same. The result is that these two materials are economically competitive as conductors.

Aluminum Conductor, Steel-Reinforced (ACSR)

From the viewpoint of mechanical strength, plain aluminum conductors cannot be hardened and, hence, cannot compare with medium- and hard-drawn copper conductors. It is sometimes alloyed, however, with other materials to increase its strength slightly, but more often, its deficiency in strength is overcome by having steel reinforce the aluminum. This is accomplished by having strands of aluminum wire wrapped around a central core of one or more strands of high-strength steel wire. The breaking strength of this type of conductor, 2 or more times that of plain aluminum, is considerably greater than even that of a hard-drawn copper conductor of the same conductivity.

Steel

Although its conductivity is relatively low, yet because of its very high mechanical strength, steel is sometimes used as an electrical conductor. Its use is limited to those few occasions where mechanical strength is of paramount importance. It is usually protected from corrosion by galvanizing or otherwise protected by some covering.

Copper-Clad Steel

The advantages of steel for strength and copper for conductivity are combined into a solid nonstranded-type copper-clad steel conductor. Obviously, this type of conductor is limited to the smaller-size copper conductor equivalents. The layer of copper is continuously bonded to the steel, resulting in a material that is essentially homogeneous. Such conductors are made in two grades of conductivity, 30 and 40 percent copper (as a percentage conductivity compared to the conductivity of hard-drawn copper of the same cross section) and in two grades of strength depending on the grade of steel around which the copper is placed. The copper covering acts to insure the conductors against destructive corrosion. This type of conductor is handled in the same manner as solid-type hard-drawn copper conductors.

Other Materials

From time to time, other materials have been employed as conductors of electricity. Silver, because of its very high conductivity, has sometimes been used in very special situations where strength and cost are not the principal concerns.

Alloys of both copper and aluminum have also found special applications. Brass and bronze, though stronger than copper mechanically, have lower conductivities, and have found application in relatively few special situations.

Similarly, aluminum alloyed with small percentages of silicon, magnesium, iron, and other metals has been used where increased hardness and tensile strength are desired along with light weight, and where conductivity is of secondary importance.

Characteristics of Conductor Materials

The more important characteristics of the several conductor materials mentioned above are given in Table 9-1. Conductivity and weight have already been discussed. While the words *strength* and *tension* have been used, further description is needed; these are quantified in the table in terms of elastic limits and ultimate strengths.

Elastic Limit and Modulus of Elasticity (Sag) The elastic limit of a metal is the amount of elongation or stretch that the material can make under stress while still being able to return to its original dimensions, i.e., without permanent deformation after the stress is removed. The elasticity of a material can be measured as a ratio between the stress applied (in pounds per square inch or kilograms per square centimeter) and the elongation produced per unit length (say, inches per foot or millimeters per meter). This ratio is known as the *modulus of elasticity* and is a measure of the way a conductor will sag under loading.

A very small percentage elongation of a conductor is accompanied by a comparatively large increase in sag. Tension is approximately inversely proportional to sag; i.e., when the sag is increased, the tension (or stress) in the conductor is decreased. The elongation, up to the elastic limit and including a factor of safety, is taken into account in computing sags.

Elongation beyond the elastic limit can continue until the conductor is at or near the breaking point, which is a measure of the ultimate strength of the conductor. For stranded conductors, the ultimate strength is taken at about 90 percent of the sum of the strengths of the individual strands. The ultimate strength has little importance in the design of electric lines, but is a figure which allows factors of safety to be determined, i.e., a ratio of stress that would ultimately cause the conductor to fail to the allowed stress.

Temperature Coefficient of Linear Expansion There is still another characteristic of materials that affects the performance of conductors: the temperature coefficient of linear expansion, or a measure of the change in length of the material with temperature. This is of great importance, as a sag installed in a line at a particular temperature, say in summertime, may be considerably different at another temperature, say in wintertime. These variations caused by temperature differences are taken into account in the design and construction of overhead lines.

Conductor Sizes Since it is impractical to manufacture an infinite number of wire sizes, standards have been adopted for an orderly and simple arrangement of such sizes for manufacturers and users. The American Wire Gauge (AWG), formerly known as the Browne and Sharpe Gauge (B&S), is the standard generally employed in this country and where American practices prevail.

In defining conductor sizes, the *circular mil* (cmil) is usually used as the unit of measurement. It is the area of a circle having a diameter of 0.001 in, which works out to be 0.7854×10^{-6} in^2. In the metric system, these figures are a diameter of 0.0254 mm and an area of 506.71×10^{-6} mm^2.

Wire sizes are given in gauge numbers, which, for distribution system purposes, range from a minimum of no. 12 to a maximum of no. 0000 (or 4/0) for solid-type conductors. Solid wire is not usually made in sizes larger than 4/0, and stranded wire for sizes larger than no. 2 is generally used. Above the 4/0 size, conductors are generally given in circular mils (cmil) or in thousands of circular mils (cmil × 10^3); stranded conductors for distribution purposes usually range from a minimum of no. 6 to a maximum of 1,000,000 cmil (or 1000 cmil × 10^3) and may consist of two classes of strandings. These wire sizes and their dimensions are given in Table 9-2.

Gauge numbers may be determined from the formula:

$$\text{Diameter, in} = \frac{0.3249}{1.123^n}$$

or

$$\text{Cross-sectional area, cmil} = \frac{105{,}500}{1.261^n}$$

where n is the gauge number (no. 0 = 0; no. 00 = −1; no. 000 = −2; no. 0000 = −3).

It will be noted that the diameter of the wire doubles approximately every sixth size (e.g., no. 2 has twice the diameter of no. 8), and the cross-sectional area therefore doubles every third size and is 4 times as great every sixth size (e.g., no. 2 has twice the area of no. 5 and 4 times that of no. 8).

The diameter of stranded wire is approximately 15 percent greater than the diameter of a solid wire of the same cross-sectional area.

The gauge numbers and wire designations apply to conductors of all materials. Usually, however, the equivalent wire sizes are denoted for the several materials in comparison to copper (e.g., 4/0 aluminum is equivalent to 2/0 copper). These are indicated in the tables for such conductors.

Conductor Coverings Although the practice has essentially been discontinued, in the early days of overhead line construction, conductors were sometimes provided with weatherproof coverings. Such coverings usually consisted of cotton braids impregnated with a water-resistant compound wrapped about the wire. These conformed to no standards, but the various thicknesses of covering used were designated by the number of braids: single-braid, double-braid, and triple-braid. These coverings were used on conductors operating at secondary voltages usually less than 500 V, and at primary voltages under 5000 V. It was felt that such coverings would prove useful in preventing short circuits in stringing new wire, when wires swung together, when they came in contact with tree limbs, or when objects fell or were thrown across the wires. Although the insulating value of such coverings is unreliable, it will be more or less in proportion to the thickness of the covering, the preservative, age, and other considerations. As indicated earlier, this practice has been essentially discontinued, but a great many such installations still exist and will be met in maintenance and reconstruction activities.

TABLE 9-2 CHARACTERISTICS OF SOLID AND STRANDED CONDUCTORS

	Both solid and stranded conductors								*Stranded conductor*	
	Cross section		*Weight, lb/1000 ft**		*Resistance, Ω/1000 ft at 20°C*					
Size	*cmil*	*in²*	*Cu*	*Al*	*Cu*	*Al*	*Solid conductor diameter, in*		*Number and diameter of strands, in*	*Diameter, in*
—	1,000,000	0.7854	3026.9	921.6	0.010	0.017	—		61 × 0.129	1.150
—	750,000	0.5891	2270.2	691.2	0.014	0.022	—		61 × 0.111	0.998
—	500,000	0.3927	1513.5	460.8	0.021	0.034	—		37 × 0.116	0.813
—	350,000	0.2749	1059.4	322.5	0.030	0.048	—		37 × 0.097 19 × 0.136	0.681 0.678
—	250,000	0.1964	756.7	230.4	0.041	0.068	—		37 × 0.082 19 × 0.115	0.575 0.573
4/0	211,600	0.1662	640.5	195.0	0.049	0.080	0.4600		19 × 0.106 7 × 0.174	0.528 0.522
3/0	167,772	0.1318	507.9	153.6	0.063	0.102	0.4096		19 × 0.094 7 × 0.155	0.470 0.464
2/0	133,079	0.1045	402.8	122.0	0.078	0.128	0.3648		19 × 0.084 7 × 0.138	0.418 0.414
1/0	105,625	0.0830	319.5	97.0	0.098	0.161	0.3250		19 × 0.075 7 × 0.123	0.373 0.368
1	83,694	0.0657	253.3	76.9	0.124	0.203	0.2893		19 × 0.066 7 × 0.109	0.322 0.328
2	66,388	0.0521	200.9	61.0	0.156	0.256	0.2576		7 × 0.097	0.292
3	52,624	0.0413	159.3	48.4	0.197	0.323	0.2294		7 × 0.087	0.260
4	41,738	0.0328	126.4	38.4	0.249	0.408	0.2043		7 × 0.077	0.232
5	33,088	0.0260	100.2	30.4	0.313	0.514	0.1819		7 × 0.069	0.207
6	26,244	0.0206	79.5	24.1	0.395	0.648	0.1620		7 × 0.061	0.184
7	20,822	0.0164	63.0	19.1	0.498	0.817	0.1443		7 × 0.053	0.167
8	16,512	0.0130	50.0	15.2	0.628	1.030	0.1285		7 × 0.047	0.154

*For PE- and PVC-insulated conductors, add 550 lb per square inch of cross section for every 1000 ft.

To convert to metric system:
$\text{in}^2 \times 645 = \text{mm}^2$
$\text{in} \times 2.54 = \text{cm}$

Courtesy The Anaconda Co., Wire & Cable Div.

Tree Wire Where wires are strung among trees with the possibility of abrasion from contacting limbs and resultant short circuits, an especially heavy covering was applied to the wires. Often, this consisted of thick fiber, hemp, or sisal coverings, in some instances applied over some rubber insulation. Again, this practice is virtually obsolete, though some tree wire still remains in place.

Where fear of wires' coming together and tree problems are still considerations to be taken into account, present practice calls for installing fully insulated wire.

Insulated Wire Use of insulated wire on overhead systems was formerly restricted to transformer connections, overhead-to-underground and other jumper connections, and an occasional span or two. Insulation consisted of rubber covered with one or more weatherproof braids. The rubber insulation was subject to deterioration from temperature changes, moisture, sunlight, pollution, and other causes.

The development of plastics, such as polyethylene (PE) and polyvinyl chloride (PVC), has made available insulated conductors in which the plastic serves both as insulation and covering or sheathing. It has completely taken the place of weatherproof covered conductors, tree wire, and other insulated wire mentioned above. Indeed, the availability of such plastic-insulated wire has increased its usage in place of bare wire for overhead and for lead-sheathed underground cables, resulting in generally improved reliability for the former and wider application of underground systems.

One of the features of some of these plastics is their hardness, particularly at low temperatures. They are therefore somewhat more difficult to handle, and the plastic must sometimes be heated before it can be removed by knife or other tool, for making connections or for other purposes.

CABLES

Conductors for use in underground systems must be provided with insulation sufficient to withstand the voltages at which they must operate. Generally, these consisted of stranded copper conductors (except very small-size conductors which were solid) with insulation of rubber, varnished cambric, or special oil-impregnated paper, all contained within a sheath made of lead. In some special circumstances, such as in heavy tree areas or where appearance was an important factor, these cables were installed on overhead systems, usually attached to a messenger wire for support between poles.

Because the rubber insulation sometimes contained sulfur compounds which reacted destructively with the copper, the conductor strands were often tin-plated, adding to the complexity and cost of such insulated cables; these were generally limited to secondary voltage applications of 500 V or less and to primary voltages of 5000 V or less.

Single-conductor cables are used for spur or lateral or branch lines of feeders where numerous branch joints or splices are required, for secondary and service supply, for street lighting, and other such purposes, or where the conductor may be very large, making a multiconductor cable impractical. Multiple-conductor cables of two, three, or four conductors are used in the main portion of feeders, where there may be few branch connections required; in such instances they may be more economical, both from material and labor standpoints, than a number of single-conductor cables.

In some instances, where electrolytic or other chemical conditions may cause sheath corrosion or erosion, lead sheaths may be replaced with nonmetallic sheaths or the sheath (and cable) may be covered with nonmetallic materials such as plastics.

In some instances, such lead-sheathed cables may be buried directly in the ground, or laid under water in submarine installations. In these instances, the lead sheath is covered with jute or tar and armor wires of steel are wound around the whole for protection.

Although the installation of lead-sheath cables is a disappearing practice, many miles of such installations exist and will continue to exist for many years to come.

Cables in which the plastic takes the place of both insulation and sheath are now used almost exclusively for distribution circuits, and are more extensively buried directly in the ground. This not only eliminates ducts and manholes, but permits longer sections of cable to be used with fewer splices required. Aluminum often replaces copper as the conductor in these newer types of cables.

SECONDARY MAINS

Secondary mains consisting of two or more conductors were sometimes fastened to insulators mounted on cross arms and more often on insulated racks attached to the sides of the poles. The "live" conductors were generally of weatherproof covered wire, though sometimes they were rubber-insulated with a covering wrapped about the rubber. The "neutral" conductor was generally a bare wire.

More recently, with the advent of plastics in this field, secondary conductors with plastic insulation are wound together or "cabled" with the bare neutral wire, the assembled conductors thus becoming self-supporting; more often, the conductors are made of aluminum, rather than the copper formerly almost universally used. Besides taking up less space on the top or side of the pole, cabled secondaries are easier to install and their reactance (which contributed to a loss or drop in voltage) is less than for the open-type conductors.

SERVICE CONDUCTORS

Overhead services for many years were of the open-wire or multiple-conductor types. Open-wire construction, with separate weatherproof covered wire and bare neutral, held apart on separate insulators, not only was cheaper, but allowed a third or fourth conductor to be added very readily. In multiple-conductor construction, sometimes known as "duplex" or "triplex" cables, the service cable consisted of one or two insulated conductors about which the neutral conductor strands were wound, the whole enclosed by weatherproof braiding. This type of construction made for better appearance, and a slightly better reactance. Many of both open-wire and multiple-conductor services still exist and will continue to do so for an indefinite time.

Services also have employed "cabled" conductors, similar to those used for secondary mains. In some instances, consumers are served from midspan taps; in others, from poles. Economics and appearance are the determining factors.

In many instances, services are placed underground, generally for the sake of appearance. Lead-sheath rubber-insulated cables installed in ducts or conduits, or supplied with armor and buried directly in the ground, have been used. Plastic-insulated conductors requiring no sheathing have largely taken the place of such underground cables. They are buried directly in the ground, as previously described for main-line conductors.

CONNECTIONS

Connections made between conductors, in joining two ends together or in making a tap off the other, should be electrically and mechanically sound. They not only should introduce no additional resistance (and associated heating) at the points of contact, but they should also not be subject to corrosion or conductor stresses or movements.

In earlier times, such connections usually consisted of wires wrapped together and soldered. Later, twisted sleeves were employed in which the two ends of the conductor were inserted in a sleeve and the whole assembly twisted. Stranded conductors had each strand serviced separately before soldering. Many of these connections still exist.

The later development of "solderless" or mechanical connectors made obsolete the wrapped and soldered splices. Parallel-groove clamps, split-bolt connectors, and crimped sleeves made splicing more simple and more uniform, with substantial reduction in labor costs. Some of these are shown in Fig. 9-1. For rapid installation, usually during periods of emergency, the "automatic" splice, employing wedges which, under pressure of the sagging wire, grip the ends of the conductors to be spliced, was also developed; this is relatively more expensive.

When necessary, friction tape, or insulating tape covered with friction tape, is employed to continue the covering or insulation. In present-day applications, the splices are often left bare.

In many instances, where it is desirable to disconnect the connection readily,

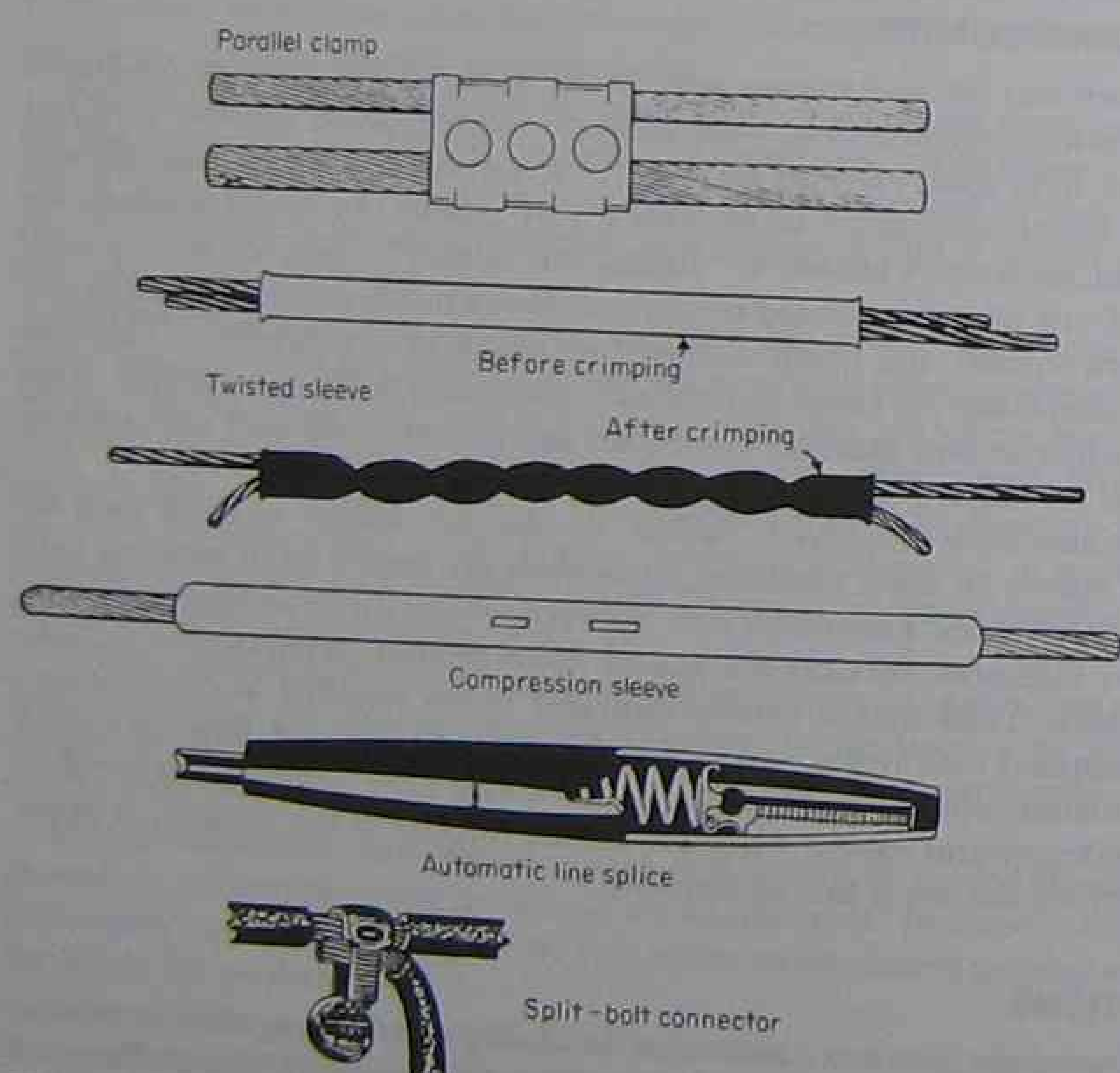


FIG. 9-1 Mechanical connectors. *(Courtesy Burndy Corp.)*

special clamps, sometimes known as "live-line" or "hot-line" clamps, are used; these are shown in Fig. 9-2.

The advent of aluminum conductors into a field in which the conductors previously were exclusively copper presents problems where conductors of dissimilar metals need to be connected together. Special care is exercised, since the connection may be affected by chemical interaction between the two metals, especially when wet and in the presence of some pollutants; but even more, because of the different rates of expansion when heated. The uneven expansion and contraction will eventually cause such splices to become loose, and their resistance to increase with consequent abnormal heating, with possible dire results.

Connectors for copper-to-copper conductors are usually made of copper, though bronze is sometimes used for greater strength. Where aluminum or ACSR conductors are to be connected to similar conductors, connectors of aluminum are used. Where the conductors to be connected are of dissimilar metals, connectors are so designed that only surfaces of similar metals come in contact with each other; aluminum clamps with copper bushings, or vice versa, are employed for this purpose. Care is taken to prevent water dripping from copper items, which may contain copper salts, from coming into contact with aluminum items.

While this discussion applies equally to overhead and underground installations, it must be noted that splices on underground cables, especially where lead-sheath cables are involved, are very much more complex. The connector must be smooth so that no corona discharge will pit the metals. The insulation covering the connector is carried over from one cable to the other by means of insulating tapes wound about the connector. The lead sheath is sweated or soldered to the cable sheaths and is usually larger in diameter. The splice may be filled with an insulating compound, which is heated and poured into the splice, where it hardens on cooling. The new plastic-insulated cables are spliced with a connector between the two conductors and plastic tape of the same material as the insulation wrapped about the assembly; the tape tends to become homogeneous with time.

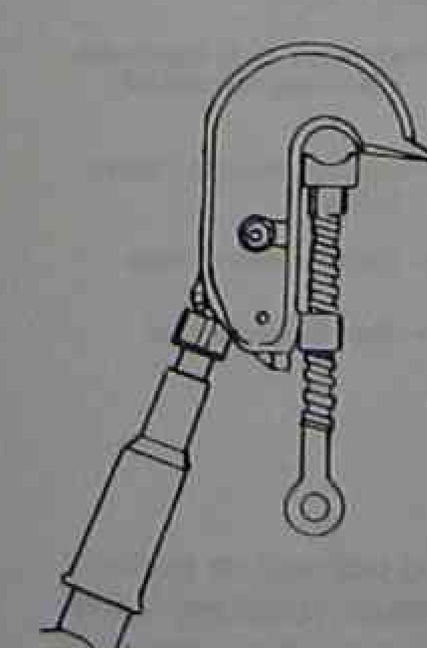


FIG. 9-2 Live-line or "hot-line" clamp. *(Courtesy A. B. Chance Co.)*

OVERHEAD-TO-UNDERGROUND CONNECTION

Connections are often required to be made between overhead and underground conductors. With the advent of plastic-insulated cables, connections have been made directly between the overhead and underground conductors. Live-line clamps furnish a means for easy and rapid disconnection of the conductors involved. Potheads and weatherheads are dispensed with.

In older installations, many of which will continue to exist, special devices have been used. For primary voltages, *potheads* have been used. Here the conductors of the underground cable are connected to terminals in which the conductors are surrounded by poured insulation compound to prevent moisture or air from entering the cable insulation. The overhead wires are connected to the female end of the terminal, enclosed in an insulated cap. The connection is made by placing the cap over the terminal extending from the pothead case. Potheads so described are known as *disconnecting* potheads. Where the connections are made directly to the terminal extending from the pothead in a permanent fashion, the pothead does not carry this distinction.

For lower secondary voltages of 500 V or less, a simpler device was used. Here the conductors of the underground cable are brought out through a preformed insulator, usually of porcelain, in an assembly which inverts the leads so that rain cannot enter the cable. Such devices are known as *weatherheads*. Connection to the overhead wires is made with ordinary connectors of the several types described; see Fig. 9-3.

