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As requested by Mr. Delligatti, please find enclosed the applicable pages of EPRI Report EL-5036, Volume 5, Grounding and Lightning Protection, which was referenced in the response to RAI SAR 3-1. Flooding calculation no. 05996.01-G(B)-02-1 is included in the PFSF Calculation Package (reference).

If you have any questions, please contact me at 303-741-7430.

Sincerely,

W P Hennessy

W. P. Hennessy
Assistant Project Manager

Enclosure

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POWER PLANT ELECTRICAL REFERENCE SERIES

VOLUME **5**

GROUNDING AND LIGHTNING PROTECTION

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Topics: System grounding
Lightning
Personnel safety

Notice

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ACRONYMS & ABBREVIATIONS

A	ampere(s)
ANSI	American National Standards Institute
AWG	American wire gage
°C	degree(s) Celsius
dc	direct current
E	rated voltage
EMT	electrical metallic tubing
flex	flexible metal conduit
ft	foot (feet)
GPR	ground potential rise
H_1,H_2,H_3	three-phase high-voltage terminals
Hz	hertz
I	current
IEEE	Institute of Electrical and Electronics Engineers
IMC	intermediate metal conduit
in.	inch(es)
kcmil	1000 circular mils
kA	kiloampere(s)
kV	kilovolt(s)
m	meter(s)
mA	milliampere(s)
mm	millimeter(s)
μs	microsecond(s)
mV	millivolt(s)
NEC®	*National Electrical Code®*
NESC	*National Electrical Safety Code*
NFPA	National Fire Protection Association
R	resistance (Eq. 5-1)
ρ	soil resistivity (Eq. 5-1)
RMC	rigid metal conduit
rms	root-mean-square
s	second(s)
UL	Underwriters' Laboratory
V	volt(s)
X	reactance
X_1,X_2,X_3	three-phase low-voltage terminals
X_0	neutral terminal
Z	impedance

VOLUME 5

GROUNDING AND LIGHTNING PROTECTION

M. D. Robinson

5.1 INTRODUCTION

Power plant grounding systems are designed to perform the following important functions:

- Protect personnel from electric shock hazards
- Protect equipment from excessive voltages
- Facilitate isolation of faulted systems
- Permit the dissipation of transient currents
- Provide a stable reference point for instrumentation and control circuit measurements

The grounding system (Figure 5-1) can be divided into subsystems: substation, instrumentation, equipment, building lightning protection, power system, and surge protection. Their unique requirements must be considered in the design of the grounding installation. This volume focuses on the design requirements of these subsystems and their integration into the overall grounding system.

An electrical power system design requires (1) an evaluation of the advantages and disadvantages of connecting one conductor or point in the circuit to ground and (2) the selection of a method to provide a system ground when it is required. This subject, extensively covered in the literature (*1, 2, 3*), is summarized in this volume.

Various types of system grounding used for power plant distribution systems are discussed in Section 5.3.

Safety is an important consideration in the design of electrical systems. Section 5.4 discusses the methods used for grounding the non–current-carrying parts of electrical equipment to reduce shock hazards.

The unique grounding methods required for low-voltage instrumentation and control circuits to minimize the effects of noise and electromagnetic interference are discussed in Section 5.5.

Lightning protection systems installed on tall structures such as chimneys and cooling towers minimize the possibility of structural damage caused by direct lightning strokes. Installation of lightning protection systems on other power plant buildings is based on an evaluation of the consequences (fire, lost revenue, and so on) of a direct strike. Present-day concepts in the design of structure lightning protection systems are discussed in Section 5.6. The proper operation of lightning protection systems and surge protective devices depends on a low-surge impedance path to ground for impulse-type overvoltages. Grounding considerations for this application are also included in Section 5.6. The application of surge protective devices to equipment is discussed in Volume 1, *Electric Generators;* Volume 2, *Power Transformers;* Volume 13, *Communications;* and Volume 14, *Electrical Noise Reduction.*

A large portion of the grounding system is not readily accessible for inspection or repair after the installation is completed because it is buried in soil, concrete, or other material. Section 5.7 discusses the need for careful selection and sizing of materials to provide a long, maintenance-free life for the system.

Finally, codes and standards applicable to power plant grounding and lightning protection are referenced (Section 5.8), and test procedures and maintenance are discussed (Section 5.9).

5.2 DEFINITION OF TERMS

Bonding The electrical interconnecting of conductive parts, designed to maintain a common electrical potential.

Charging current The current that flows in a circuit due to the capacitive coupling to ground inherent in elements of the system. Capacitively coupled-to-ground elements include cables, buses, overhead lines, transformer and rotating machine windings, surge capacitors, and power factor capacitors.

Earth resistivity The electrical resistance of a unit volume of soil. The commonly used unit of measure, the ohm meter, refers to the resistance between opposite faces of a cubic meter of soil.

Ground A conducting connection, whether intentional or accidental, by which electrical equipment or an electrical circuit is connected to the earth or to some conducting body of relatively large extent that serves in place of the earth. Grounds are used for establishing and maintaining the potential of the earth (or of the conducting body), or approximately that potential, on conductors connected to it as well as for conducting ground current to and from the earth (or the conducting body).

Grounded conductor A conductor that is intentionally grounded, either solidly or through a current-limiting device such as a resistor or a reactor.

Grounded system A system of conductors in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through a non-interrupting-current-limiting device.

Grounding conductor The conductor that is used to establish a ground and that connects a piece of equipment, a device, a wiring system, or another conductor (usually the neutral conductor) with the grounding electrode or electrodes.

Grounding electrode A conductor used to establish a ground, such as a driven ground rod, a buried wire, or a buried plate.

Grounding transformer A transformer intended to provide a neutral point for grounding purposes.

Ground potential rise A rise of an electrode potential with respect to remote earth, caused by the portion of fault current that is conducted by a ground electrode into the earth.

Ground resistance The ohmic resistance between the grounding electrode and a remote grounding electrode of zero resistance. (*Remote* is defined as "a distance such that the mutual resistance of the two electrodes is essentially zero.")

Impedance grounding A method of connection in which a device is grounded through impedance. The components of impedance and the device to be grounded need not be at the same location.

Mutual resistance The voltage change in a grounding electrode produced by 1A of direct current in another grounding electrode, expressed in ohms.

Resistance grounding A method of connection in which a device is grounded through an impedance, the principal element of which is resistance. The resistance may be inserted either directly in the connection to ground or indirectly, as, for example, in the secondary of a transformer, the primary of which is connected between neutral and ground or in series with the delta-connected secondary of a wye-delta grounding transformer.

Solid grounding A method in which a device is connected directly through an adequate ground connection in which no impedance has been intentionally inserted. (*Adequate* as used here means "suitable for the purpose intended.")

Step voltage The difference in surface potential experienced by a person bridging a distance of 1 m with his feet without contacting any other grounded conducting object.

Touch voltage The potential difference between the GPR and the surface potential at a point where a person is standing with his hand in contact with a grounded structure.

Transferred voltage The voltage between points of contact, hand to foot or feet, in a station