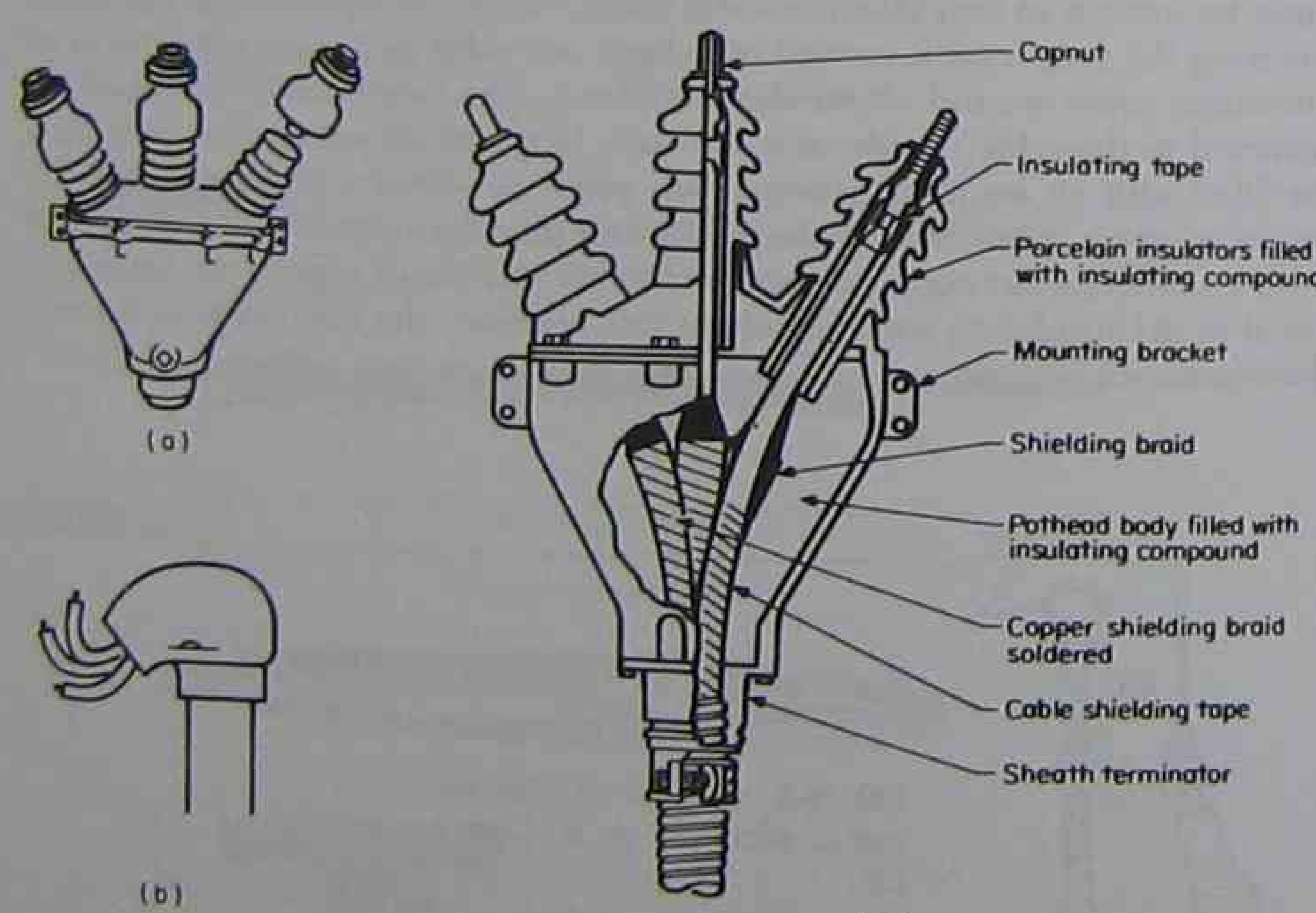


FIG. 9-3 Connection between overhead and underground lines: (*a*) pothead for primary lines; (*b*) weatherhead for secondary lines; (*c*) cross section of pothead. *(Courtesy G&W Electric Specialty Co.)*

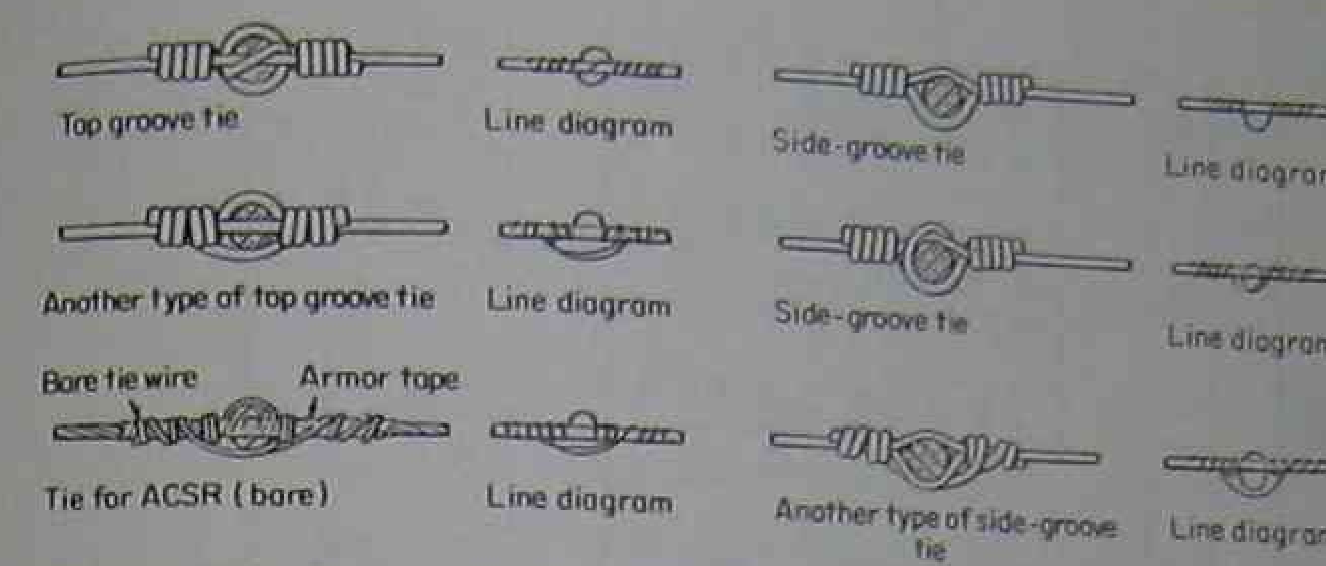


FIG. 9-4 Wire ties for overhead conductors: handmade wire ties. *(Courtesy EEI Overhead Reference Book.)*

TIES

Ties are pieces of wire used to attach the conductors to the insulators on overhead systems. They should be flexible enough to be handled easily, but must be mechanically strong to prevent the conductor from pulling away from the insulator under stress. For bare copper conductors, this tie wire is usually of soft-drawn copper; for weatherproof covered conductors, bare or weatherproof covered wire is used. For aluminum or ACSR conductors, soft-drawn aluminum wire is used. Wire sizes are optional, but are generally small enough to be flexible but strong enough for the purpose. Often such ties are made from old or discarded conductors of small sizes, no. 6 or no. 8 conductor. Where such ties

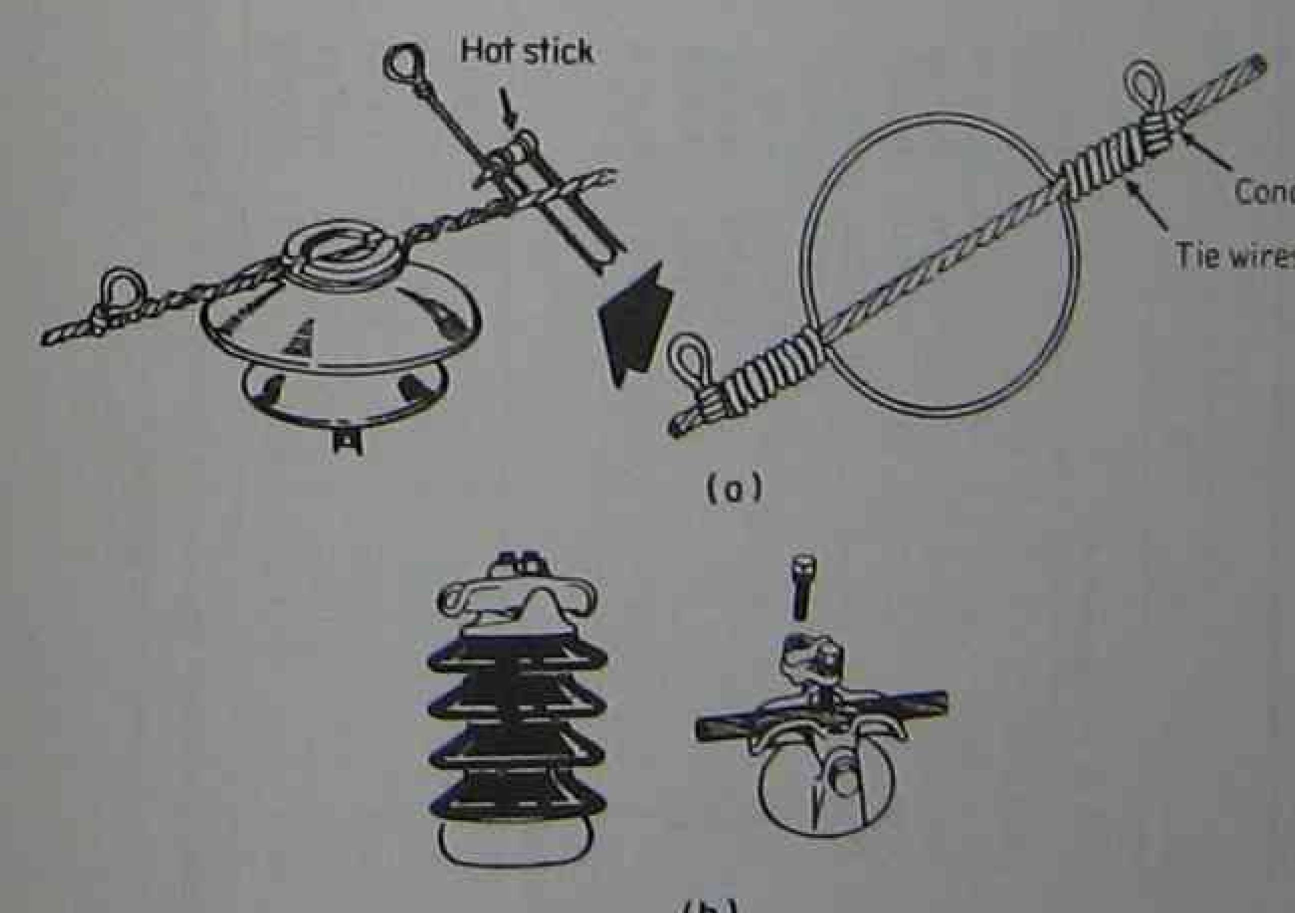


FIG. 9-5 Wire ties for overhead conductors: (*a*) live-line-type tie; (*b*) clamp-type tie. *(Courtesy A. B. Chance Co.)*

TABLE 9-3 INDUCTIVE REACTANCE PER SINGLE CONDUCTOR: COPPER OR ALUMINUM, 60 CYCLE, Ω/1000 ft

Wire size,	*Spacing between conductors, in*											
	⅜	½	1	2	4	6	8	12	18	24	30	36
Cmil or no. stranded												
1,000,000	—	—	—	0.0377	0.0534	0.0628	0.0693	0.0787	0.0881	0.0947	0.1000	0.1042
750,000	—	—	0.0250	0.0419	0.0568	0.0663	0.0727	0.0823	0.0915	0.0982	0.1025	0.1073
500,000	—	—	0.0286	0.0445	0.0604	0.0696	0.0762	0.0855	0.0948	0.1014	0.1065	0.1107
350,000	—	—	0.0354	0.0487	0.0646	0.0738	0.0803	0.0897	0.0990	0.1055	0.1107	0.1149
250,000	—	—	0.0365	0.0524	0.0683	0.0775	0.0841	0.0934	0.1027	0.1093	0.1144	0.1180
4/0	—	—	0.0384	0.0543	0.0702	0.0794	0.0860	0.0953	0.1046	0.1112	0.1163	0.1205
3/0	—	—	0.0411	0.0570	0.0729	0.0821	0.0887	0.0980	0.1073	0.1139	0.1190	0.1232
2/0	—	—	0.0437	0.0596	0.0755	0.0847	0.0913	0.1006	0.1099	0.1165	0.1210	0.1258
1/0	—	—	0.0464	0.0623	0.0782	0.0874	0.0940	0.1033	0.1126	0.1192	0.1248	0.1285
1	0.0276	0.0342	0.0501	0.0660	0.0819	0.0911	0.0977	0.1070	0.1163	0.1229	0.1280	0.1322
Solid												
2	0.0303	0.0369	0.0528	0.0686	0.0845	0.0938	0.1004	0.1097	0.1990	0.1256	0.1307	0.1348
3	0.0329	0.0395	0.0554	0.0713	0.0872	0.0964	0.1030	0.1123	0.1216	0.1282	0.1334	0.1375
4	0.0356	0.0422	0.0581	0.0740	0.0899	0.0991	0.1057	0.1150	0.1243	0.1309	0.1360	0.1402
6	0.0409	0.0475	0.0634	0.0793	0.0952	0.1044	0.1110	0.1203	0.1296	0.1362	0.1413	0.1455
8	0.0462	0.0528	0.0687	0.0846	0.1005	0.1097	0.1163	0.1256	0.1349	0.1415	0.1466	0.1508

Note: For stranded conductors, the inductance is approximately 0.0013 Ω less than for the same size solid conductors.

From *Overhead Systems Reference Book.*

are handled while the conductors remain energized, ties designed with loops that can be handled with so called hot-line tools or hot sticks are employed. Several types of ties are shown in Figs. 9-4 and 9-5.

For special conditions, especially for live-line operations, clamps that are designed to hold the conductors, but are easily opened, are used. The economics of such clamps, however, are such that they are rarely used. Tie wires are almost universally used.

ELECTRICAL CHARACTERISTICS

Resistance values for the various sizes of conductors are assumed to be the same for ac and dc operation; the skin effect prevalent in ac circuits at the values normally encountered in distribution circuits is small and may be neglected; refer to Table 9-2.

Inductive reactance values, for multiwire circuits, depend on the distance between conductors with respect to each other; these are shown in Table 9-3. For distances between conductors not shown, values of inductive reactance may be interpolated from the values shown.

CHAPTER 10

POLES, CROSS ARMS, PINS, RACKS, AND INSULATORS

WOOD POLES

Overhead distribution lines are almost universally supported on poles made of wood, though concrete and metal (steel and aluminum) are also used.

Kinds of Wood

The kinds of wood used frequently reflect the availability of materials in the different areas of the country. Western red cedar has wide application in western and northern regions, while southern or long-leaf yellow pine predominates in the rest of the country. Large amounts of northern white cedar and chestnut, however, still exist among older installations; limited amounts of Douglas fir may be found in the west and redwood in the far west, while cypress is occasionally used locally in some swampy areas of the southeast. Other woods are sometimes also used in the local areas in which they are produced. For special situations where high strength is required, wallaba may be used, though it is imported from northern South America and is comparatively denser and heavier and more expensive than other woods.

Blight has accounted for the rapid disappearance of chestnut, and northern white cedar has become obsolete not only because of diminished supply, but because it is inclined to be knotty and not very straight, making it harder to handle and work on, while it also does not present the best of appearances. Both chestnut and northern white cedar, however, have relatively long natural lives, and many still exist and may continue in service for some time. Most other woods (and particularly long-leaf yellow pine), however, are more susceptible to decay and must be treated with some kind of preservative to attain an economical life span.

Moisture Absorption

Wood, being porous, has a tendency to absorb moisture, and the moisture content depends on the conditions under which the material is used. Wood exposed to the weather can absorb large amounts of water. Since wood is a hygroscopic substance, it tends to give off or take on water vapor until it comes into equilibrium with the surrounding air; changes in atmospheric humidity produce a continual fluctuation in the moisture content of the wood. The relation of the equilibrium moisture content of wood to the relative humidity of the ambient at three different temperatures is shown in Fig. 10-1.

Decay

Much of the difficulty experienced with wood poles is due to decay, particularly at the ground line. Decay is caused by fungi attacking the wood fibers, and the conditions most favorable to the growth of decay fungi are air, moisture, and heat, with the wood acting as their food supply. In the part of the pole below ground, moisture is usually present but air is in short supply; in the part above ground, the reverse is generally true. At and near the ground line, both of these elements exist in relatively substantial quantities and, hence, this particular area is more subject to decay.

Preservatives

To eliminate, or at least retard, this destructive process, wood poles are first heated in a vacuum to drive out moisture (and to kill some of the fungi) and then treated with a preservative under pressure to fill the pores of the wood fiber; this not only poisons the food supply of the fungi (and insects), but also inhibits the absorption of moisture. Many different preservatives have been employed with varying degrees of effectiveness. No penetration process, however, is completely successful, and so periodic inspection and maintenance of the poles is usually scheduled.

Poles are turned on large lathes to improve their appearance before being subjected to treatment with preservatives for their full length. Preservatives may add as much as 25 percent to the weight per cubic foot of the wood.

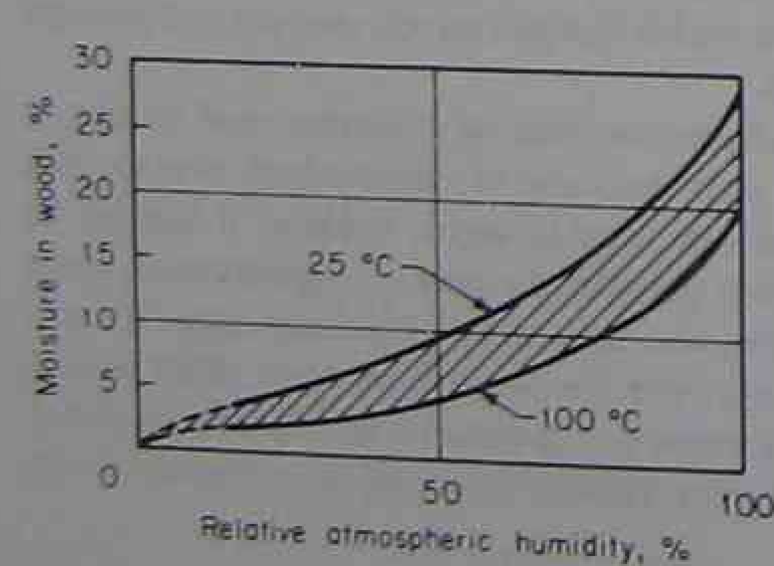


FIG. 10-1 Absorption of atmospheric moisture by wood.

Pole Classification

Pole lengths are standardized and come in increments of 5 ft and range from 20 ft to over 90 ft; for distribution lines, however, lengths are usually limited to from 25 to 55 ft.

The strength of poles depends not only on the material, but on their cross-sectional dimensions. This feature is also standardized and is denoted by "class" numbers, ranging from 00 to 10. For each standard length, the dimensions for each class are defined by standardized circumferences at the top of the pole and at a point 6 ft from the butt or bottom (approximately at the ground line). The top circumference for poles of all of the kinds of wood of the same class is the same; the lower circumference is different for different kinds of wood and determines the taper of the pole. American Standards Association (ASA) standard dimensions are given in Table 10-1 for southern pine, western red cedar, and wallaba poles; also shown are standard depth settings for the several lengths of poles.

Pole Depth Setting

For ordinary soils, depth settings start at 4 ft for 20-ft-length poles and progress to 7½ ft for 55-ft poles; in rock, similar settings range from 3 ft to 5 ft. Pole setting depths for poles over 55 ft increase 0.5 ft for each 5 ft of incremental length, from 8 ft for 60-ft poles to 11 ft for 90-ft poles.

For less resistant soils and other media, deeper settings must be considered, as well as other methods for reinforcing the strength and stability of the pole, such as push braces, cribbing, and guying. Guying is one of the most efficient methods of relieving the pole from some or all of its horizontal load; it has been discussed in Chap. 5.

Pole Strengths

Poles of equal classes will carry equal loads at 2 ft from the top of the pole when set in the ground at standard ASA setting depths. The transverse loads which different class poles will carry are given in Table 10-2.

Some average figures regarding the characteristics of several kinds of wood are shown in Table 10-3.

Pole Framing

In preparing wood poles for use, any cutting or boring is done before the preserving process to eliminate points in which decay may occur. In older poles, a "roof" was cut either in the shape of a gable or at an angle, to prevent snow, ice, and water from accumulating on top and causing decay. Present preserving practices make this unnecessary.

For attaching cross arms, a "gain" cut into the side of the pole, in the form of a channel gouged out to the dimensions of the cross arm, at standard locations on the pole, may be found in older poles. Present practice calls for planing a flat surface on one side of the pole, referred to as a "slab" gain.

TABLE 10-1 ASA STANDARD POLE DIMENSIONS AND DEPTH SETTINGS

			Minimum circumference at 6 ft from butt (approximate ground line), in								
			Class and minimum top circumference, in								
Pole length, ft	*Depth setting, ft*	*Wood**	*00* *29*	*0* *28*	*1* *27*	*2* *25*	*3* *23*	*4* *21*	*5* *19*	*6* *17*	*7* *15*
20	4	P	—	—	31.5	29.5	27.5	25.5	23.5	22.0	20.0
		C	—	—	34.5	32.0	30.0	28.0	25.5	23.5	22.0
		W	32.0	30.0	28.5	26.5	25.0	23.0	21.0	—	—
25	5	P	—	—	34.5	32.5	30.0	28.0	26.0	24.0	22.0
		C	—	—	38.0	35.5	33.0	30.5	28.5	26.0	24.5
		W	35.0	33.0	31.0	29.0	27.0	25.5	23.5	—	—
30	5½	P	—	—	37.5	35.0	32.5	30.0	28.0	26.0	24.0
		C	—	—	41.0	38.5	35.5	33.0	30.5	28.5	26.5
		W	38.0	36.0	33.5	31.5	29.5	27.5	25.5	—	—
35	6	P	45.0	42.5	40.0	37.5	35.0	32.0	30.0	27.5	25.5
		C	49.0	51.5	43.5	41.0	38.0	35.5	32.5	30.5	28.0
		W	40.5	38.0	36.0	33.5	31.5	29.0	27.0	—	—
40	6	P	47.0	44.5	42.0	39.5	37.0	34.0	31.5	29.0	27.0
		C	51.0	48.5	46.0	43.5	40.5	37.5	34.5	32.0	—
		W	42.5	40.5	38.0	35.5	33.5	31.0	28.5	—	—
45	6½	P	50.0	47.0	44.0	41.5	38.5	36.0	33.0	30.5	28.5
		C	54.0	52.0	48.5	45.5	42.5	39.5	36.5	—	—
		W	45.0	42.5	40.0	37.5	35.0	32.5	30.0	—	—
50	7	P	—	—	46.0	43.0	40.0	37.5	34.5	32.0	29.5
		C	—	—	50.5	47.5	44.5	41.0	38.0	—	—
		W	46.5	44.0	41.5	39.0	36.5	34.0	31.5	—	—
55	7½	P	—	—	47.5	44.5	41.5	39.0	36.0	33.5	—
		C	—	—	52.5	49.5	46.0	42.5	39.5	—	—
		W	48.5	46.0	43.0	40.5	38.0	35.0	32.5	—	—
60	8	P	—	—	49.5	46.0	43.0	40.0	37.0	34.5	—
		C	—	—	54.5	51.0	47.5	44.0	—	—	—
		W	50.0	47.5	44.5	42.0	39.0	36.5	33.5	—	—
65	8½	P	—	—	51.0	47.5	44.5	41.5	38.5	—	—
		C	—	—	56.0	52.5	49.0	45.5	—	—	—
70	9	P	—	—	52.5	49.0	46.0	42.5	39.5	—	—
		C	—	—	57.5	54.0	50.5	47.0	—	—	—
75	9½	P	—	—	54.0	50.5	47.0	44.0	—	—	—
		C	—	—	59.5	55.5	52.0	48.5	—	—	—
80	10	P	—	—	55.0	51.5	48.5	45.0	—	—	—
		C	—	—	61.0	57.0	53.5	49.5	—	—	—
85	10½	P	—	—	56.5	53.0	49.5	—	—	—	—
		C	—	—	62.5	58.5	54.5	—	—	—	—
90	11	P	—	—	57.5	54.0	50.5	—	—	—	—
		C	—	—	63.0	60.0	56.0	—	—	—	—

*P = yellow pine; C = western red cedar; W = wallaba.

TABLE 10-2 STANDARD MAXIMUM HORIZONTAL FORCE THAT CAN BE APPLIED TO CLASSES OF POLES*

Pole class	*Load resistance 2 ft from top (approximate load that pole must withstand), lb*	*Increment between class numbers*
10	(No specifications)	—
9	900	—
8	1000	100
7	1200	200
6	1500	300
5	1900	400
4	2400	500
3	3000	600
2	3700	700
1	4500	800
0	5400	900
00	6400	1000

*At standard depth settings.

Dielectric Value of Wood

Wood offers a marked resistance to the passage of an electric current and, at least for lower voltages, may be classed as a nonconductor. Its dielectric strength varies with the different species and is greater across the grain than along the grain; changes in temperature affect the dielectric strength substantially, approximately doubling with each decrease of 22.5°F or 12.5°C. The most significant variation, however, takes place with changes in moisture content: as wood dries from fiber saturation to the vacuumed oven-dry condition, its dielectric value approaches infinity. Preservatives, however, have great influence on the dielectric strength of the wood, especially those consisting of chlorides; older poles treated with creosote and its derivatives have been found to experience

TABLE 10-3 CHARACTERISTICS OF VARIOUS WOODS

Wood	*Weight, lb/ft³*	*Ultimate strength, lb/in²*
Northern white cedar	23	3,600
Redwood	24	4,400
Cypress	29	4,800
Western red cedar	23	5,600
Chestnut	41	6,000
Southern yellow pine	35	7,400
Douglas fir	32	8,000
Wallaba	—	11,000
Locust	—	12,800

little change in dielectric strength as a result of the treatment. As the wood seasons, the effect of still more aging on its dielectric strength diminishes and ceases to be serious in the period of a year or so. Although the wood of poles (and cross arms) aids in the insulation of line conductors from each other and from grounds, it is not to be relied upon where safety to the public and workers is concerned.

Life Expectancy

The life of wood poles, under "normal" conditions of soil and weather, when they are treated and maintained with reasonably effective preservatives, has been estimated to be from 25 years to over 100 years. These figures have been used in making economic studies, in establishing sinking funds for the retirement of poles (and other wood structures), and in designing pole lines calling for considerably larger and stronger poles than initially necessary. In view of the continuing changes in consumer requirements, in civic and traffic requirements, and in the materials and methods employed in providing electric service, the higher longevity considerations (100 years, or even 50 years) appear to be somewhat unrealistic.

CONCRETE AND METAL POLES

General

Concrete and metal poles are at present not used extensively for distribution purposes in the United States. They are, however, used extensively in Europe and other lands where woods suitable for poles are not readily or economically available. Concrete and metal poles are usually used where great strength and appearance are paramount requirements; concrete poles are made in several colors and finishes. Both concrete and metal poles come in cross sections that are circular, square, or polygonal (usually six- or eight-sided). Both allow electrical risers to be installed in the hollow space within them.

Access to Pole-Top Facilities

The problem of access to the facilities at the top of concrete and metal poles has been met by the use of pole steps, whether they are installed permanently, or whether means are provided for their temporary installation. The permanent installation of steps is frowned upon from considerations of safety; their temporary installation is time-consuming, as well as similarly unsafe, as such steps can be installed by unauthorized people. This contrasts with the safety provided by wood poles, where skilled and trained workers, employing climbers, essentially eliminate this unauthorized access by the general public. The widespread use of bucket-type trucks that enable access to pole-top facilities has essentially eliminated the need of climbing, as well as the need for the installation of steps on the pole. Hence, this means has become common to all types of poles.

CONCRETE POLES

Manufacture

Concrete poles are manufactured with hollow cores to reduce their weight, which has been (and still is) a disadvantage, especially when they are handled in the field. Reinforcing steel strands are installed longitudinally for the full length of the pole and prestressed before the concrete is placed; reinforcing steel strands are also installed, essentially at right angles to the longitudinal reinforcing strands, usually as special coils wrapped around and welded to them in a manner to prevent movement during concrete casting. See Fig. 10-2.

In addition to their heavier weight (compared with wood), concrete poles are relatively more expensive, another reason for their lessened usage. Representative data on the characteristics of hollow round and square reinforced concrete poles are contained in Appendix 10A at the end of this chapter.

All concrete poles are tapered, and the square ones have chamfered corners. All provide cable entrance openings and hand holes to permit the installation of electric riser cables in their hollow cores.

Advantages

Concrete poles are not adversely affected by wet or dry rot, birds (especially woodpeckers), fire, rust, or chemicals (such as fertilizers and salt spray). Besides being stronger and more rigid than wood, they are essentially maintenance-free;

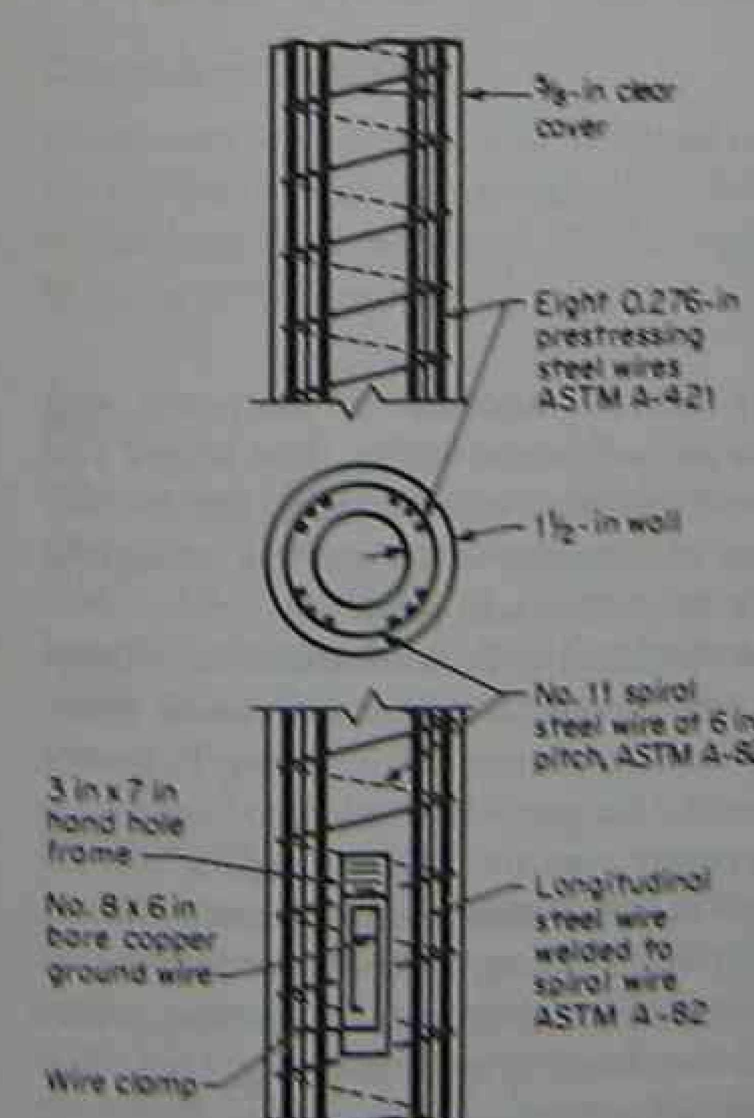


FIG. 10.2 Typical reinforced concrete hollow pole section. (Courtesy Centrecon, Inc.)

ground moisture and weather, which work against other types of poles, work in favor of concrete, hardening, toughening, and protecting its integrity. Considering the potential lifespans, concrete claims the lowest cost per year.

METAL POLES

Metal poles are manufactured according to specifications drawn up for particular uses; their length and the thickness of the metal employed depend on their use and the desired strength. They are tapered and come in the same shapes as concrete poles—round, square, and polygons. They may also include provision for pole steps. Though generally of the color of the metal of which they are made, they may be painted in specified colors. They may be buried directly in the ground, set directly in bases of concrete, or bolted to metal base plates permanently set in concrete.

CROSS ARMS

Cross arms are the most common means of supporting distribution conductors on poles. Although they are being used less frequently, their use will persist for some time.

Standard Arms

Standard cross-section dimensions for wood cross arms (width by height) are:

$3\frac{1}{4}$ in by $4\frac{1}{4}$ in

$3\frac{1}{2}$ in by $4\frac{1}{2}$ in

$3\frac{3}{4}$ in by $4\frac{3}{4}$ in

4 in by 5 in

Of these, the first two are most commonly used for distribution purposes, and usually only one of these will be stocked by an individual utility. The larger size finds greater use in the harsher northern and western climates, while the smaller finds use in the south and southwest. The rectangular cross section is slightly rounded or "roofed" on the top surface to shed rain and snow.

The length of the cross arm depends on the number of conductors it is to support and the spacing between them. Standard cross arms include two-, four-, six-, and eight-pin arms, although the four- and six-pin arms, 8 ft in length, are the more widely used. Spacing between pins for the six-pin 8-ft arm is standardized at $14\frac{1}{2}$ in, except for the space between the two center pins, the "climbing space" for the lineman's safety; for primary voltages up to 15,000 V, this climbing space is 30 in, and for voltages above that value it is 36 in (with spacing between the six pins reduced to 13 in). Spacing between pins for the four-pin 8-ft cross arm is 26 in, with a space between the two center pins of 36 in, the climbing space. See Fig. 10-3. Vertical spacing between cross arms is standardized at 2 ft.

Both Douglas fir and southern yellow pine are used for cross arms because

Allowable variations	Over	Under
c	1/16"	1/16"
d	1/8"	1/8"
l	1/4"	1/4"
cd	1/16"	1/8"

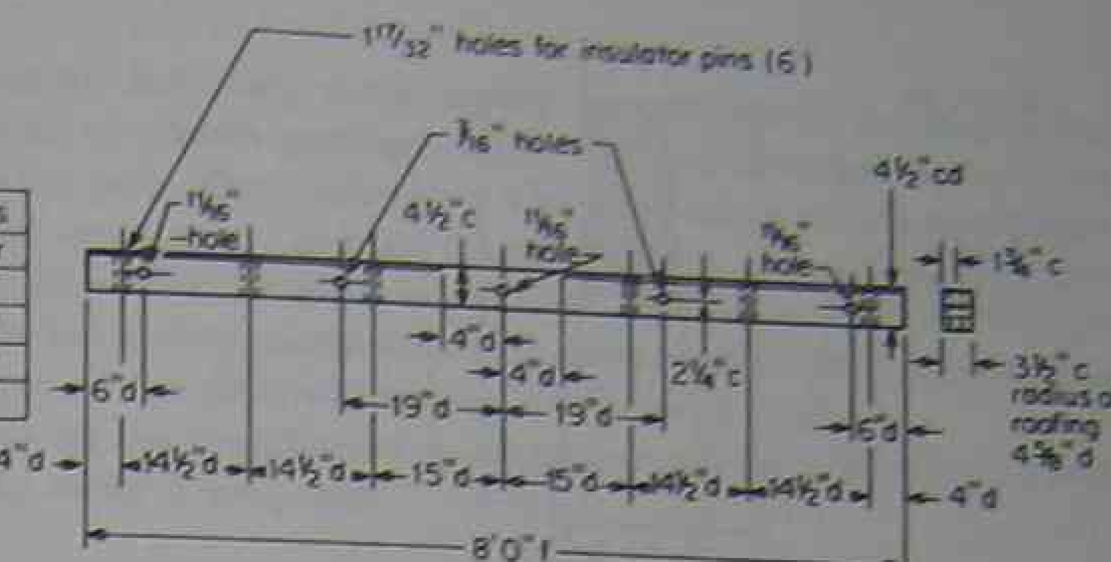


FIG. 10-3 Standard 6-pin 8-ft wood cross arm. *(From Overhead Systems Reference Book.)*

of their comparatively high bending strengths and their durability. Both are treated with preservatives after holes for pins and bolts have been bored in them. Their insulating properties are similar to those described for wood poles.

Steel Cross Arms

Cross arms made of steel are used where stresses are very large and cannot be accommodated by other means such as double arms or arm guys; they do not have the insulating property that wood cross arms have.

Cross-Arm Braces

Galvanized flat steel braces are used to provide strength and rigidity to the cross arm. They are usually attached to the cross arm by means of carriage bolts and to the pole by a lag screw. For heavier loads, a one-piece vee-shaped angle-iron brace is sometimes used.

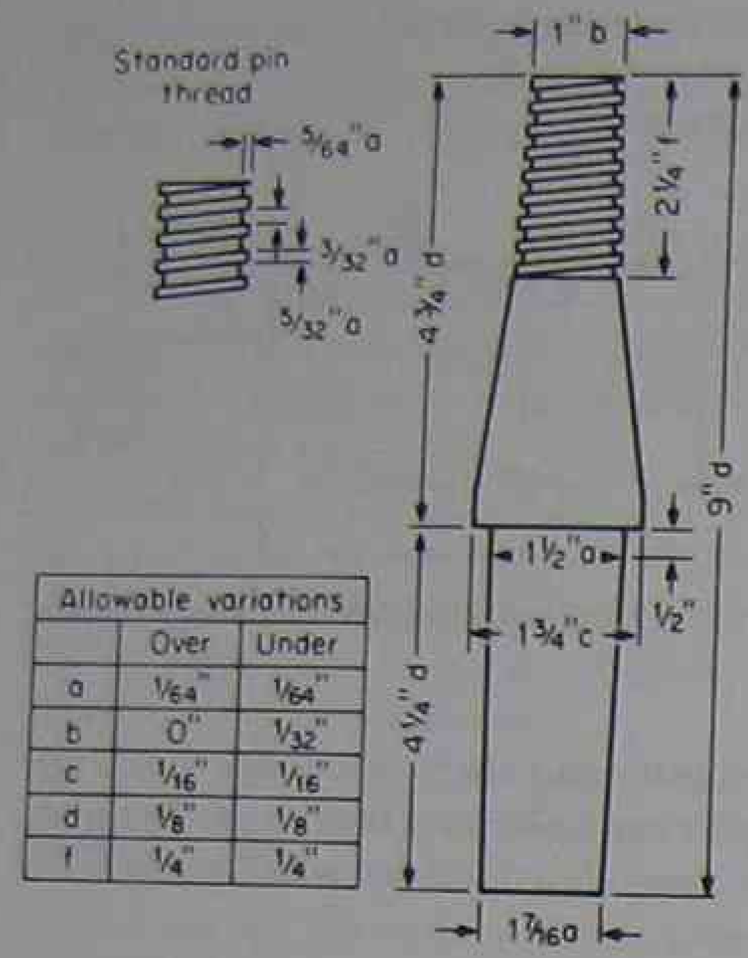
PINS

Pins are used to hold the insulators to which conductors are fastened. They may be made of wood, usually locust because of its strength and durability (refer to Table 10-3, p. 291), or of iron or steel where greater strength or extra-long lengths are required. Pins fastened to cross arms are made of wood or steel, while those fastened directly to poles are made of steel.

Wood Pins

Wood pins are generally made of yellow or black locust, having an ultimate fiber bending strength of about 10,000 lb/in². They are standardized in the dimensions of the pin and in the threads which accommodate the insulators. Where greater strength is required, galvanized metal pins having an ultimate fiber strength of 50,000 lb/in² for malleable iron and 60,000 lb/in² for steel are used.

Standard locust pins are 9 in. in length, with a shank $1\frac{1}{4}$ in. in diameter that



Allowable variations		
	Over	Under
a	1/64"	1/64"
b	0"	1/32"
c	1/16"	1/16"
d	1/8"	1/8"
f	1/4"	1/4"

FIG. 10-4 Standard wood pin. *(From Overhead Systems Reference Book.)*

fits into the cross-arm hole. A 1¾ in shoulder above this shank tapers to a 1-in-diameter part 2¼ in long, which is threaded to receive the insulator; refer to Fig. 10-4.

Steel Pins

Steel pins have many shapes; some are designed to be bolted through the cross arm, others to be clamped around the arm; while others are designed to be bolted directly to the top of the pole. The steel pins may vary in length, and some may also be of hollow core section. Several types of steel pins are shown in Fig. 10-5.

Long steel pins with angle bases, bolted to the side of the pole, serve to replace the cross arm in supporting conductors, making for a more streamlined, stronger, better-appearing line; refer to Fig. 5-13 in Chap. 5.

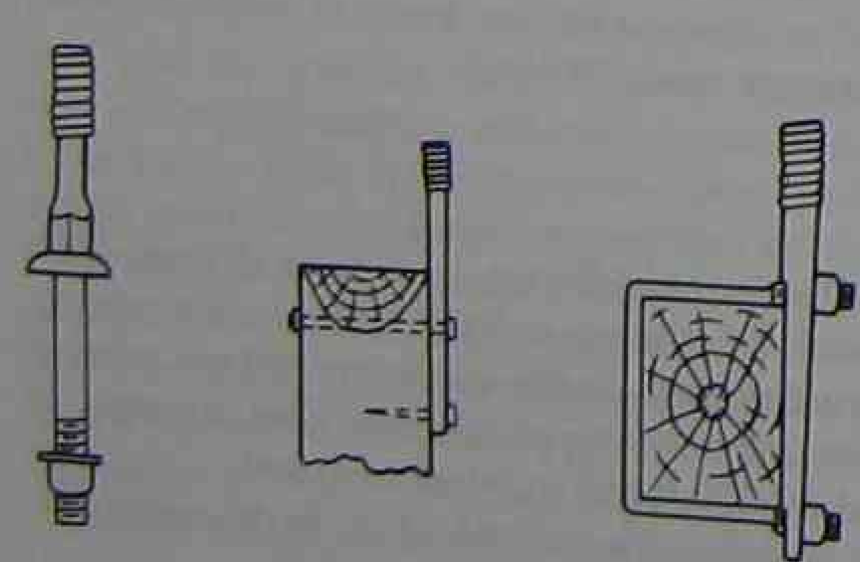


FIG. 10-5 Typical steel pins. *(Courtesy A. B. Chance Co.)*

RACKS

Secondary conductors, for many years supported horizontally on wood cross arms, were relocated to a lower position on the pole and mounted vertically on a rack attached to the pole. They make for a better appearance and are stronger and less costly than cross arms; and the wires being in a vertical plane, service wires running in different directions do not cross each other. With this design the worker on the secondary conductors and services need not approach the primary conductors on the pole, making for a safer work method.

Many secondary-service installations on cross arms and on racks still exist and will continue to do so for a long time.

Multispool Racks

Racks, made of galvanized steel, are attached to the pole by one or more through bolts, some of which may be replaced by lag screws where loadings permit. The racks support insulators, spaced 6 or 8 in apart (although some may have a 4-in spacing), to which the conductors are attached. The conductors may be attached to a number of individual single-insulator racks, or to one rack containing several insulators. The insulators may be of the spool or knob type, as shown in Fig. 10-6.

Single-Spool Racks

Single-spool racks are also manufactured; on these, each insulator is bolted individually to the pole. While spool-type insulators are the more frequently used type, knob-type insulators are also used.

Cabled Secondary Mains and Services

The rack has been supplanted in many instances by a single uninsulated clamp attached to the pole and supporting the secondary mains. Here, the conductors are cabled around a neutral wire, which also acts as a messenger wire carrying the conductors. A similar type of cabled conductor is used for services, with the

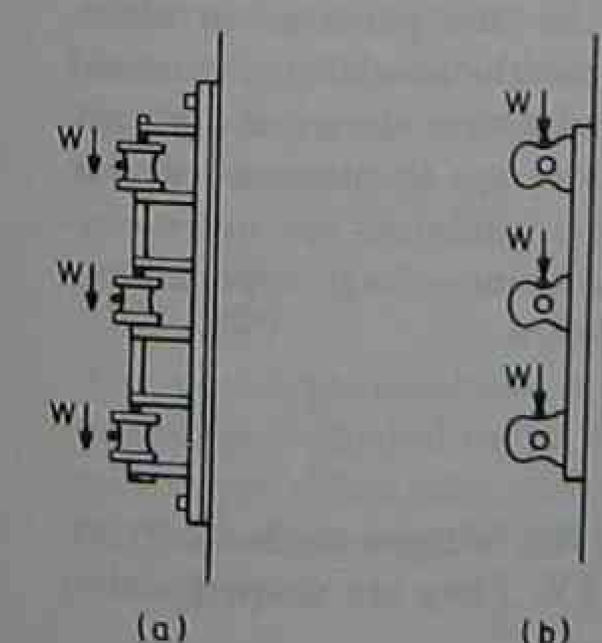


FIG. 10-6 Typical secondary rack: (*a*) spool type; (*b*) knob type. *(Courtesy McGraw Edison Co.)*

neutral-messenger supporting the conductors from the pole to the consumer's premises.

INSULATORS

Materials

Insulators, placed between energized conductors and the supporting structures, are now almost universally made of porcelain, although a great many glass insulators are still in service and will be for a long time. Fiberglass, epoxy, and other plastics are now beginning to be used in the manufacture of insulators.

Glass Glass insulators, made in a variety of shapes and sizes, are electrically and mechanically adequate and very economical. Their usage, however, has been generally limited to circuits operating at voltages under 5 kV, principally because of their relatively (compared to porcelain) low resistance to shock and high coefficient of expansion. While the dielectric properties of glass may vary considerably depending on its particular treatment, its mechanical properties are reasonably consistent. Its tensile strength is usually less than 10,000 lb/in^2; its minimum compressive strength is 50,000 lb/in^2; its modulus of elasticity is 10,000,000 lb/in^2; and its coefficient of expansion is 400 to 600 $\times$ 10^{-6} per degree Fahrenheit, or 720 to 1080 $\times$ 10^{-6} per degree centigrade.

Pyrex, a form of glass, partially overcomes the two deficiencies concerning shock and temperature changes, but its relatively high cost restricts its application generally to high-voltage transmission lines.

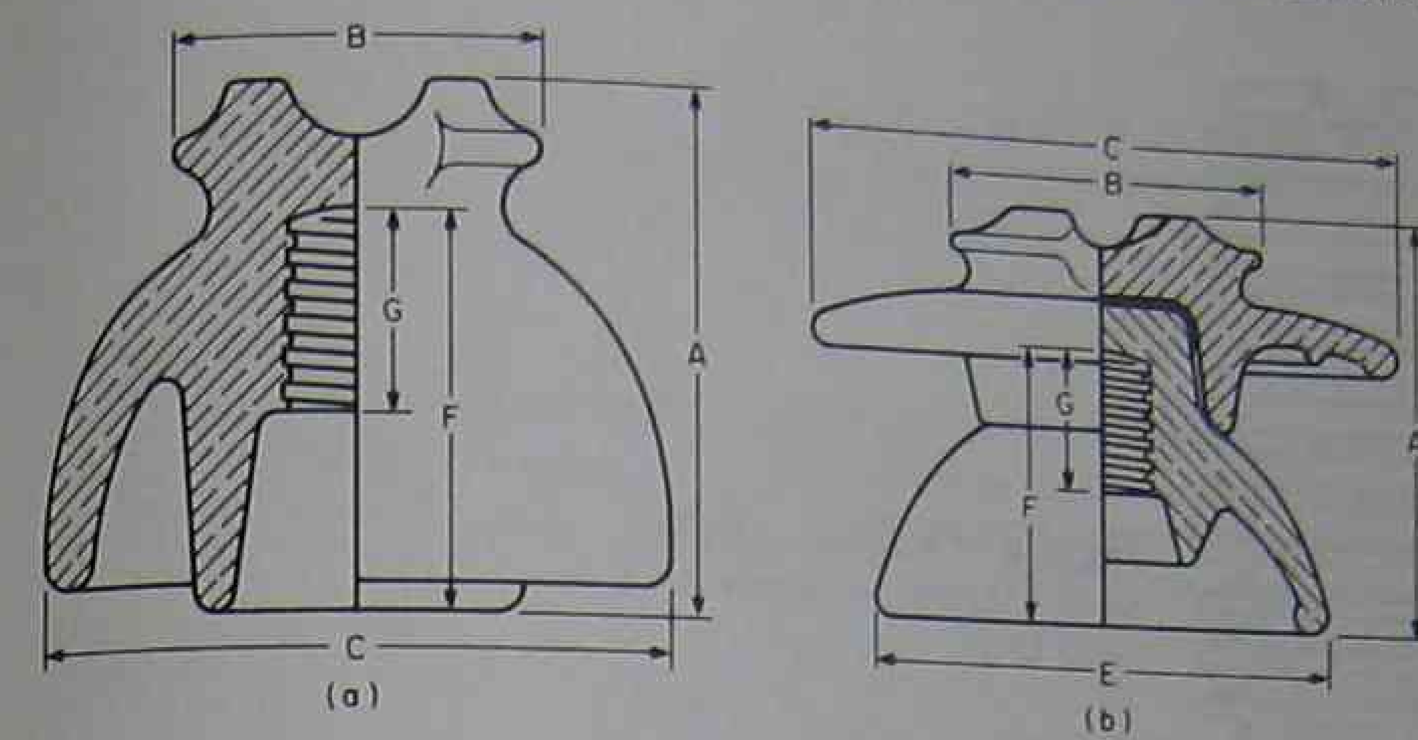
Porcelain Porcelain is made from white clay to which powdered feldspar and silica are added. The material has greater (compared to glass) ability to resist sudden changes in temperature, and an external glaze protects it from shock. Depending on how insulators are manufactured, the tensile strength of the porcelain may vary from less than 2000 lb/in^2 to as much as 9000 lb/in^2, and the corresponding minimum compressive strengths, from 15,000 to 60,000 lb/in^2; its coefficient of expansion may be as low as 16.6 $\times$ 10^{-6} per degree Fahrenheit, or 30 $\times$ 10^{-6} per degree centigrade. The dielectric strength generally exceeds 16 kV/mm (16,000 kV/m), or some 400 kV/in.

Porcelain insulators are made by two processes: the "wet process," in which the insulation is molded, and the "dry process," in which the insulation is pressed into shape in steel molds. The dry-process insulator has less electrical and mechanical strength, but is also less expensive; it is more apt to puncture under electrical stress rather than to flash over. Dry-process insulators are more economical, however, and their use is generally limited to lower-voltage applications.

The principal types of insulators are described below.

Pin-Type

Pin-type insulators may be constructed in one piece for voltages to about 35 kV and in two or three pieces from that voltage to 69 kV. They are shaped with a



	Max.	Min.
A	4 1/2	3 1/4
B	3	2 1/2
C	6 1/2	4 1/4
F	3 3/8	2 3/8
G	2	1 1/2

	Max.	Min.
A	6	5 3/8
B	5	4 1/2
C	9	9
E	7	7
F	4 1/8	3 3/4
G	2	1 7/8

FIG. 10-7 Typical pin-type porcelain insulators: (*a*) one-piece 11- to 15-kV pin insulator; (*b*) two-piece 33-kV pin insulator. *(From Overhead Systems Reference Book.)*

groove on top in which the conductor lies and is tied in place; they may also have a groove around the sides in which the conductor is placed and tied. The side groove is generally used where the line turns and the conductor imposes strains on the side. Both glass and porcelain insulators are shaped so as to provide a long path from the line conductor to the point of support where the insulator is screwed to the pin, usually considered a ground. Several ridges on the underside extend this path so that, figuratively, the insulator may be described as having an outside skirt and a number of inner petticoats; see Fig. 10-7. Though constructed in a variety of shapes, colors, and ratings, all types of pin insulators share a common standard in the diameter, shape, and number of insulator threads per inch, a standard that matches that of the pins with which they are usually associated.

Post-Type

The post-type insulator is a variation of the pin-type insulator, in which the porcelain is shaped into a cylindrical block with its surface corrugated horizontally to provide a long path from the conductor to the point of support; grooves for the attachment of the conductor are provided at the top of the insulator; see Fig. 10-8.

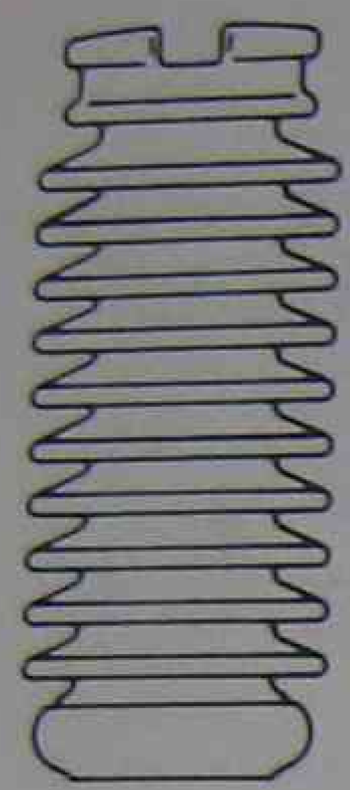


FIG. 10-8 Typical post-type porcelain insulator. *(Courtesy Ohio Brass Co.)*

Suspension- or Strain-Type

The suspension- or strain- (or string-) type insulator consists of a porcelain disk contained between a ball-and-socket (or clevis-and-pin, or other) arrangement so that the porcelain is in compression; each disk has certain electrical and mechanical characteristics. The ball-and-socket arrangement permits units to be added to each other in a string, thus accommodating higher voltages. Several such strings can be connected mechanically in "parallel" to achieve necessary strength requirements. Disks vary in diameter from about 5 to 10 in, with standard vertical distances between ball and socket (or other components) of $4\frac{3}{4}$ and $5\frac{3}{4}$ in, and are rated for an allowable tension of 12,000 lb. See Fig. 10-9.

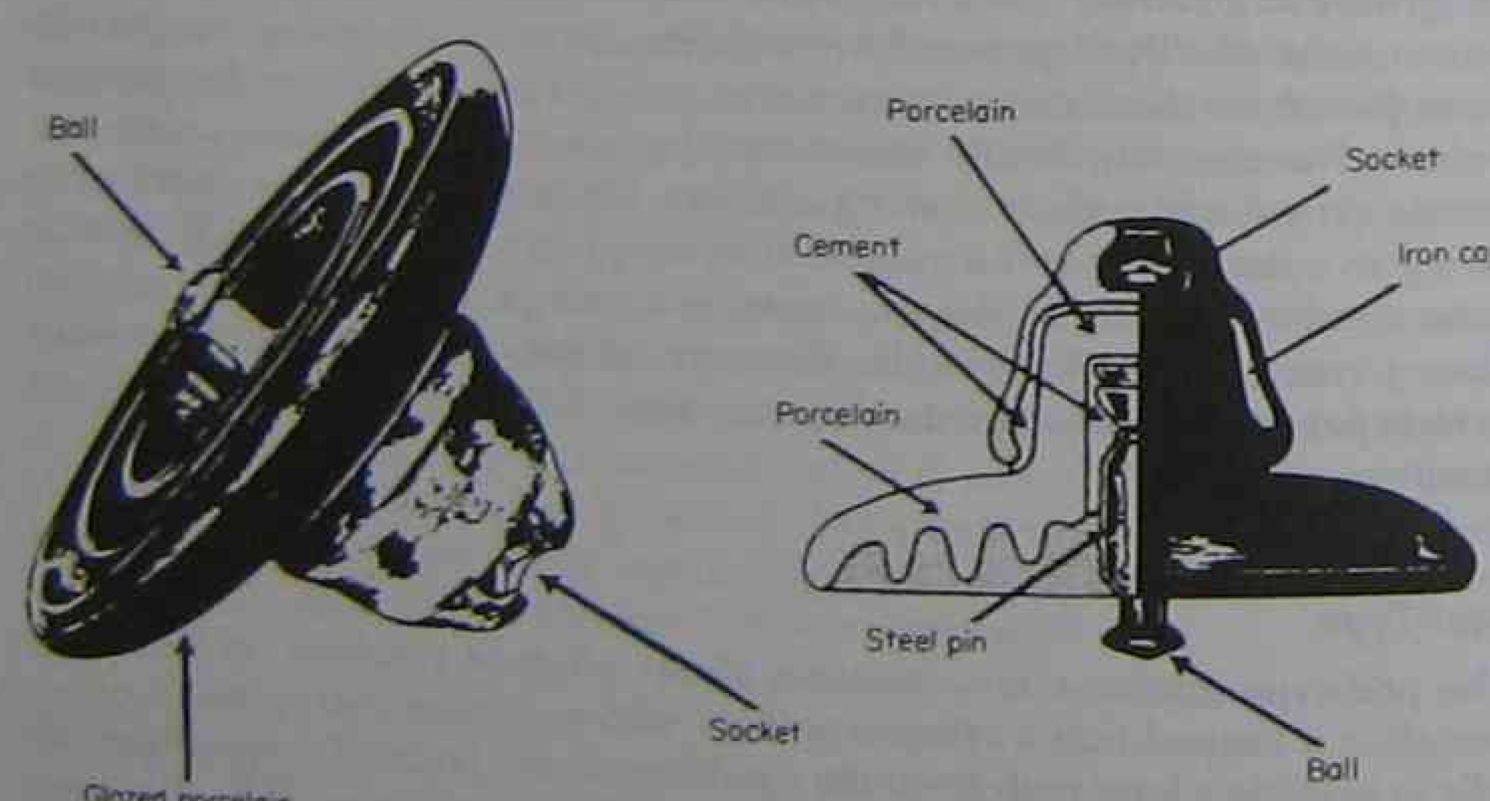


FIG. 10-9 Typical suspension or strain-type porcelain insulator. *(Courtesy Locke Insulator Co.)*

Spool-Type

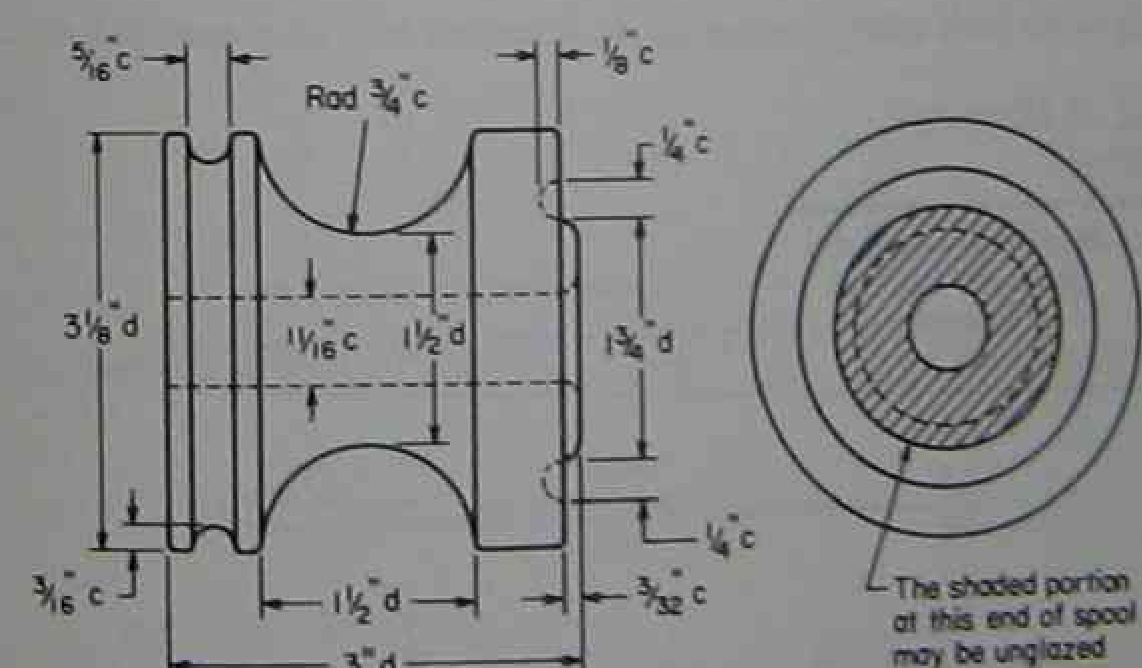
Spool-type insulators are used with secondary racks or in service brackets to support secondary mains and services; they come in two different sizes and colors for identification purposes. See Fig. 10-10.

Strain-Ball Type

The strain-ball insulator is generally employed in guys to insulate the upper part from the lower part; the lower part is insulated to protect people on the ground, while the upper part is insulated from the ground to protect the lineman on the pole. In some instances involving wye circuits with a common primary and secondary grounded neutral, this insulator is sometimes not inserted in the guy wire. The insulator consists of a ball or block of porcelain in which two transverse holes at right angles to each other contain the guy wires so arranged that the porcelain is always under compression. See Fig. 10-11. This type of insulator is also used to dead-end smaller conductors at the cross arm where the operating voltage is less than 5000 V.

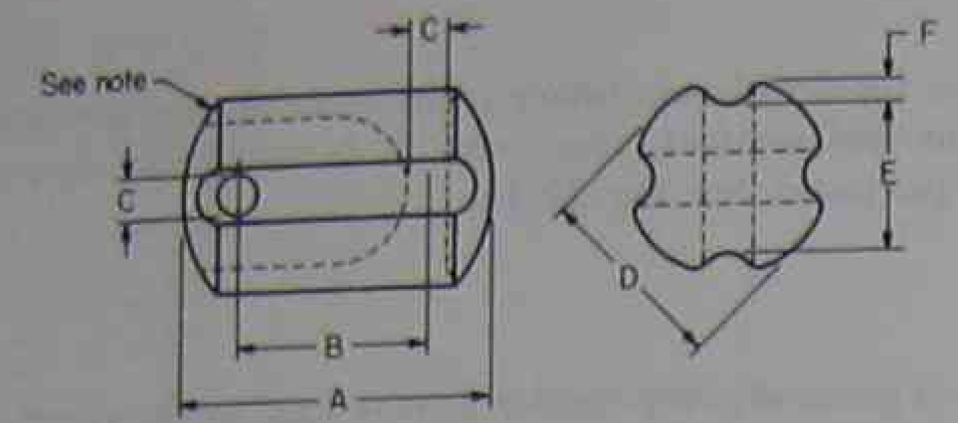
Other Types

Other insulator types include the knob types sometimes used with secondary racks, previously described; and various other shapes for use as bushings, bus and service supports, and other specific purposes. Where porcelain is used, it is always designed to be under compression.



Allowable variations		
	Over	Under
c	1/16"	1/8"
d	1/8"	1/16"

FIG. 10-10 Typical spool porcelain insulator for secondary rack. Material: porcelain. Finish: brown glazed. *(From Overhead Systems Reference Book.)*



Trade no	A	B	C	D	E	F	Strength in compression
502	3¼" f	1¾" f	7/16" c	2½" d	1¾" f	5/16" c	10,000 lb
504	3¾" f	2¼" f	9/16" c	2⅞" d	2⅛" f	⅜" c	12,000
506	5¼" f	3⅛" f	¾" c	3⅜" d	2⅜" f	½" c	15,000

Allowable variation		
	Over	Under
c	1/16"	1/16"
d	⅛"	⅛"
f	¼"	¼"

FIG. 10-11 Typical strain-ball-type porcelain insulator. Material: porcelain, wet process. Finish: brown glazed. *Note:* One end of insulator may be unglazed. *(From Overhead Systems Reference Book.)*

TEST VOLTAGES

Nominal ratings of insulators include not only their operating voltage, but flashover values as well. Flashover values depend in general on the leakage distances provided between the conductor and the point of attachment to the support. These values, however, may be subject to other factors, including local atmospheric and environmental conditions, types of support, maintenance programs, etc. Typical minimum flashover voltage values are contained in Table 10-4.

TABLE 10-4 TYPICAL FLASHOVER VOLTAGE REQUIREMENTS

Nominal voltage (between phases), kV	*Minimum rated dry flashover voltage of insulators, kV**
0.75	5
2.4	20
6.9	39
13.2	55
23.0	75
34.5	100
46.0	125
69.0	175

*Interpolate for intermediate values.

For current industry recommended values, refer to the latest revision of the National Electric Safety Code.

APPENDIX 10A
CONCRETE DISTRIBUTION POLES: REPRESENTATIVE SPECIFICATIONS*

SCOPE

These specifications apply to the manufacture of machine-made, pretensioned, prestressed concrete distribution poles, designed in accordance with recommendations of the American National Standards Institute (ANSI).

SHAPE

The poles shall be single, hollow, round or square cross section, with a taper of 1 to 150. They shall have a uniform nominal wall thickness of 1½ in as shown in Fig. 10-12.

DIMENSIONS AND STRENGTH

Round Poles

The dimensions and strength of the round poles shall be as shown in Table 10-5. The poles shall be grouped into seven classes based on the design ultimate strength as given in Table 5-22 in Chap. 5.

Square Poles

The dimensions and strength of the square poles shall be as shown in Table 10-6.

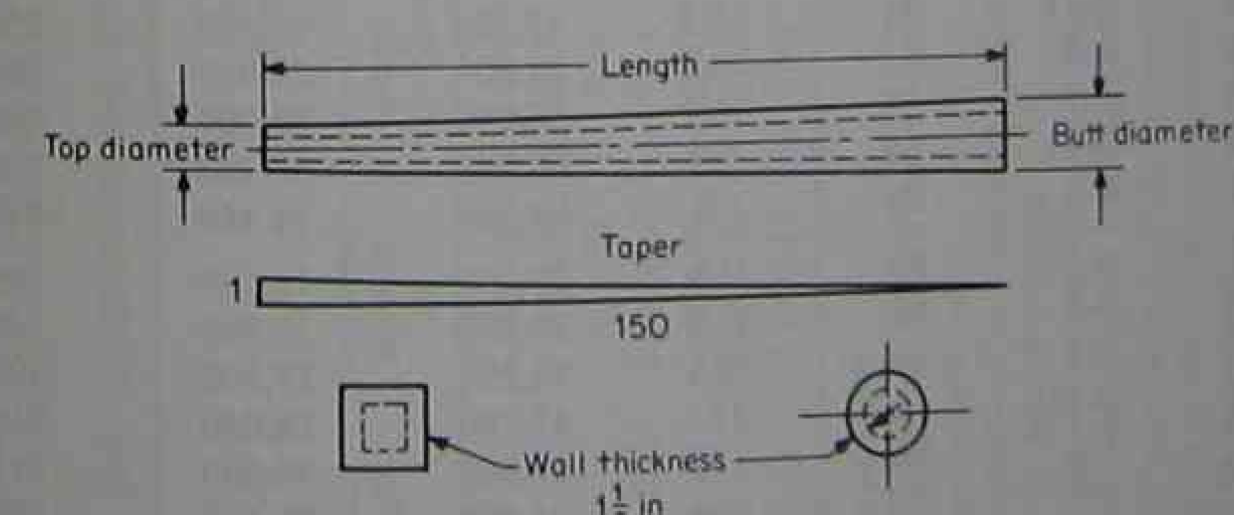


FIG. 10-12 Typical reinforced concrete hollow distribution pole. *(Adapted from Centrecon, Inc.)*

*Adapted from data furnished by Centrecon, Inc., and by Concrete Products, Inc.

TABLE 10-5 DIMENSIONS AND STRENGTHS—ROUND HOLLOW CONCRETE POLES

Overall length m	Overall length ft-in	Class	Setting depth, ft-in	Top diameter, in	Butt diameter, in	Design ultimate moment, ft · lb	Allowable moment—SF = 2, ft · lb	Nominal weight, lb
12	39-4	A	5-11	7½	13 13/16	100,530	50,260	2540
13	42-8	A	6-3	7½	14 3/16	110,130	55,060	2830
14	45-11	A	6-7	7½	14 13/16	119,470	59,730	3130
15	49-2	A	6-11	7½	15⅜	128,800	64,400	3470
16	52-6	A	7-3	7½	15⅞	138,400	69,200	3800
12	39-4	B	5-11	7½	13 13/16	84,830	42,410	2480
13	42-8	B	6-3	7½	14 3/16	92,930	46,460	2760
14	45-11	B	6-7	7½	14 13/16	100,800	50,400	3060
15	49-2	B	6-11	7½	15⅜	108,680	54,340	3380
16	52-6	B	7-3	7½	15⅞	116,780	58,390	3710
9	29-6	C	4-11	6 11/16	11 7/16	50,810	25,400	1520
10	32-10	C	5-3	6 11/16	11 13/16	57,560	28,780	1770
11	36-1	C	5-7	6 11/16	12 7/16	64,130	32,060	2010
12	39-4	C	5-11	7½	13 13/16	70,690	35,340	2430
13	42-8	C	6-3	7½	14 3/16	77,440	38,720	2710
14	45-11	C	6-7	7½	14 13/16	84,000	42,000	3000
15	49-2	C	6-11	7½	15⅜	90,560	45,280	3310
16	52-6	C	7-3	7½	15⅞	97,310	48,650	3640
9	29-6	D	4-11	6 11/16	11 7/16	41,780	20,890	1490
10	32-10	D	5-3	6 11/16	11 13/16	47,330	23,660	1720
11	36-1	D	5-7	6 11/16	12 7/16	52,730	26,360	1960
12	39-4	D	5-11	7½	13 13/16	58,120	29,060	2390
13	42-8	D	6-3	7½	14 3/16	63,670	31,840	2670
14	45-11	D	6-7	7½	14 13/16	69,070	34,540	2960
15	49-2	D	6-11	7½	15⅜	74,460	37,230	3260
16	52-6	D	7-3	7½	15⅞	80,010	40,000	3570
9	29-6	E	4-11	6 11/16	11 7/16	33,870	16,930	1470
10	32-10	E	5-3	6 11/16	11 13/16	38,370	19,180	1700
11	36-1	E	5-7	6 11/16	12 7/16	42,750	21,370	1930
12	39-4	E	5-11	7½	13 13/16	47,130	23,560	2360
13	42-8	E	6-3	7½	14 3/16	51,630	25,810	2640
14	45-11	E	6-7	7½	14 13/16	56,000	28,000	2930
15	49-2	E	6-11	7½	15⅜	60,380	30,190	3220
16	52-6	E	7-3	7½	15⅞	64,880	32,440	3530
9	29-6	F	4-11	6 11/16	11 7/16	27,100	13,550	1460
10	32-10	F	5-3	6 11/16	11 13/16	30,700	15,350	1680
11	36-1	F	5-7	6 11/16	12 7/16	34,200	17,100	1920
12	39-4	F	5-11	6 11/16	13	37,700	18,850	2160
13	42-8	F	6-3	6 11/16	13½	41,300	20,650	2410
14	45-11	F	6-7	6 11/16	14 1/16	44,800	22,400	2680
15	49-2	F	6-11	6 11/16	14 7/16	48,300	24,150	2960
9	29-6	G	4-11	6 11/16	11 7/16	21,450	10,720	1460
10	32-10	G	5-3	6 11/16	11 13/16	24,300	12,150	1670
11	36-1	G	5-7	6 11/16	12 7/16	27,080	13,540	1900
12	39-4	G	5-11	6 11/16	13	29,850	14,920	2150
13	42-8	G	6-3	6 11/16	13½	32,700	16,350	2400
14	45-11	G	6-7	6 11/16	14 1/16	35,470	17,730	2660
15	49-2	G	6-11	6 11/16	14 7/16	38,240	19,120	2930

Courtesy Centrecon, Inc.

TABLE 10-6 DIMENSIONS AND STRENGTHS—SQUARE HOLLOW CONCRETE POLES

Overall pole length, ft	Pole size—tip/butt, in	E.P.A., ft^2 — Concrete strength, lb/in^2: 6000, standard	E.P.A., ft^2 — Concrete strength, lb/in^2: 7000, when specified	Ultimate ground-line moment, ft · lb	Breaking strength load 2 ft. below tip, lb	Deflection per 100 ft · lb, in	Deflection limitations, ft · lb	Pole weight, lb
25	7.6/11.65	43.3	45.3	84,000	4540	0.03	4100	2260
30	7.6/12.46	38.7	40.7	132,000	5740	0.03	5000	2880
35	7.6/13.27	33.8	36.2	147,000	5350	0.03	5900	3600
40	7.6/14.08	29.4	31.7	163,000	5090	0.03	6800	4370
45	7.6/14.89	25.7	28.1	178,000	4880	0.06	3850	5225
50	7.6/15.70	22.3	24.7	193,000	4710	0.06	4300	6160
55	7.6/16.51	19.1	21.7	209,000	4590	0.06	4750	7270

Glossary of Terms

E.P.A. Effective projected area, in square feet of transformers, capacitors, streetlight fixtures, and other permanently attached items which are subject to wind loads.

Concrete strength This is a reference to the compressive strength of the concrete in pounds per square inch as measured by testing representative samples 28 days after casting.

Ultimate ground-line bending moment This is the bending moment applied to the pole which will cause structural failure of the pole. This is the result of multiplying the load indicated in the column Breaking Strength by a distance 2 ft less than the pole height (i.e., 2 ft less than the length of pole above ground). Figures under Ultimate Ground-Line Moment assume embedment of 10 percent of the pole length plus 2 ft. The figures in this column on technical charts are maximum moments expected to be applied to the pole. Appropriate safety factors should be used by the designer.

Breaking strength This is the approximate load which, when applied at a point 2 ft below the tip of the pole, will cause structural failure of the pole.

Ground line The point at which an embedded pole enters the ground or is otherwise restrained.

Deflection The variation at the tip of the pole from a vertical line resulting from the application of loads such as equipment, wind, ice, etc.

Ground-line bending moment The product of any load applied at any point on the pole multiplied by its height above ground line.

Dead loads This refers to the load on a pole resulting from the attachment of transformers and other equipment permanently.

Live loads These are loads applied to the pole as a result of wind, ice, or other loads of a temporary nature.

Ultimate Strength

The design ultimate strengths are determined to meet the working strength requirement of wood poles in accordance with the ASA *Specifications and Dimensions for Wood Poles*. The factor of safety of 2 shall be used for prestressed concrete poles.

COLORS AND FINISHES

The poles shall be furnished in colors and finishes specified by the buyer. Colors shall be white, gray, buff, green, brown, and black. Finishes shall be Mold Finish; Natural Aggregate, exposed or polished; or Terrazzo Aggregate, exposed or polished. Other finishes will be furnished on request.

MATERIALS

Cement

The cement used for the concrete shall be portland cement, type I, II, or III, conforming to ASTM designation C-150.

Aggregates

The concrete shall be made with fine and coarse aggregates conforming to ASTM designation C-33.

The fine aggregates shall be graded from $\frac{3}{8}$ in to no. 100 sieve, with 100 percent passing the $\frac{3}{8}$-in sieve and not more than 10 percent passing the no. 100 sieve.

The maximum-size coarse aggregate shall not exceed one-fifth of the minimum dimension of the member nor three-fourths of the clear spacing between the prestressed wires. The maximum size of coarse aggregate to be used shall conform to the smaller of the two limitations mentioned above.

Water

The water used for mixing concrete shall be clean and free of injurious quantities of substances (acid, alkalines, oil, and vegetable matter) deleterious to concrete or to prestressing steel.

Admixture

The admixture used for the concrete shall conform to ASTM C-494, and shall not contain more than a trace of calcium chloride.

Reinforcement

The prestressing steel wire shall conform to ASTM A-421 with the strengths as noted in the following table.

Diameter	*Yield strength*	*Tensile strength*
9 mm (0.354 in)	192,000 lb/in²	220,500 lb/in²
7 mm (0.276 in)	177,000 lb/in²	206,200 lb/in²

The reinforcing steel wire used for main reinforcement and spiral reinforcement shall conform to ASTM A-82.

Embedded Materials

The embedded materials, such as sleeves for through holes, sockets for step bolts, and other inserts, will be corrosion-resistant and weatherproof.

GENERAL REQUIREMENTS

Design Ultimate Strength

The design ultimate strength for each class of pole shall be as given in Table 5-22 (in Chap. 5) for round poles and in Table 10-6 for square poles.

Through Holes

The through-hole spacing and sizes for framing shall be as shown in Fig. 10-13*a*, *b*, and *c* for round poles and Fig. 10-14 for square poles.

Step Bolts

Each pole may have provisions (if specified) for installing step bolts to gain access to, and perform work on, the poles as shown in Fig. 10-13*a*, *b*, and *c* as well as Fig. 10-14.

Grounding Wire Exits

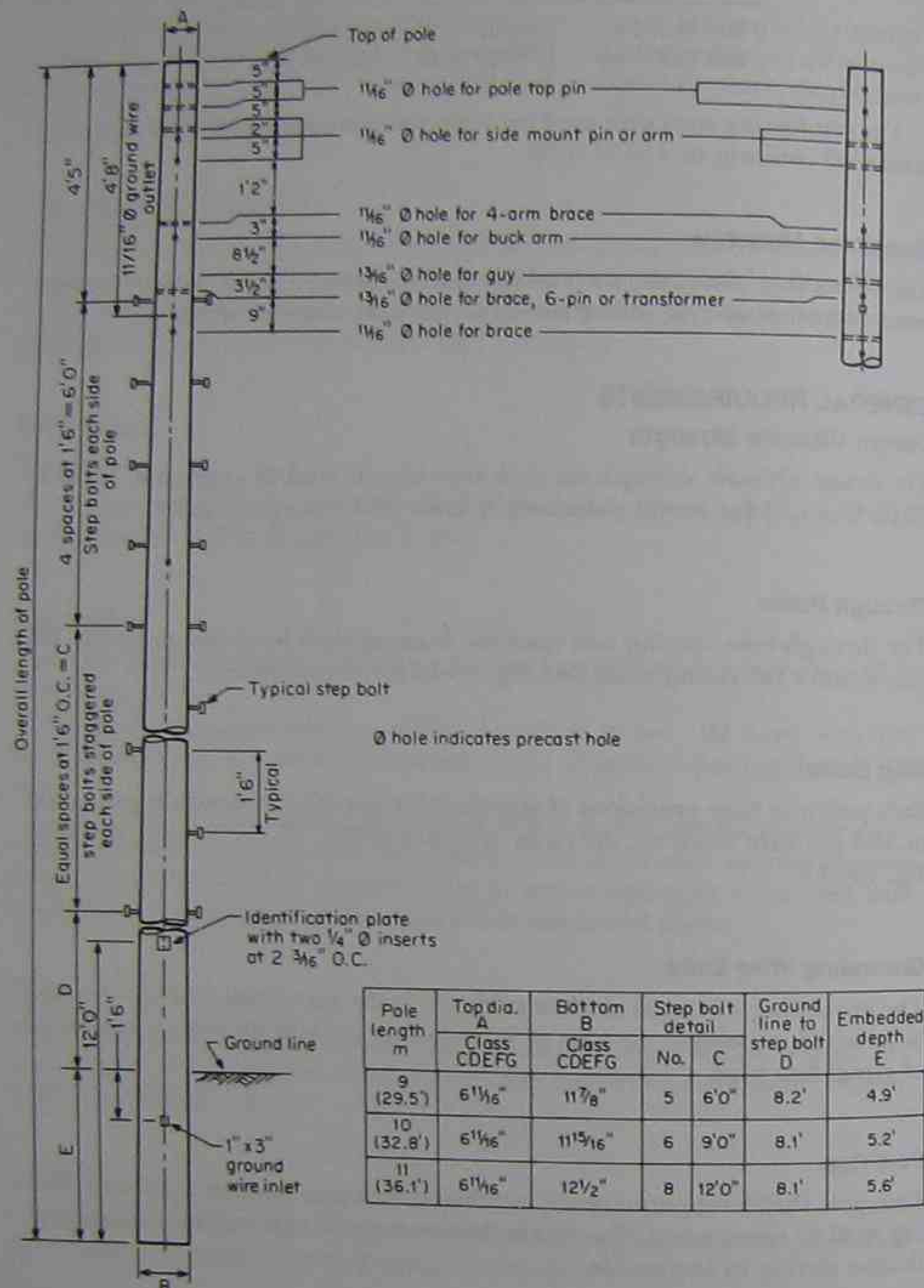
The grounding wire exits shall be as shown in the specifications. Fish wire shall be attached to poles at the time of manufacture to facilitate ease in installation of grounding wire.

Pole Cap

Each pole shall have permanently attached to its top an insulating pole cap. This cap shall be constructed of a nonconductive material that will not become conductive during its service life.

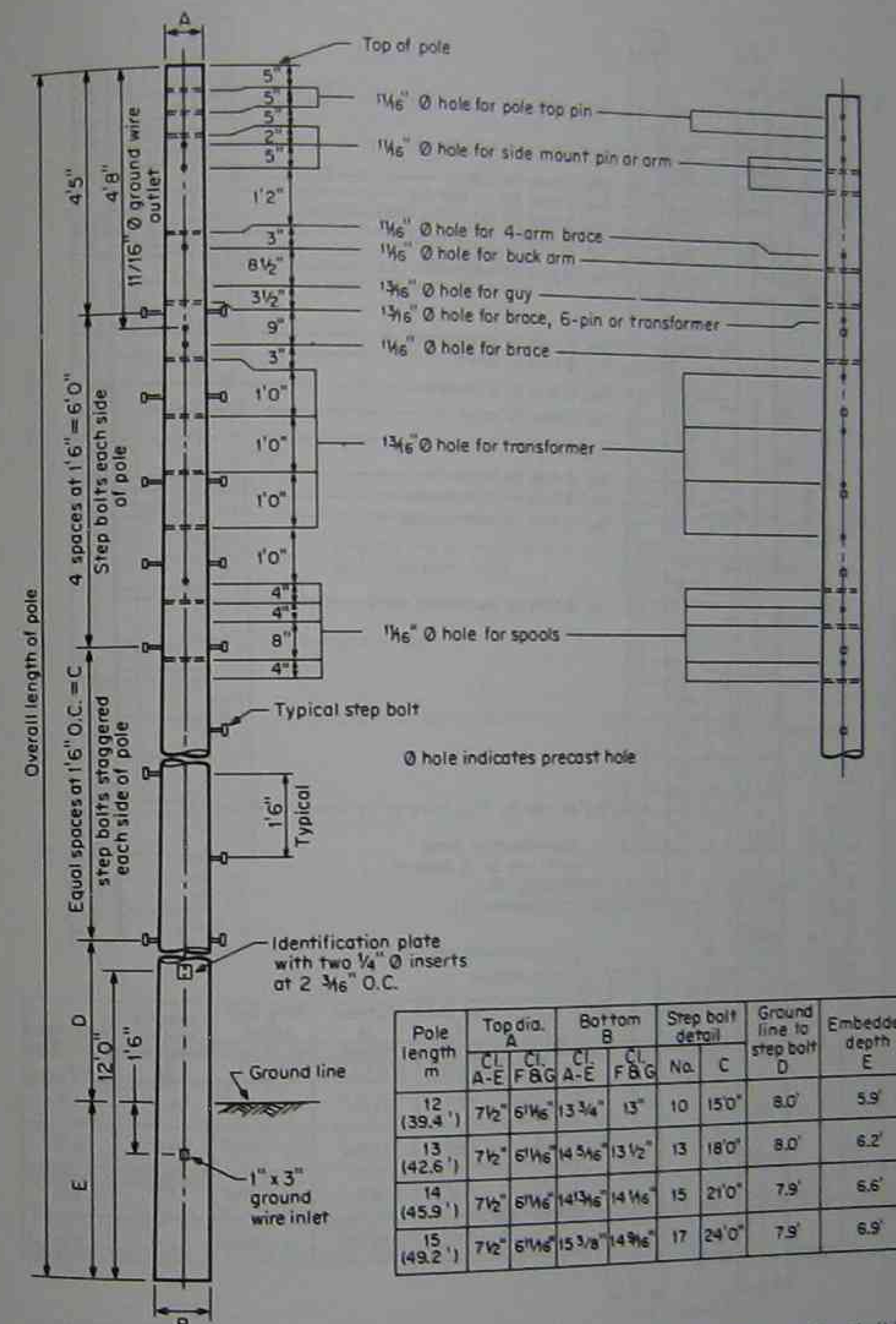
Butt Cap

Each pole manufactured under this specification shall have permanently attached thereto a concrete butt cap.



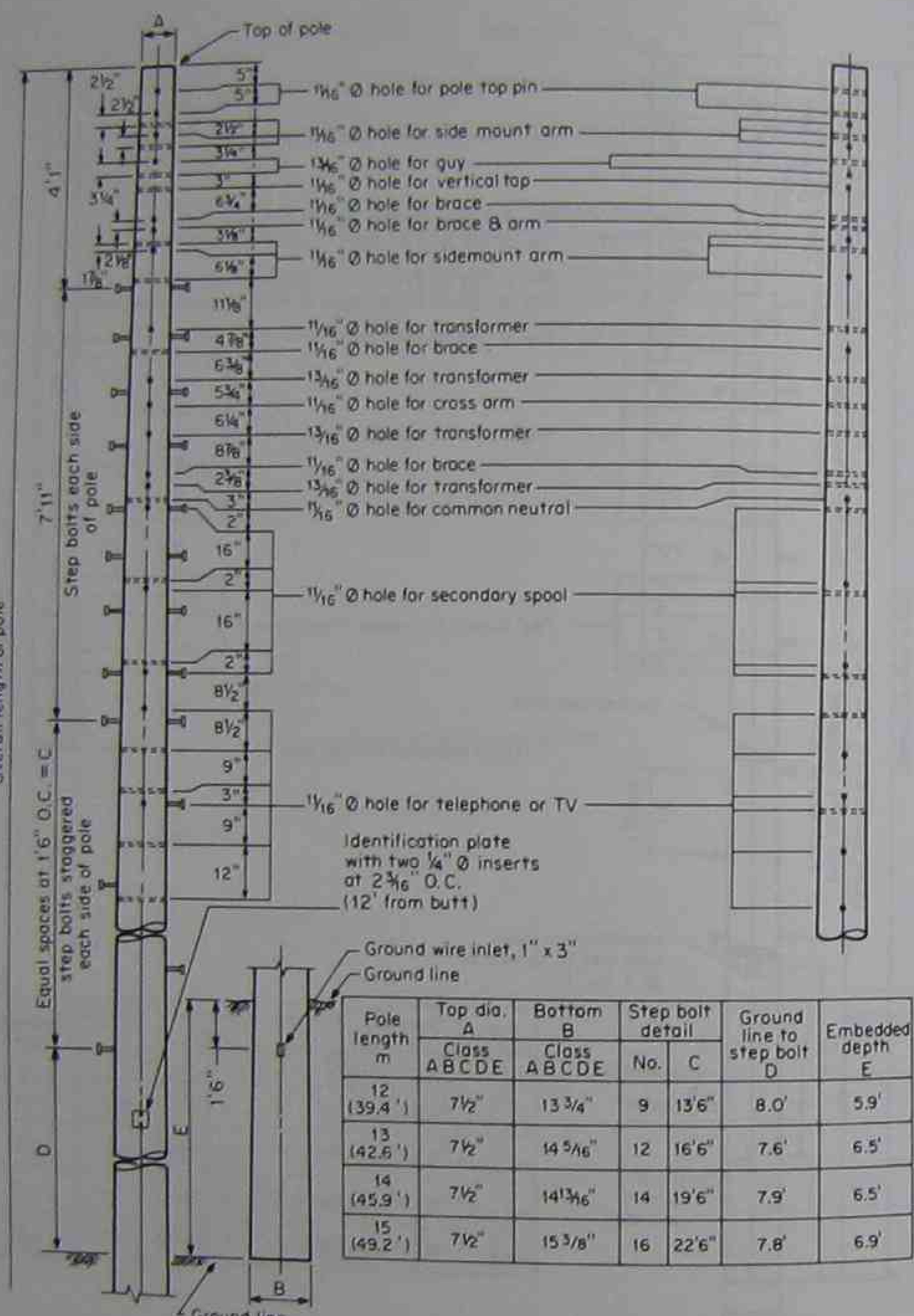
Pole length m	Top dia. A	Bottom B	Step bolt detail		Ground line to step bolt D	Embedded depth E
	Class CDEFG	Class CDEFG	No.	C		
9 (29.5')	6 11/16"	11 7/8"	5	6'0"	8.2'	4.9'
10 (32.8')	6 11/16"	11 15/16"	6	9'0"	8.1'	5.2'
11 (36.1')	6 11/16"	12 1/2"	8	12'0"	8.1'	5.6'

FIG. 10-13 Reinforced concrete round hollow distribution pole. Pole steps optional. (*a*) Use of top third of upper part of pole. *(Courtesy Centrecon, Inc.)*



Pole length m	Top dia. A		Bottom B		Step bolt detail		Ground line to step bolt D	Embedded depth E
	Cl. A-E	Cl. F&G	Cl. A-E	Cl. F&G	No.	C		
12 (39.4')	7½"	6 11/16"	13 3/4"	13"	10	15'0"	8.0'	5.9'
13 (42.6')	7½"	6 11/16"	14 5/16"	13 1/2"	13	18'0"	8.0'	6.2'
14 (45.9')	7½"	6 11/16"	14 13/16"	14 1/16"	15	21'0"	7.9'	6.6'
15 (49.2')	7½"	6 11/16"	15 3/8"	14 9/16"	17	24'0"	7.9'	6.9'

FIG. 10-13 Reinforced concrete round hollow distribution pole. Pole steps optional. (*b*) Use of top two-thirds upper part of pole. *(Courtesy Centrecon, Inc.)*



Pole length m	Top dia. A	Bottom B	Step bolt detail		Ground line to step bolt D	Embedded depth E
	Class ABCDE	Class ABCDE	No.	C		
12 (39.4')	7½"	13 3/4"	9	13'6"	8.0'	5.9'
13 (42.6')	7½"	14 5/16"	12	16'6"	7.6'	6.5'
14 (45.9')	7½"	14 13/16"	14	19'6"	7.9'	6.5'
15 (49.2')	7½"	15 3/8"	16	22'6"	7.8'	6.9'

FIG. 10-13 Reinforced concrete round hollow distribution pole. Pole steps optional. (c) Use of top full upper part of pole. *(Courtesy Centrecon, Inc.)*

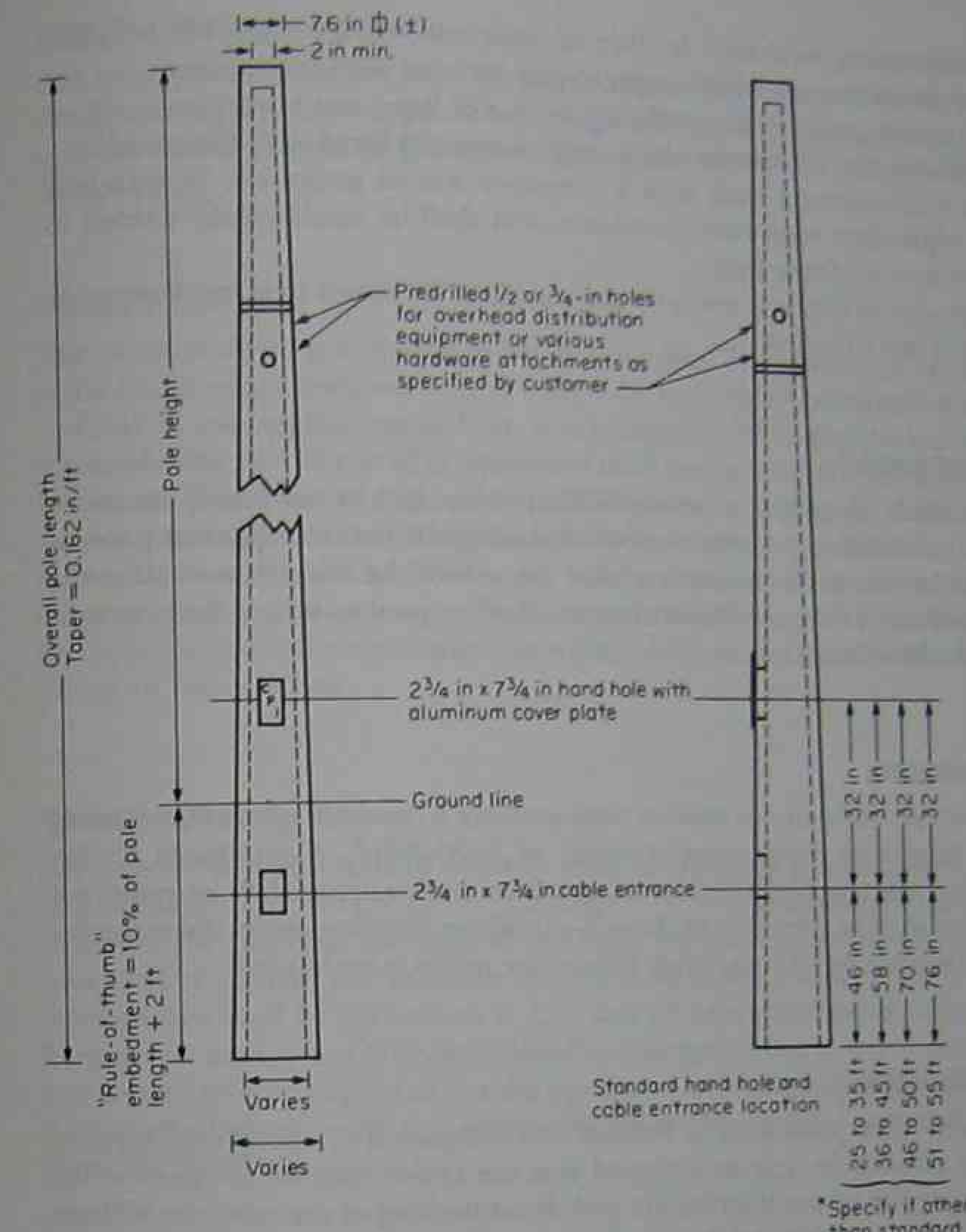


FIG. 10-14 Reinforced concrete square hollow distribution pole. *(Courtesy Concrete Products, Inc.)*

Cable Entrance

These poles shall be furnished with cable entrance opening, hand hole, and hollow core or PVC raceway for use with underground wiring.

MANUFACTURE

Placement of Steel Reinforcement

All prestressing steel and reinforcing steel shall be accurately positioned and satisfactorily protected against the formation of rust or other corrosion prior to placement to the concrete.

All prestressing steel shall be free of loose rust, dirt, grease, oil, or other lubricants or substances which might impair its bond with the concrete.

All unstressed reinforcing steel shall be free of loose rust, dirt, grease, oil, or other lubricants or substances which might impair its bond with the concrete.

Spiral reinforcement shall have a minimum size of gauge no. 11 with 6-in pitch, or equivalent steel ratio in volume, and shall be mechanically welded to the unstressed reinforcement.

The amount of concrete cover on the outside of the major steel reinforcement shall be not less than $\frac{3}{8}$ in.

Embedded Items

Sleeves, sockets, inserts, or other embedded items shall be accurately set in the molds and secured to prevent movement during the concrete placing process. They shall be cast in the concrete so that the axis of the insert is normal to the outside surface of the pole. Particular care shall be used to insure proper cover on all embedded items.

Mixing Concrete

The proportions of water to cement shall produce a concrete after steam curing having a minimum compressive strength of 3500 lb/in². A minimum 28-day compressive strength of 6000 lb/in² after atmospheric curing shall be required.

Concrete shall be mixed until there is a uniform distribution of the materials and shall be discharged completely before the mixer is recharged.

Placing Concrete

Round Poles The poles shall be formed and compacted by centrifugal force in a machine of suitable type so designed that the molds may be revolved at the required speed to insure distribution and dense packing of the concrete without the creation of voids behind the reinforcing steel.

Metal molds shall be used which shall be adequately braced and stiffened against deformation under pressure of the wet concrete during spinning. They shall also be sufficiently rigid to take the prestressing force without allowing deformation, which will reduce the spinning speed.

Filling the mold and spinning shall be a continuous operation and the spinning shall take place before any of the concrete in the mold has taken an initial set. Excess water forced to the center of the mold during the spinning cycle must be drained in a suitable manner.

Square Poles Square poles shall be cast in steel molds which are true to shape and line.

Concrete shall be poured in one continuous operation while being vibrated with high-frequency vibration to achieve consolidation and insure high density.

Applying Prestressing Force

The intial prestressing force shall be the smaller of 70 percent of tensile strength or 80 percent of yield strength. Tensioning shall be carried out in such a manner that the initial prestressing force shall vary no more than ±5 percent from design value.

Concrete Curing

The poles shall be cured with low-pressure steam for as long as necessary to reach the strength required by the design for transfer of prestressing force.

Prior to the application of heat, a minimum initial setting period of 2 h is required. The rate of rise of temperature shall not exceed 20°F per hour during the second 2 h of the curing cycle nor 60°F per hour during the third 2 h. The maximum temperature shall not exceed 175°F. Fresh concrete shall be protected so as to be free from rain, hot sun, or wind and rapid loss of moisture prior to the start of the steam-curing cycle. Temperature and moisture for each steam-curing cycle shall be continuously controlled and recorded to ensure the adequate curing of the concrete.

Concrete Testing

Samples for strength tests of concrete shall be taken not less than once each day in accordance with ASTM C-172. Standard 4- × 8-in test cylinders shall be used to insure the required strength of products. Standard cylinders for acceptance tests shall be molded and laboratory-cured in accordance with ASTM A-39. Each strength test shall be performed at 1, 7, and 28 days after casting. The strength level of the concrete will be considered satisfactory if the averages of all sets of two consecutive strength test results equal or exceed the required strength and if no individual strength test result falls below the required strength by more than 500 lb/in².

Bending Test

A bending strength test of a pole shall be performed in order to assure that the pole meets the minimum structural strength requirements in accordance with specifications.

Manufacturing Tolerance

1. Length: $\pm\frac{3}{8}$ in per 10 ft of length
2. Outer dimension: $+\frac{3}{16}$ in, $-\frac{1}{8}$ in
3. Wall thickness: $-\frac{1}{8}$ in
4. Deviation from straight line: not more than $\frac{1}{8}$ in per 10 ft of length

5. Location of reinforcement: main reinforcement cover, ±⅛ in; spacing of spiral, +¼ in
6. Location of embedded items: ±⅛ in

Workmanship

All poles shall be unpolished but free of burrs, chips, holes, excess cement, and other surface irregularities. All poles shall present a straight and symmetrical appearance after erection. Crooks, curvatures, and twisting edges shall be prohibited. All raceway openings to cable entrance and hand holes shall be free of burrs, cement, or aggregate. Any surface roughness or obstructions that would injure or harm the insulation of electrical cables under normal installation or operating procedures will be prohibited.

Quality Control

Manufacturing procedures and quality control shall follow the recommendations of the Prestressed Concrete Institute.

CHAPTER 11

TRANSFORMERS, CUTOUTS, AND SURGE ARRESTERS

TRANSFORMERS

The transformer, one of the most efficient pieces of electrical apparatus (usually better than 98.5 percent efficient), having no moving parts, transfers electric power from one circuit to another magnetically; in the process, it enables changes to be made in the voltage (and current) output. It is this latter characteristic that has enabled the development of economically feasible ac systems.

While output voltage values may thus be stepped up (at power plants and transmission substations), they can also be stepped down to values suitable for distribution purposes. The first such transformation takes place at the distribution substation, where incoming transmission line voltages are stepped down to primary feeder voltage values. A second transformation takes place at the distribution transformer connected to the primary feeder; here, the voltage is further reduced to values suitable for utilization at the consumer's premises.

Main Parts

Transformers consist essentially of two windings, insulated from each other, wound around a common core usually made of steel and having excellent magnetic properties. The assembly is contained in a steel tank and submerged in an insulating coolant, usually an oil of high dielectric strength. The electric leads connecting the coils to their respective circuits are passed through the tank by bushings made of porcelain or plastics. The dielectric values of the insulations of the several components are deliberately so scaled between them that voltage surges which may cause damage will cause failure to occur at the bushings, a point which can be readily discovered and repaired or replaced at relatively minor cost. More detailed discussion of this insulation coordination is contained in Chap. 4.

Core Types Cores may be of the *shell* type or *core* type. In the first, the steel core surrounds the windings; though providing a better magnetic circuit, the units become larger and heavier, and are usually restricted to the larger-size transformers generally found in substations and in underground network units; they are usually polyphase units.

In the core type, the windings surround the steel core, resulting in a more compact, smaller unit, generally more suitable for the sizes of transformers associated with overhead and radial primary distribution systems; these are almost always single-phase units.

Windings Windings are usually designed to have the requisite number of turns take up the minimum amount of space, to sustain the forces set up when large or short-circuit currents flow in them, and to allow space for the cooling medium to transfer the heat created to the tank and atmosphere. They are also designed electrically to produce an optimum combination of I^2R losses and IZ impedance drops (IR resistance and IX reactance voltage drops).

In core-type transformers, the low-voltage winding is usually placed next to the core and the primary winding outside and next to the secondary winding, requiring only one high-voltage insulation between the two windings and the core. In shell-type transformers, the primary and secondary windings consist of a number of pancake-shaped coils connected in series, but the primary and secondary "pancake coils" are placed alternately around the core; the arrangement reduces the reactance between windings and provides better cooling paths for heat dissipation.

Polarity In a transformer, the vector relationship between the primary and secondary voltages depends on the way the windings are wound in relation to each other. To identify this relationship, if both windings are connected in series, as in an autotransformer, the voltage in the secondary can add to or subtract from the primary voltage. Where the primary and secondary voltage vectors are in opposite directions, the transformer is said to have *additive* polarity; where the vectors are in the same direction, the transformer is said to have *negative* or *subtractive* polarity. These polarities are shown in Fig. 11-1.

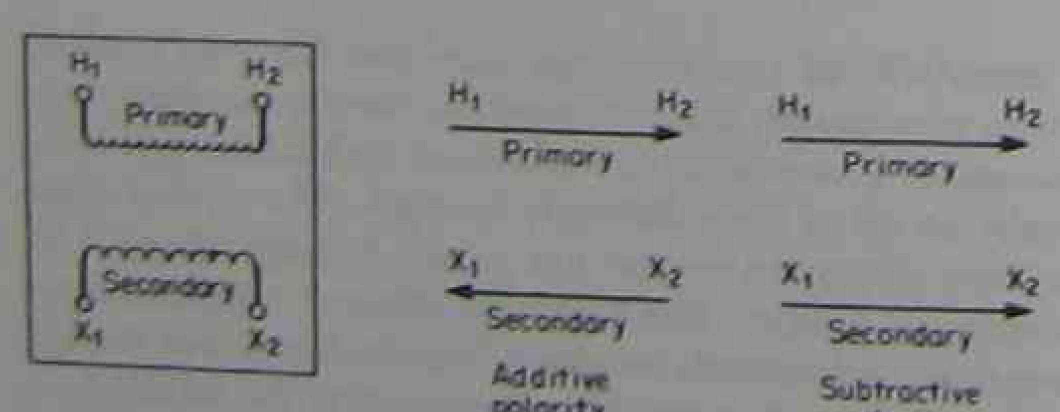


FIG. 11-1 Polarity of a transformer.

Since transformers are connected in parallel with each other, or in polyphase banks, it is essential that the terminals be connected so that the proper voltage relationships ensue. The polarity marks or designations provide the means of accomplishing this. Primary terminals are marked H_1, H_2, H_3, etc., while the secondary terminals are marked X_1, X_2, X_3, etc. See Fig. 4-6*a* through *k* in Chap. 4 for transformer connections using these markings. In these standardized designations, the H_1 (primary) and X_1 (secondary) terminals in a transformer having subtractive polarity will be on the *left* when the observer faces the low-voltage bushings; for an additive-polarity transformer, the X_1 (secondary) terminal only will be on the *right* when the observer faces the low-voltage bushings. Standards of the ASA call for distribution transformers rated up to 200 kVA and voltages below 8600 V to have additive polarity, and those above these values to have subtractive polarity; the polarity is usually specified on the transformer nameplate.

DISTRIBUTION TRANSFORMERS

Distribution transformers may be installed on poles, on the ground on pads, and under the ground directly or in manholes and vaults. The transformers used in these types of installations differ mainly in their packaging, as the internal operating features are very much the same.

Overhead Transformers

The overhead type of distribution transformer is mounted directly on a pole by means of two lugs, welded to the transformer tank, that engage two bolts on the pole, as shown in Fig. 11-2*a*; this is known as *direct mounting*, in contrast to older methods in which the transformer was bolted to a pair of hanger irons that were hung over a cross arm. Where more than one transformer is required, as in power banks, the transformer lugs engage studs on a bracket which is bolted, like a collar, around the pole; the units form a cluster around the pole, from which the term *cluster mounting* is derived; see Fig. 11-2*b*.

Where the load (weight) of the transformer or transformers may be too great for the pole, they may be placed on a platform erected between two or more poles in a structure, or they may be placed on a protected ground-level pad.

Pad-Mounted Transformers

Transformers may be mounted on concrete pads at, or slightly below, ground level within an enclosure or compartment that may be locked for protection. These are generally installed as part of so-called underground residential distribution (URD) systems, where appearance is a major consideration; refer to Fig. 6-19 in Chap. 6.

The transformers may have their energized terminals exposed when the compartment is open, or the terminals may be mounted behind an insulating barrier and connections from the cables made through bayonet-type connections on insulated elbows which are plugged into jacks connected to the terminals;

these units are referrred to as *dead-front* units and provide an additional margin of safety. Refer to Figs. 6-18 and 6-19 in Chap. 6.

Underground Transformers

In the underground type of transformer, also called the subway type, the tank is not only hermetically sealed for water tightness, but its walls, bottom, and cover are made thicker to withstand higher internal and external pressures; the cover is bolted to the tank (with intervening gaskets) by a relatively large number of bolts, and in some instances, welding is used. These units are designed to operate completely submerged in water.

In larger units, where cooling of the tank itself is not sufficient, radiator fins are welded to the tank to provide additional cooling surface, or pipes are welded to the tank for the circulation of oil through them; in the latter case, the additional surface of the pipes as well as the circulating oil is useful for cooling.

Connections to the supply cables are made by means of watertight wiped joints between a fluid-tight bushing and the cable sheath. Another means provides for the making of connections in a chamber attached to the transformer tank in which the primary-voltage transformer windings are brought out in fluid-tight bushings. In some units, this chamber also houses high-voltage disconnecting and grounding switches.

Where these units supply low-voltage secondary networks, they also house the network protector in another watertight compartment, usually situated at the opposite end of the transformer tank from the primary connection and switch chamber. Refer to Fig. 6-4 in Chap. 6.

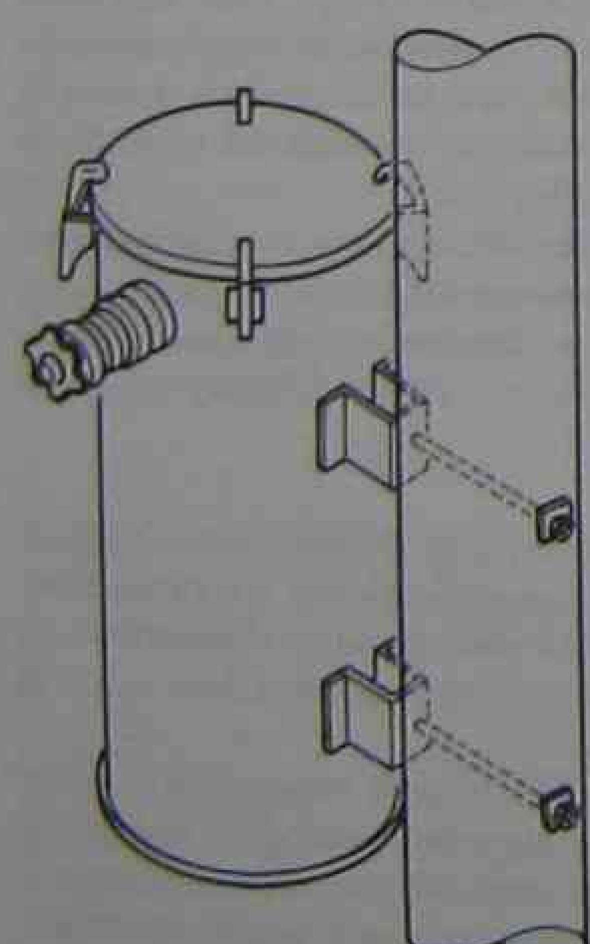


FIG. 11-2 (*a*) Direct pole mounting of a transformer *(Courtesy Westinghouse Electric Co.)*

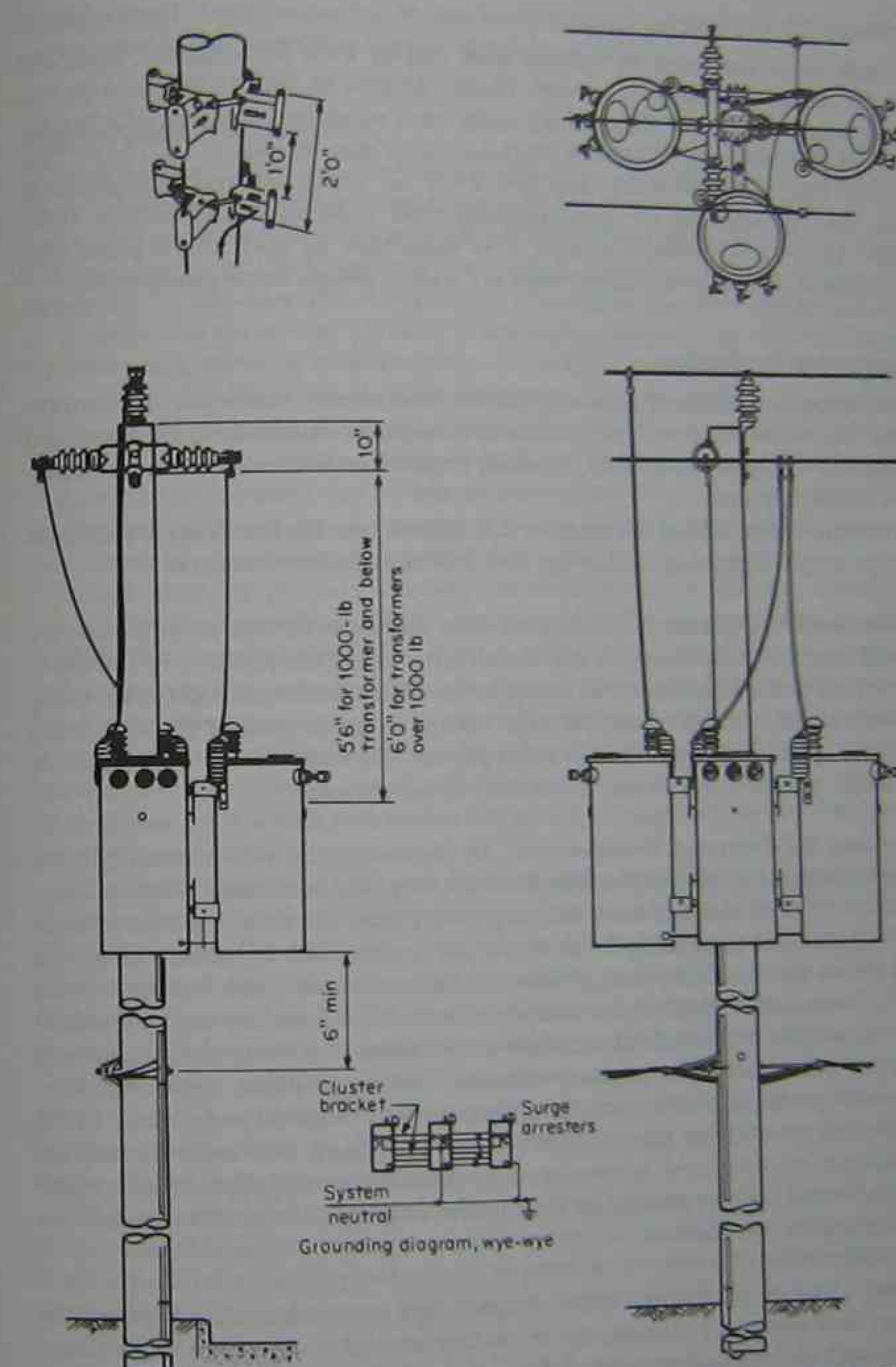


FIG. 11-2 (*b*) Cluster mounting of transformers. *(Courtesy Long Island Lighting Co.)*

Ratings

Transformers are rated by voltage class and in kVA for capacity. Standard voltage classes are 2400, 4160, 7620, 13,200, 23,000, 34,500, 46,000, and 69,000 V for single-phase and three-phase units, with secondary voltages of 120/240, 120/208, 240/480, and 277/480 V. Standard sizes may include 5, 10, 15, 25, 37½, 50, 75, 100, 167, 250, 333, and 500 kVA for overhead and pad-mounted units, and in addition to these, underground units may also include 667-, 1000-, 1500-, and 3000-kVA units. The units may be both single-phase and three-phase, although the larger sizes are almost always three-phase units.

Transformer Protection

Distribution transformers generally fall into two broad classifications: "conventional," in which the protective devices are mounted externally to the unit; and completely self-protected (CSP), in which protection devices are included inside the transformer tank.

Protection is provided the transformer against overload or failure, and from voltage surges (lightning, switching) that may damage the insulation.

Conventional Transformers Associated with the conventional transformer are a fused cutout which separates the transformer from the primary in the event of overload or the failure of some component of the transformer, and a lightning or surge arrester which bleeds the high-voltage surge to ground before it has a chance to damage the insulation or other parts of the transformer. Fused cutouts and surge arresters will be discussed later in this chapter.

Completely Self-Protected Transformers In the completely self-protected transformer, the primary fuse is situated within the case, and because its characteristics are different from those of the external primary fuse, it is referred to as a "weak link." Additional protection from overloads is provided by means of circuit breakers on the secondary side, which coordinate with the weak link; i.e., in the event of overload or fault on the secondary main, the secondary circuit breakers open before the weak link blows. The surge arrester is mounted outside the tank, but connected to its primary terminal. For single-phase units on a wye-grounded system, therefore, only one connection is required to be made to the primary line; this makes for a simpler, neater-appearing, and more economical mounting of transformers. Moreover, these units are also equipped with a warning light which may be seen from the ground and which indicates the unit has been thermally overloaded.

Grounds In a grounded wye system employing a common neutral for both the primary and secondary systems, the secondary neutral is connected to the transformer tank and the tank grounded. For safety purposes, a second visible ground conductor is connected between the neutral terminal and the neutral conductor of the secondary mains.

Similar protection is provided for ground-level or pad-mounted transformers. Surge protection is usually not required for transformers installed underground, although exceptions are made where such transformers are installed close to underground risers connected to overhead systems; surge arresters may then be installed at the transformer or at the pole, or both.

Single-Phase Transformers

Most of the distribution transformers in service are single-phase units supplying single-phase loads directly or supplying polyphase loads in banks of two or three units. The secondary winding is usually divided into two equal parts, each part having a voltage of 120 V between its terminals. The two parts may be connected in parallel for two-wire 120-V operation, in series for two-wire 240-V operation, or in series for three-wire 120/240 V operation; refer to Fig. 4-6*a* in Chap. 4. In older units, the four leads from the two parts of the secondary winding were brought outside the tank through insulated bushings, and connections were made outside the tank; in more recent construction, the connections of the parts are made inside the tank and only those leads are brought out that the circuit requires. In many cases, the middle or neutral lead is not brought out through an insulated bushing, but is connected to a stud on the tank which also serves as a means of grounding the transformer tank.

Leads from the primary winding are brought out of the tank through insulated bushings usually made of porcelain of sufficient dimensions to accommodate the intended primary supply voltage. Where the primary supply is a delta-connected or ungrounded wye circuit, the leads employ two bushings. Where the primary supply is a grounded wye circuit, only one lead is brought out through a porcelain bushing; the other lead is connected to the tank and brought out by means of a stud, which may also be connected to the secondary neutral lead, and which also serves for making connection to the distribution-circuit neutral conductor.

(It is most important that care be exercised when connecting or energizing single-bushing transformers, or any transformer with one end of the primary coil connected to the transformer tank, to make *absolutely* certain that the ground connections on the tank of the transformer are made to the system neutral *first*. Failure to do so could lead to energizing the transformer tank at line voltage, jeopardizing the safety of anyone working at or near that transformer.)

Single-phase units may also be used to supply two-phase and three-phase loads from a polyphase primary supply; they may also be used as boosting or bucking transformers in single-phase primary supply circuits; connections are shown in Fig. 4-6*a* through *k* in Chap. 4.

The primary windings may also be furnished with taps which permit changes in the transformation ratio to accommodate the need for a fixed raising or lowering of the secondary voltage, or to provide for phase transformation from three-phase to two-phase (or vice versa) as noted previously.

Polyphase Transformers

In polyphase (usually three-phase) transformers, the connections between the phase windings on both the primary and secondary sides are made within the tank of the transformer, and the leads are brought out through porcelain bushings. Whether connected for delta or wye and whether on the primary or secondary side, three leads are brought out on each side. In most instances where a grounded wye circuit is involved, the neutral is brought out through a stud connected to the transformer tank, as mentioned previously for single-phase units. In the relatively few instances where ungrounded wye circuits are involved, the "neutral" or common junction point is brought out through a fourth porcelain bushing.

Taps on the primary side are also furnished to permit the same changes in ratio of transformation as were described for single-phase transformers.

Transformer Cooling

Most distribution transformers, whether overhead, pad-mounted, or subway types, have their cores and coils submerged in insulating oil. The heat produced by the iron and copper losses is carried by convection currents in the oil to the tank and there dissipated into the atmosphere. Excessive temperatures and the formation of hot spots are thus prevented, avoiding damage to the insulation and conductors.

Moisture and sludge formed from the effect of the oxygen in the air on hot oil tend to reduce the dielectric quality of the oil.

Where the use of oil is undesirable, principally because of fire hazard, air-cooled or askarel-cooled units may be employed, although these are generally limited to larger sizes and to transformers installed in vaults. Askarels, although nonflammable, are heavier, less effective coolants, and more expensive than oil; they are also environmentally undesirable, containing carcinogenic PCB compounds, and are extremely irritating to eyes and skin.

Transformer Impedance

Transformer nameplate data also include the impedance of the transformer expressed as a percentage of its nominal rated voltage. This information is important when transformers are connected in parallel, or in polyphase banks, as units of different impedances will not share the load equitably and will cause circulating currents producing unnecessary heating when connected in banks; refer to Chap. 4 for additional discussion.

FUSE CUTOUTS

Distribution transformers (of the conventional type) are usually connected to the primary supply lines through a fuse cutout. The cutout contains a fusible element (a link) whose melting automatically disconnects the transformer from the primary to prevent damage from overloads; it also disconnects the line from the transformer in the event of a fault in the transformer, not only preventing spread of damage in the faulted transformer, but also preventing interruption to the primary supply circuit that would affect other transformers and consumers served from that circuit.

Fuse cutouts are also used to disconnect faulted or overloaded parts of a primary circuit from the remaining unfaulted portion of the circuit.

The size of the fuse is generally based on the size of the transformer or load on the primary section it is to protect.

For voltages of 5000 V or lower, the fuse element, enclosed in a fiber tube, is mounted inside a porcelain box, engaging the two contacts at the top and bottom of the box. The fuse is usually mounted on the door of this box, which is hinged at the bottom; in some models, the melting of the fuse causes the door to drop open as an indication that the fuse has blown. See Fig. 11-3*a*.

For voltages above 5000 V, the fuse element is mounted in the open between two contacts at either end of an insulating porcelain support, as shown in Fig. 11-3*b*. The tube containing the fuse drops when the fuse melts, indicating that the fuse has blown. For obvious reasons, this type is known as an open-type cutout.

The design of fuse cutouts should take into consideration the voltages which will be applied to them and the currents that will flow through them. As the currents that may flow under fault conditions may be of rather large magnitude, the fuse cutouts should be strong enough to withstand the resultant forces without damage to themselves or to surrounding objects.

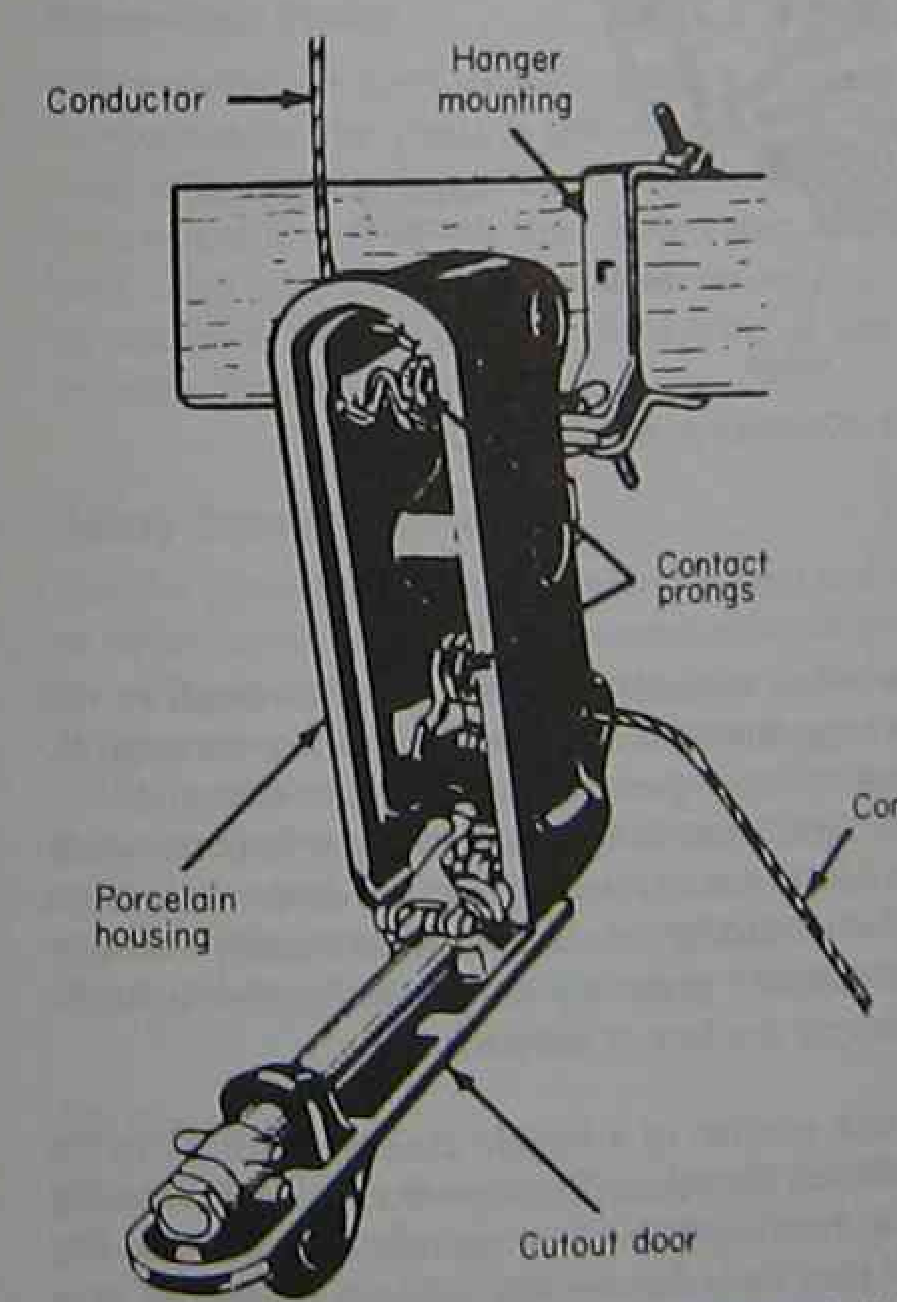


FIG. 11-3 (a) Door-type fuse cutout. *(Courtesy A. B. Chance Co.)*

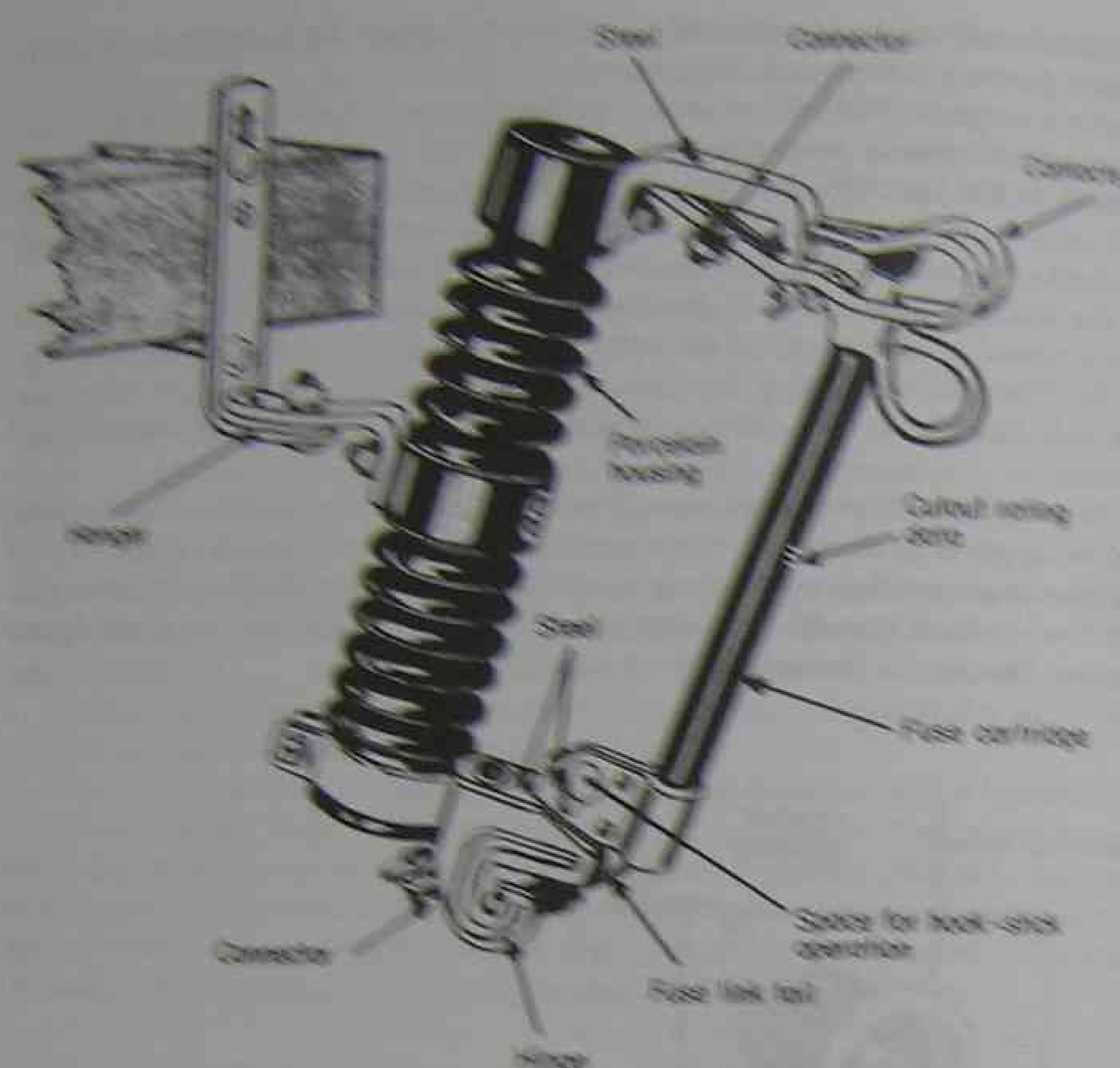


FIG. 11-8 (b) Open-type fuse cutout. (Courtesy A. B. Chance Co.)

Fuses

A fuse is a fusible link that melts when excessive current flows through it, the time of melting varying with the magnitude of the current flowing through it. Further description and discussion of fuse operation are given in Chap. 4.

Fuses for different applications are of several types; those used in connection with the primaries of distribution feeders and transformers are of the expulsion type. These contrast with the open or link types used with secondary voltages and the filled-type fuses of large capacity generally used with higher voltages such as are found on incoming supply feeders at substations.

Expulsion-Type Fuses The fuse link consists of a fusible element with a cap on one end and a flexible stranded cable on the other. The fuse fits into an insulating tube, usually of fiber, with the cap holding it in place on one end and making contact with the nut or fitting at that end; the flexible cable is held taut by a spring or by being wound around a stud and held in place by a knurled nut. The assembly is fitted between the stationary terminals of the cutout.

The minimum time required to melt the link is determined by the composition and dimensions of the link. At the primary voltages involved, however, an arc will persist between the ends of the melted link. The rapid expansion of the surrounding air confined in the tube will tend to blow out the arc; the heat acting on the fiber will also produce a gas under pressure, aiding in extinguishing the arc. The mounting or enclosure of the fuse, therefore, will determine the length of time to extinguish the arc. The clearing time of the fuse will be the sum of these two times, the melting time and the arc-extinguishing time. Hence, the fuses are rated on their voltage class, their normal current-carrying capacity, and a time-current relationship expressed as fast or slow (e.g., type K, type T, etc.; refer to Chap. 4).

In the open-type cutout, the expulsion tube may be made to vent at both ends by having the cap at the top made deliberately weak to blow off when high currents produce high gas pressures. Thus, this type of cutout permits the expulsion tube to vent at only one end when fault currents are low, and to "double-vent" when fault currents are high, allowing a higher interrupting rating for the fuse and cutout.

Three-Shot Fuses

When fuses are used to sectionalize a primary feeder, it is sometimes desirable to reenergize the portion disconnected by the blowing of a fuse, e.g., after a fault of a temporary nature. Three fuses are mounted in parallel, but only one fuse is connected in the line. When that fuse blows, as it swings open it trips a latch that places the second fuse in service. Should this fuse also blow, the operation is repeated for a third fuse. If the third fuse should blow, the line remains deenergized.

Safety Considerations

Besides providing adequately for normal and fault currents and for the voltage at which a cutout is to be operated, designs provide for the mounting or cutout to withstand severe climatic conditions, including snow, ice, rain, and severe temperature differences. Protection is also provided against decay, insects, birds, rodents, snakes, etc. Metal parts are made noncorrosive, not only from rust but from corrosive atmospheres. All nonenergized metal parts are bonded together and connected to one or more grounds. The cutouts are also installed out of reach of the general public and are operated with auxiliary devices such as an insulated switch stick handled from the ground.

Oil Fuses

Where very large interrupting capacity is required in a fuse, it is submerged in oil in a hermetically sealed steel tank. Here, the hot gases are not expelled, but are allowed to expand into sealed explosion chambers at the top of the cutout; the remnants of the fuse remain under the relatively cool oil. The magnetic field set up by the large current flowing through the fuse in turn sets up magnetic fields within the tank that aid in snuffing out the arc that forms, the insulating lining of the tank preventing the arc from contacting the tank.

The fuse link is fitted on an insulating frame that fits between the contacts inside the tank. The assembly is so shaped that it can only be inserted into an open position, preventing a premature blowing of the fuse before the assembly is locked in the closed position. Stationary contacts inside the tank are brought out by means of porcelain bushings.

The relatively high cost of oil fuses generally restricts their use to transformers in vaults or underground manholes, and to where voltages are less than 15 kV.

SURGE ARRESTERS

Lightning or surge arresters serve to bleed a high-voltage surge to ground before it reaches the line or equipment which they are to protect. They do this by presenting a lower-impedance path to ground than that presented by the line or equipment. The voltage surge breaks down the insulation of the arrester momentarily, allowing the surge to go to ground and dissipate itself; the insulation of the arrester then recovers its properties, preventing further current from flowing to ground, and returning the arrester to a state ready for another operation.

Types of Arresters

Lightning or surge arresters consist basically of an air gap in series with another element which has the special characteristic of providing a relatively low resistance or impedance to the current produced by a high-voltage surge, and a high resistance or impedance to the flow of power current at the relatively low operating voltage of the distribution line to which it is connected. In some later units, the air gap may be omitted.

Pellet Type In the pellet type of arrester, the second element is made up of a tube full of lead pellets. The lead pellets are actually lead peroxide coated with

TABLE 11-1 STANDARD RATINGS OF SURGE ARRESTERS FOR DISTRIBUTION VOLTAGES

Voltage reference class, kV	*Crest voltage, kV**	*Voltage reference class, kV*	*Crest voltage, kV**
1.2	30	15	110
2.5	45	23	150
5.0	60	34.5	200
8.7	75	46	250
12.0	95	69	350

*Basic insulation level (BIL) in kilovolts with a standard 1.5- by 40-μs wave.

Courtesy McGraw Edison Co.

lead oxide. The pellets normally act as insulation preventing current from flowing to ground. When a high-voltage surge is impressed on them, a current will flow that heats them and turns the lead oxide (a poor conductor) into lead peroxide (a good conductor). After the surge is discharged to ground, the surface of the pellets is changed by the discharge current back to lead oxide and restores the arrester to its original condition. Although rapidly becoming obsolete, a great many of this type of arrester exist and will for a long time.

Valve Type In the valve type of arrester, the second element may be made of some particular substance such as ceramic material containing conducting particles, such as metal oxides (Thyrite and Granulon are commercial names), or other substances having characteristics under surge-voltage conditions similar to those described above. Many of these are built in modular units, several connected in series to accommodate the line voltage impressed on them.

Expulsion Type The expulsion type of arrester may or may not employ a second air gap enclosed in a tube made of fiber in series with a fixed air gap. As with fuse holders made of fiber, when a high voltage occurs creating an arc across the gap, the heat acting on the fiber gives off a nonconducting gas under pressure that blows out the arc, interrupting the flow of surge current and restoring the arrester to its original condition.

Installation

Surge arresters are installed as close as possible to the equipment or line to be protected so that the resistance of the connection to ground may be held to a minimum. The ground is of the utmost importance, as the arrester will not operate without one. If possible, the arrester should have its own ground, in addition to connections to other grounds.

Since the arrester is to protect the insulation of the line or equipment associated with it, its insulation should be coordinated with that of the line or equipment. This is discussed in some detail in Chap. 4.

Rating

Standard arresters are rated not only on the nominal voltage class of the line to which they are to be connected, but also as to the crest voltage (the basic impulse insulation level) they can withstand; refer to Chap. 4 for more detail. Table 11-1 lists some standard ratings for surge arresters associated with distribution circuits of various voltage classes.

CHAPTER 12

REGULATORS, CAPACITORS, SWITCHES, AND RECLOSERS

VOLTAGE REGULATORS

A voltage regulator is used to hold the voltage of a circuit at a predetermined value, within a band which the control equipment is capable of maintaining and within accepted tolerance values for distribution purposes. Regulators may be installed at substations or out on distribution feeders on poles, pads, or platforms or in vaults.

Voltage regulators are essentially autotransformers, with the secondary (or series) portion of the coil arranged so that all or part of its induced voltage can be added to or subtracted from the line or incoming primary voltage (across which the primary or exciting portion of the winding is connected). The voltage variations are accomplished by changing the ratio of transformation automatically without deenergizing the unit.

Types

There are two types of voltage regulators in use in distribution systems: the induction regulator and the tap-changing-under-load (TCUL), or step-type, regulator. The first is usually limited to circuits operating at 5000 V or less and is being rapidly replaced by the latter, employed where relatively larger amounts of power and higher voltages are involved.

Induction Regulator In the induction type of voltage regulator, the primary (high-voltage) winding and the secondary (or series) windings are so arranged that they rotate with respect to one another (Fig. 12-1). The primary coil is usually the stator and the secondary coil the rotor, the direction of rotation

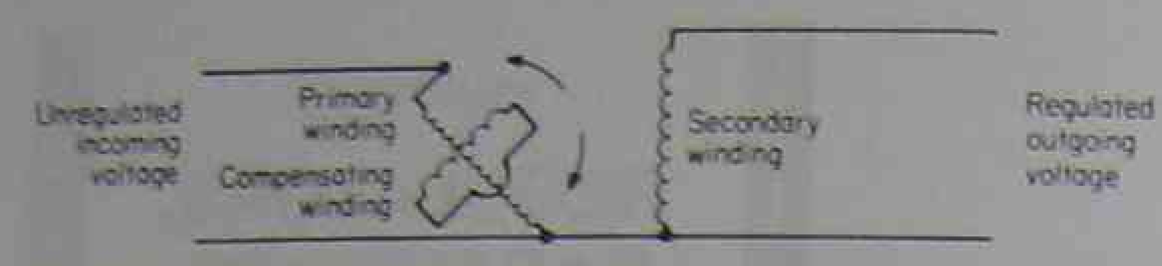


FIG. 12-1 Induction regulator windings.

generally depending on whether the incoming voltage is to be raised or lowered. The voltage induced in the secondary or series winding will depend on the position in relation to the primary winding. Depending on the position, the induced voltage can add to or subtract from the input voltage to obtain the outgoing voltage.

During the rotation of the primary coil, the moving magnetic field can cause a large reactance voltage drop in the secondary. To dampen (or cancel) this effect, a third coil is mounted at right angles to the primary coil on the movable core and short-circuited on itself. The moving primary coil will induce a voltage in the third coil which will, in turn, set up a moving magnetic field of its own, which will tend to oppose that set up by the motion of the primary coil. The reactance of the regulator unit is thus kept essentially constant.

Step-Type (or TCUL) Regulator The TCUL, or step-type, regulator is also essentially an autotransformer, and is connected in the circuit in the same manner as the induction regulator. This type does not employ rotation of one of the coils, but changes voltages by means of taps in the primary coil, as shown schematically in Fig. 12-2. The portion of the coil with taps is a separate part of the primary coil with arrangements included for a reversal in its connection so that the voltage within that portion of the primary coil can be added to or subtracted from the voltage in the rest of the primary coil.

Each tap is changed by the opening and closing of an associated "selector" switch. To avoid disconnecting the transformer from the line each time a tap is changed, the taps are so arranged that two adjacent taps are connected through a small autotransformer each time the tap change is in progress. The midpoint of this "preventive" autotransformer is connected to the primary coil, as illustrated in Fig. 12-3. A small air gap is inserted in the core of the autotransformer to reduce the size of the magnetic field, which could cause an excessive voltage drop in the coil.

Small circuit breakers, known as *transfer switches*, make and break the circuit under oil. The selector switches are always closed while the corresponding transfer switch is open, and opened while the transfer switch is closed. In this design,

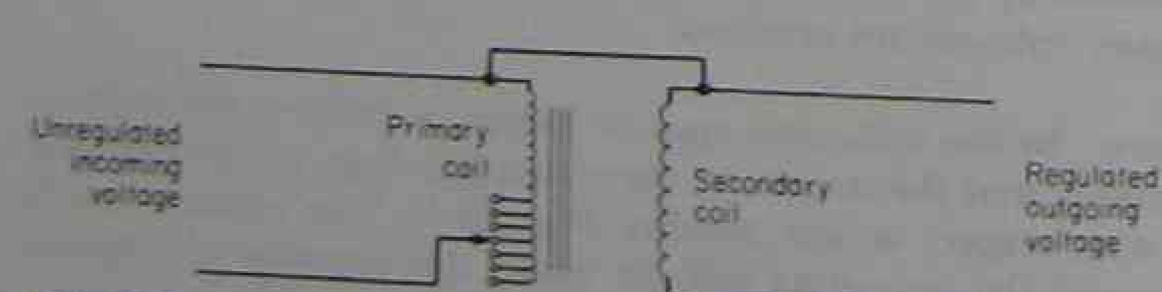


FIG. 12-2 Step-type or TCUL regulator.

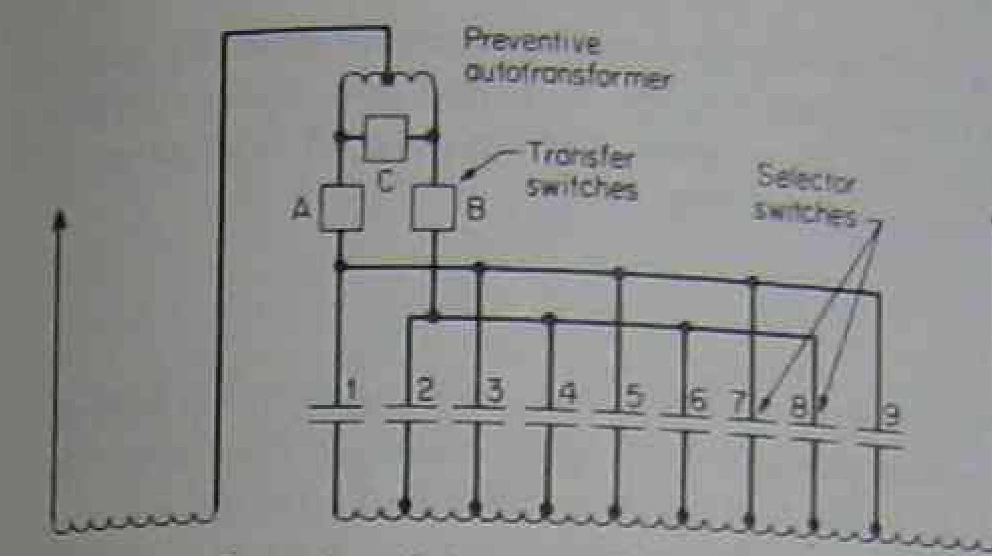


FIG. 12-3 Operation of step-type (TCUL) regulator. *(Courtesy Westinghouse Electric Co.)*

three transfer switches and one selector switch for each tap are required for operation. The transfer switches are often contained in a separate compartment attached to the main tank of the regulator so that they may be maintained without the necessity of draining the oil from the entire regulator unit. The oil in this compartment may be more readily contaminated because of the frequency of the switches' operation.

The sequence of operation of both the selector and transfer switches is shown in Table 12-1. The switches are operated in proper sequence by a motor-operated mechanism which may be controlled manually or automatically. A time-delay device prevents short-duration dips from operating the control relays.

Control

The rotation of the primary coil in the induction regulator and the tap changing in the step-type (TCUL) regulator are controlled by a voltage-regulating relay (earlier known as a *contact-making voltmeter*) connected to the output side of the

TABLE 12-1 SEQUENCE OF OPERATION OF TCUL REGULATOR SWITCHES

	Position																
Switch	*1*		*2*		*3*		*4*		*5*		*6*		*7*		*8*		*9*
Transfer switch A	X	X		X	X	X		X	X	X		X	X	X		X	X
B		X	X	X		X	X	X		X	X	X		X	X	X	
C	X		X		X		X		X		X		X		X		X
Selector switch 1	X	X															
2		X	X	X													
3				X	X	X											
4						X	X	X									
5								X	X	X							
6										X	X	X					
7												X	X	X			
8														X	X	X	
9																X	X

Courtesy Westinghouse Electric Co.

regulator. Associated with it is a *line-drop compensator*, which is essentially a miniature reproduction of the electric circuit to be regulated and determines the voltage applied to the voltage-regulating relay. A more detailed description of these devices' operation is contained in Chap. 4.

Rating

Both induction and step-type regulators are rated on their nominal voltage classification and their plus-minus percent of voltage regulation. Their capacity, or kVA rating, as a percentage of the volt-amperes transformed is the same as the percent voltage transformed using the incoming primary voltage as a base. This is the same rating used for autotransformers.

For example, if the regulator boosts (or bucks) the voltage 10 percent, it transforms only 10 percent of the load in kVA. If the load to be served is 1000 kVA, the size of regulator required is 100 kVA.

CAPACITORS

Capacitors are also used to improve voltage regulation on distribution circuits, but their operation differs from that of induction and step-type regulators. By introducing capacitive reactance in the circuit, they effectively counteract the inductive reactance of the circuit, affecting its impedance. This, in turn, may cause a voltage drop or rise. It will also tend to improve the circuit power factor, thereby decreasing the current required for a given load and reducing losses in the circuit.

Construction

Capacitors are usually constructed of sheets of aluminum foil separated by liquid-insulating-impregnated paper or other material, wrapped in bundles. The bundles are connected together electrically in series-parallel circuits, and the number of such bundles determines the voltage and capacitance rating of the units. The bundles are contained in a steel tank through which the leads are brought out by means of porcelain bushings.

Operation

Sufficient numbers of units are assembled in a bank of capacitors to provide the required capacitance or reactive power. Capacitors should be installed as close as possible to the inductive load (equipment) so that the current supplied over the circuit will be as nearly as possible in phase with the voltage (unity power factor).

In utility practice, however, capacitors are installed at intervals on the circuit to counter the effect of the inductance of the circuit itself as well as that of the inductive loads connected to it. Capacitor banks may be installed outdoors on poles in racks, on platforms, or on pads. They may also be installed indoors in vaults or other enclosures, and in substations.

Since the loads on a circuit change almost continuously, means are sometimes

provided to switch on or off some or all of the units in a capacitor bank, so that the capacitance (approximately) cancels out the inductance of the system. This may be accomplished by time clocks, overvoltage or undervoltage relays, or remote-control devices.

Protection When installed outdoors, capacitor banks are usually protected by fuse cutouts and surge arresters, somewhat in the way transformer installations are protected. In indoor installations, the banks may be protected by switches or fuse cutouts. Large banks of capacitors, such as may be found connected to substation buses, are usually connected by means of circuit breakers of ample capacity and short-circuit duty to accommodate the switching on and off of such banks, either in their entirety or in part. The employment of capacitors is discussed in greater detail in Chap. 4.

To protect against the failure of one unit in a bank affecting the entire bank, each capacitor unit in the bank is usually fused individually.

Discharge of Capacitors Some arrangement of resistors or reactors connected to the terminals of the capacitors is often provided for discharging the potentially dangerous energy that remains in a capacitor that has been charged, even after it is disconnected from the line. This phenomenon is known as *dielectric absorption*. Where the capacitors are connected between a phase of the primary feeder to which distribution transformers are connected and ground, discharge facilities may not be required, since the charge in the capacitor will drain off through the transformer winding. The rapidity at which this occurs will depend on the distance and the size and configuration of the conductors between the capacitor and the transformer.

Series Capacitors

Capacitors may be connected in series with the line to compensate for reactive voltage drop in the circuit and provide an instantaneous and almost perfect voltage regulation. Their use is generally limited to low-voltage heavy-current application, such as welders and furnaces. The units so employed may be the same as those used for shunt operation.

Rating

Capacitor units are rated according to their nominal voltage class (e.g., 2400 or 7620 V) and their kVA rating: 15, 25, 50, 100, 150, 200, and 300 kVA. Banks of such units, both for single-phase and three-phase operation, are assembled to provide the required capacitance.

Maintenance

Capacitors require little maintenance beyond occasional inspection for blown fuses, cracked bushings, leaking tanks, and the accumulation of dirt or other pollutants (severe smoke, salt fog, chemical fumes, etc.) on insulating surfaces. Maintenance is often accomplished by replacing only the unit in the bank requiring attention.

SWITCHES

In addition to the fuse cutouts and potheads mentioned in Chap. 9 and 11, other devices are used for connecting or disconnecting circuits or portions of them.

Disconnects

Disconnects are switches designed *not* to be opened when any amount of load current flows through them. Their use is generally limited to places where no load current or only a small charging current is to be interrupted. They are usually installed in a circuit so as to enable a line or a piece of equipment to be isolated from the energized portion of the circuit; they provide a visual break in the circuit as a positive safety measure for the worker. On the other hand, when used as normally open devices, they may be closed to energize a line or piece of equipment where only charging current will flow; in some instances, some relatively large load current may also flow when the disconnect is closed. In either case, the disconnect should be closed firmly to prevent the possibility of arcs forming between the blade and terminal clip as the blade approaches the (energized) clip.

Disconnect switches, air-break switches, and oil switches are sometimes gang-operated; i.e., the three single-pole disconnects (for a three-phase system) are mechanically connected and operated together.

Air-Break Switches

Air-break switches are generally used to interrupt relatively small amounts of load current, such as in sectionalizing primary feeders or interrupting the exciting current of large transformers or a group of smaller transformers. The switches may be closed to pick up loads, but extreme care must be used in opening a circuit carrying load.

Air-break switches are essentially disconnect switches equipped with so-called arcing horns. These are metal rods attached at an angle to the stationary terminal of the switch. As the blade of the switch is opened under load, the arcing horns remain in contact with the blade until after the main contacts have separated. As the blade continues to travel, an arc will form between it and the arcing horn. The arc will lengthen as the blade continues to travel, until it can no longer sustain itself and becomes extinguished. Pitting or burning from the arc occurs on the horn and part of the switch blade, where it can be tolerated.

Auxiliary devices are sometimes employed to increase the load-interrupting capability of such switches. One scheme interposes a low-capacity high-interrupting-duty fuse between the stationary contact and the moving element or blade; the fuse interrupts the circuit safely while the switch blade is still in place.

Construction Air-break switches are built rather ruggedly not only because they may have large fault currents flowing through them, but also because they are exposed to the weather. They are designed to operate under severe weather variations, with special attention paid to prevent contacts and hinges from "freezing" in position in cold, snowy, and icy weather.

Oil Switches

Operation Where load currents are to be interrupted relatively often, oil switches not designed to interrupt fault currents are used. Here, the switch is opened under oil, the oil serving to quench the arc that forms. Usually, however, a fuse is connected in series with the switch to clear the circuit should the switch fail to interrupt the circuit. Oil switches of this type, such as double-throw switches, are often used to transfer a primary service from one feeder to another and may be operated manually or automatically.

While the oil switch is more dependable than the air-break switch, it is more costly and its use is generally limited to those applications where other means are unsatisfactory.

Rating Like disconnects and air-break switches, oil switches are rated on their voltage classification and their normal current-carrying capacities. Inasmuch as fault current may flow through them, their fault-current-carrying capabilities are often included in their specifications.

CIRCUIT BREAKERS

Types

A circuit breaker generally is an oil switch but is built more ruggedly to enable it to interrupt not only the relatively large load currents but also the much larger fault currents which may occur on a circuit. Some circuit breakers, however, are designed to open in air, with special provisions for handling the arc that follows when the contacts are opened. These are known as air circuit breakers, and their interrupting capability is usually much lower than that for oil circuit breakers. Other circuit breakers are designed to have their contacts open in a vacuum or in an ambient of inert gas such as sulfur hexafluoride (SF_6), with improved interrupting capability claimed for these latter types.

Operation

All types of circuit breakers are designed to operate automatically in opening the circuit under fault conditions, or to be opened or closed manually when desired.

Circuit breakers are generally installed at substations on the ends of primary feeders. They may be used elsewhere, however, where heavy short-circuit currents must be interrupted and cannot be handled by other means such as fuses. Such locations, for example, are at-large consumers served at primary voltages.

Circuit breakers are usually actuated by overcurrent- or fault-sensing relays which serve to open them. This is done by tripping a compressed spring. Opening may be achieved in from 2 to 60 or more cycles, including the extinguishing of the arc, from the time the relay contacts are made. Relays also control their reclosure, which is accomplished by means of solenoids or electric motors. Circuit breakers may be set for a single operation, or for multiple reclosing operations before "locking out."

To insure their operation, the operating power source for the operation of the relays and the circuit breakers may be storage batteries floated on the line through a rectifier so that they are continuously fully charged.

Further discussion of circuit breakers may be found in Chaps. 4, 7, and 13.

Rating

In addition to their voltage classification and current-carrying capacity, the interrupting capability is a most important part of the circuit breaker rating.

RECLOSERS

Reclosers are essentially circuit breakers of relatively lower normal current- and short-circuit current-carrying capability. Their overcurrent- and fault-sensing devices and reclosing controls are a part of the unit and are contained within it.

Operation

The coils operating the closing mechanism obtain their power from the source side of the recloser. These coils also operate a mechanism that compresses the springs, which, when tripped, open the circuit breaker contacts rapidly. Another coil, in series with the coil operating the closing mechanism, trips a latch that releases the compressed springs to open the circuit breaker. A relay reenergizes the coil operating the closing mechanisms, which automatically close the circuit breaker. A time delay inserted in the relay circuit permits the reclosing of the breaker a number of times (usually three) before locking it open. The reclosing feature may be switched out of operation when only a single operation is desired (e.g., when workers may be working on the circuit). The unit may also be operated manually.

Reclosers may be installed out on one or more branches of a circuit so that a fault on those branches need not affect the entire circuit. Temporary faults (such as a tree limb falling on the line) will not cause a lengthy outage to service on the branch, but only a momentary interruption.

Reclosers may sometimes be installed at substations as circuit breakers on distribution feeders where loads are relatively small and likely short-circuit or fault current low enough not to exceed the rating of the recloser. Such conditions may often be found in rural areas.

Rating

Recloser units may be single-phase or polyphase, and are rated according to voltage class, normal carrying current, and fault-current interrupting capability. Additional discussion may be found in Chap. 4.

CHAPTER 13

DISTRIBUTION SUBSTATION EQUIPMENT

EQUIPMENT

The principal equipment usually found in a distribution substation includes power transformers; circuit breakers and their associated protective relays and control devices; high-voltage fuses; air-break and disconnect switches; surge or lightning arresters; voltage regulators; storage batteries; measuring instruments; and, in some instances, capacitors and street lighting equipment. Associated with all of these are cables and buses and their supports.

Many of these items have been discussed previously in connection with their functions in the planning and design of distribution systems and in their construction and installation; this discussion may generally be found in Chaps. 2, 4, 5, 6, 7, 11, and 12. Discussion in this chapter will focus on those characteristics of these same items which were not discussed previously but which are associated with the activities of the distribution engineer.

TRANSFORMERS

Substation transformers function in a manner similar to distribution transformers, but have significant differences in their construction and operation. Features shared by both categories include the usual employment of oil (sometimes air or askarels) for insulating and cooling purposes, taps for changing the ratio of transformation, and insulation coordination together with basic insulation levels. Transformers may be of the single-phase or three-phase types.

Core

Substation transformers, and especially the polyphase units, are usually constructed with shell-type cores which surround the windings, as compared with the usual distribution transformer, in which the windings surround the core.

Polarity

Substation transformers are usually wound for additive polarity, in accordance with EEI, NEMA, and other standards, as contrasted with the subtractive polarity of distribution transformers.

Bushings

The bushings of substation transformers on the low-voltage side are usually made of porcelain and are similar to the primary bushings found on distribution transformers, but of greater current-carrying capacity. The high-voltage-side bushing, however, in addition to the greater current-carrying capability, depending on the magnitude of the voltage, may consist of a solid porcelain cylinder (with petticoats) as insulation for voltages up to about 35 kV, or an oil-filled hollow porcelain cylinder for values up to about 69 kV; for 69 kV and higher voltages, the hollow porcelain cylinder may contain layers of oil-impregnated paper insulation with metal foil inserted at several locations among the layers, forming a series of capacitors which serve to even out and equalize the electrostatic stresses set up within the bushing; see Fig. 13-1. Other high-voltage bushings may be filled with an inert gas such as sulfur hexafluoride (SF_6).

Like distribution transformers designed for line-to-ground operation, single-phase transformers may have only one bushing on both the high- and low-voltage sides; three-phase transformers may have only three high- and three low-voltage bushings, with a neutral stud as a common terminal for both high- and low-voltage windings.

Oil

Substation transformers may also show evidence of greater precaution taken in keeping air and moisture from the oil. In some units, an inert gas, such as nitrogen, fills the space above the oil, and the transformer tank is sealed. A "relief diaphragm" is sometimes installed in a vent in the sealed transformer which ruptures when the internal pressure exceeds some predetermined value, indicating possible deterioration of the insulation. In some units, a pressure relay is installed to give an indication of pressure rise in the tank.

Some outdoor units are equipped with a tank on top of the transformer, called a *conservator*, in which the expansion and contraction of the oil takes place. The tank is sometimes open to the atmosphere through a breathing device. The condensation of moisture and the formation of sludge take place in the tank, which is also provided with a sump from which the condensation and sludge may be drawn off. See Fig. 13-2.

Cooling

Substation transformers may be equipped with fins or radiators to enhance the ability of the transformers to dissipate the heat generated by their copper and iron losses. Both the fins and the radiators increase the surface area transferring heat to the atmosphere. The radiator, in addition, increases the natural circulation of oil by the convection currents set up within the unit.

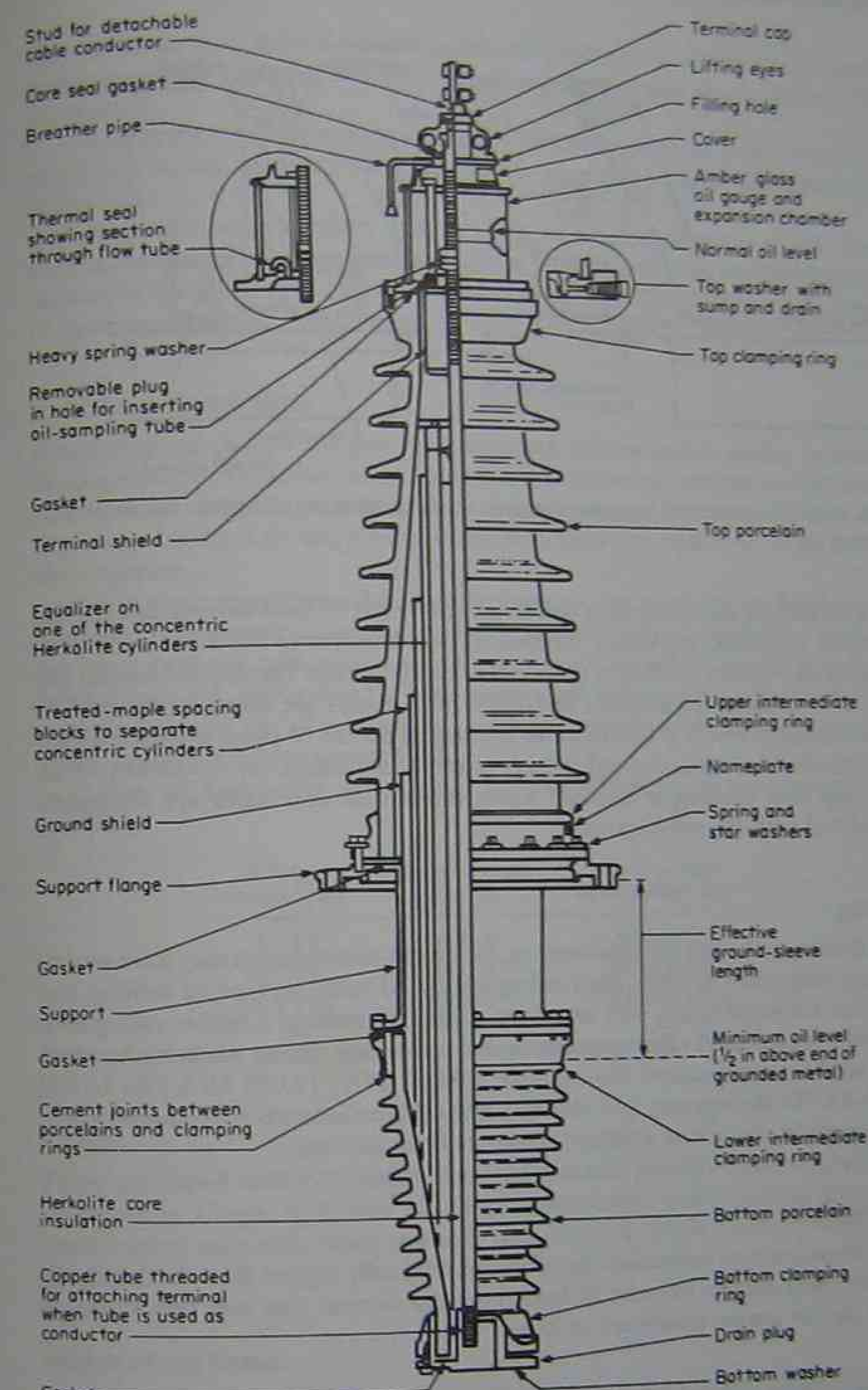


FIG. 13-1 Typical oil-filled bushing for a 69-kV transformer. *(Courtesy General Electric Co.)*

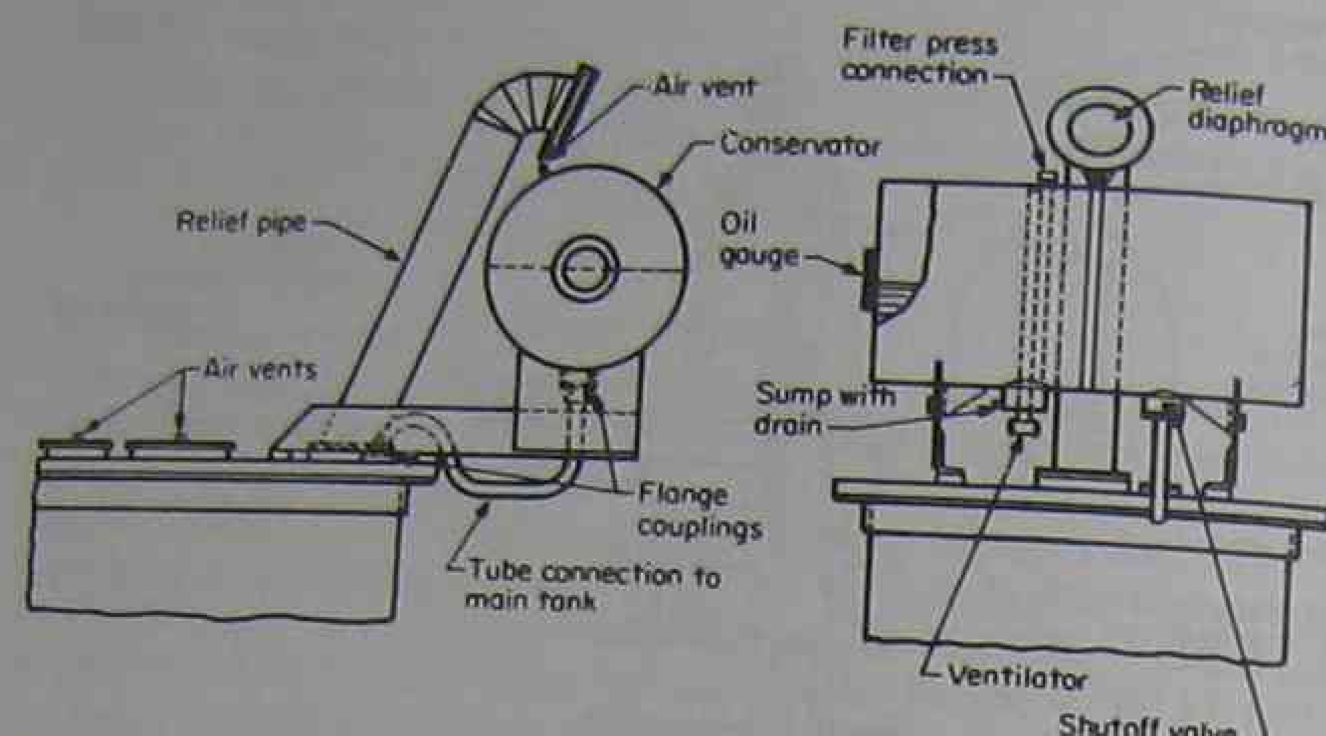


FIG. 13-2 Diagram showing main features of a conservator. *(Courtesy General Electric Co.)*

This cooling capability may be further increased by fans blowing against the fins and radiators, increasing the rate of heat transfer to the surrounding atmosphere. Further cooling may be obtained by pumps forcibly increasing the rate of circulation of oil in the radiators. Both means are often used together. In some cases, resort is had to water cooling by means of pipes installed within the transformer tank through which water is circulated, or by means of an external heat exchanger through which the hot oil and water are separately circulated with the aid of pumps.

Rating

In addition to the voltage classification, substation transformers may have several ratings expressed in kVA, each rating associated with the type of cooling employed: a normal rating with no added means of cooling; a higher rating with forced air or forced oil circulation; and a still higher rating when both means are used in combination; for example, 10,000 kVA; 12,000 kVA-FA; 15,000 kVA-FA/FO. Ratings may also include permissible noise levels at maximum loads, expressed in decibels at standard distances from the unit.

Impedance

The impedance of substation transformers is usually higher than that of distribution transformers in order to hold down the current that may flow during a fault on the system connected to its low side.

CIRCUIT BREAKERS AND PROTECTIVE RELAYING

Protective devices have been described in Chaps. 4, 7, and 12. The same considerations that apply to the types of bushings for the several levels of voltage

for transformers on their high-voltage side also apply to circuit breakers. Current transformers for relaying, metering, or other purposes may also be included in the bushing.

Circuit breakers may be single-phase or three-phase; these may consist of a single pole within an individual tank, or the three poles may be contained in a single tank.

Ratings of circuit breakers include their voltage classification in kV, their normal current-carrying capacity in amperes, their short-circuit- or fault-current interrupting capability in amperes or kVA, and, in some instances, their speed of opening, in cycles.

Metal-Clad Switch Gear

Modular metal-clad switch gear is constructed to incorporate circuit breakers, disconnecting devices, interlocks, measuring instruments, current and potential transformers, relays, and buses into a single, compact, factory-assembled unit or module for each circuit; a number of these units are capable of being assembled together.

Beside the compactness, the modular construction provides for flexibility in switching arrangements and for ready, inexpensive future expansion. With no live parts exposed and with interlocks to prevent energized switch gear from being drawn out, protection for both worker and equipment is enhanced. Connections into and out of this type of switch gear can be made via underground cables, making for neat appearance.

Ratings of metal-clad switch gear are determined by its current-breaking capability:

Voltage classification	*Normal current capacity*	*Fault-current interrupting duty*
5 kV	2000 A	50,000 kVA
15 kV	2000 A	500,000 kVA
34.5 kV	2000 A	1,500,000 kVA

Units above these ratings may be tailor-made for specific installations.

FUSES

Fuses associated with distribution transformers and primary circuits have been described in Chaps. 4, 5, and 11. Their time-current characteristics and their coordination with each other and with reclosers and circuit breakers have been discussed.

High-Voltage Fuses

In some smaller or rural substations, where possible short-circuit currents may be limited to relatively low values, a high-voltage fuse may be substituted for the incoming circuit breaker. While its operation, including coordination with other protective devices on the same circuit, is the same as for distribution fuses,

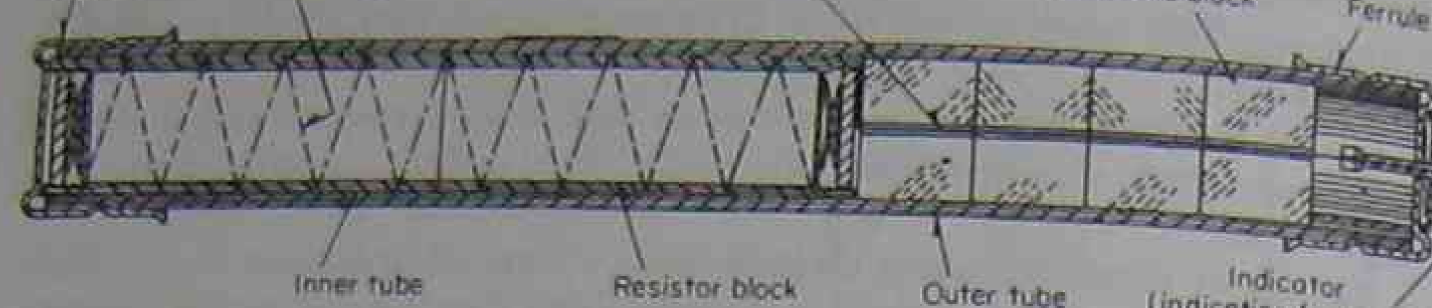


FIG. 13-3 Cross section of boric acid-type expulsion fuse. *(Courtesy Westinghouse Electric Co.)*

its construction is greatly different from that associated with door- and expulsion-type cutouts. The high-voltage fuse links are usually enclosed in a container, which tends to suppress and confine the arc and vaporizing metal, making the fuse capable of interrupting moderate short-circuit currents at the higher voltages.

Liquid-Filled Fuses In liquid-filled construction, the fuse link is enclosed in a tube that is filled with a fire-extinguishing fluid such as carbon tetrachloride. A spring holds the fuse under tension so that, when it blows, the resultant arc is quickly lengthened and quenched in the fluid; the gas formed is inert and aids in blowing out the arc. If the pressure becomes excessive, provision is made to have the cap on the "outgoing" side of the fuse blow off, preventing the rupture of the tube and confining damage to the fuse itself.

Solid-Filled Fuses In solid-filled construction, the material surrounding the fuse element may be sand or powdered boric acid. In the sand-filled type, the heat and gases generated when the fuse melts are absorbed by the sand, which tends to squelch the arc. In the boric acid type, the heat produced decomposes the boric acid, which forms steam under pressure that acts to squelch the arc. See Fig. 13-3.

Ratings

High-voltage fuses for this type of application are rated not only for their voltage classification and normal current-carrying capacity, but also as to their short-circuit-current interrupting capability.

DISCONNECT AND AIR-BREAK SWITCHES

Disconnects are rated by voltage classification in kV and normal current-carrying capacity in amperes. They are not rated to interrupt any current. These have been discussed in Chaps. 4, 5, 7, and 12.

Also discussed in these chapters have been air-break switches. They may be single-pole or three-pole gang-operated. They are also rated by their voltage

classification and normal current-carrying ability, but, in addition, have a current-interrupting capability expressed in amperes.

SURGE OR LIGHTNING ARRESTERS

Surge arresters may be of the valve or expulsion type and have been described in Chap. 6. They are rated not only on their normal voltage classification in kV, but also on their crest voltage capability in kV at a standard 1.5×40-μs wave (or other specified wave), and their discharge-current capability in amperes or thousands of amperes (kA). For high-voltage application, surge arresters may consist of a number of unit-value valve arresters connected in series in one overall unit, as shown in Fig. 13-4 for a 69-kV arrester.

VOLTAGE REGULATORS

Voltage regulators may be of the induction type or the TCUL or step type, and have been described in Chaps. 4, 7, and 12. A cross section of an induction regulator is shown in Fig. 13-5. Regulators are rated by voltage classification in kV and the plus-minus percent voltage-regulation capability. In step-type regulators, the percent voltage of each step and the number of steps is often also

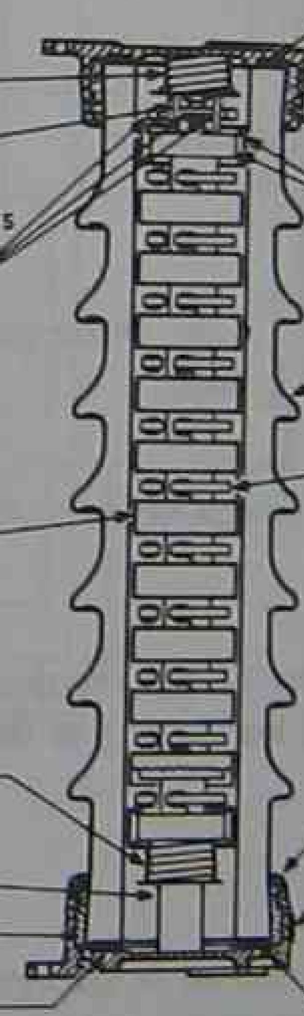


FIG. 13-4 Cross section of a 69-kV Thyrite (valve) surge arrester. *(Courtesy General Electric Co.)*

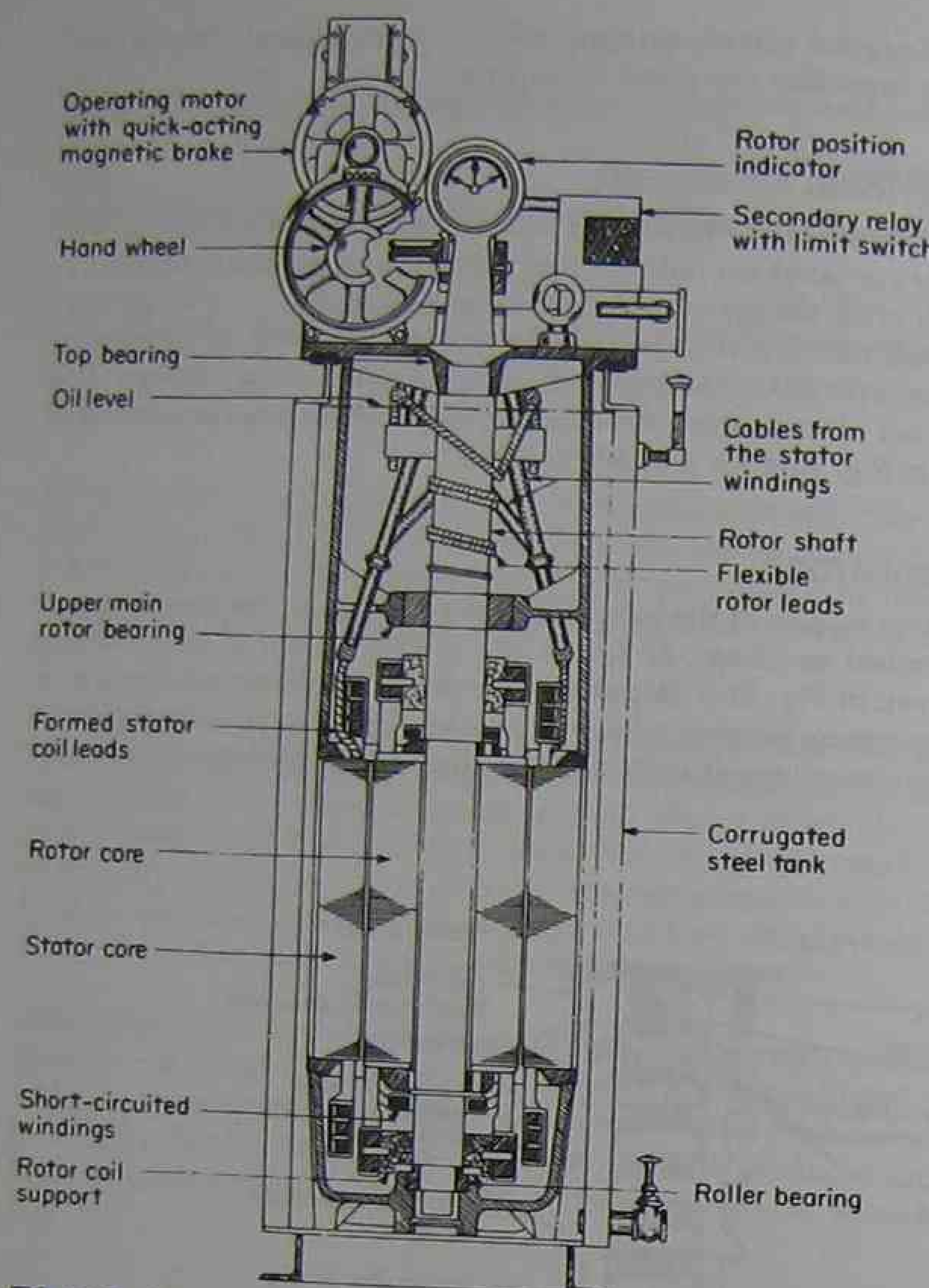


FIG. 13-5 Cross section of typical induction voltage regulator. *(Courtesy Westinghouse Electric Co.)*

specified. The current or kVA capability of the regulators is the same as the maximum voltage change times the full load rating of the circuit in which they are connected.

STORAGE BATTERIES

Storage batteries constitute a reliable source of dc energy to the control systems in substations. Such control systems may operate at nominal voltages of 6, 12, 24, 48, or 120 V, although the latter three are the preferred values. Since the batteries are made up of a number of individual cells, each producing approximately 2 V, a number of them are connected in series-parallel circuits to provide

the required voltage and capacity. These have been mentioned in Chap. 7 in connection with the operation of circuit breakers and their associated relays.

The most frequently used batteries are the so-called lead-acid type and the nickel-alkaline type (sometimes also called the Edison battery). The first type employs plates made of lead and sulfuric acid as the electrolyte; the second, plates made of nickel oxide and iron or cadmium, with potassium hydroxide as the electrolyte. Separators are made of treated wood, glass wool, porous rubber, or plastic material. Containers for the lead-acid cells are usually made of glass, rubber, plastic, or asphaltic compositions, with ports or vents for exhausting of gases and renewal of water or acid. Containers for the nickel-cadmium alkaline cells are nickel-plated sheet steel, hermetically sealed, but with valves to allow the venting of gases; the electrolyte needs no replacement.

Storage batteries are usually rated in ampere-hours and their capacity on the basis of an 8-h rate. Battery efficiencies run from 85 to 90 percent, with the lower efficiencies experienced at the more rapid rates of discharge and charge.

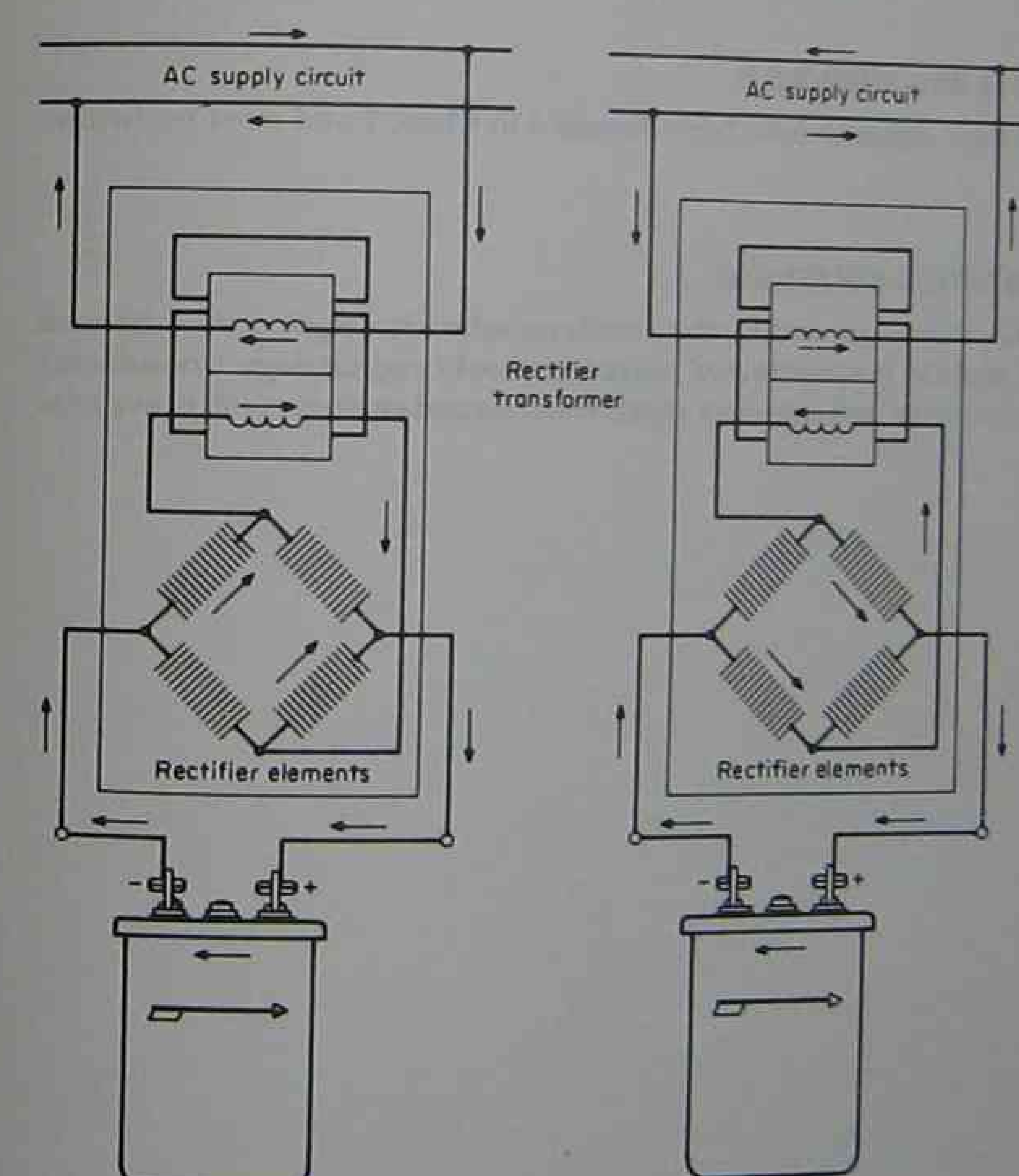


FIG. 13-6 Basic rectifier connections for battery charging.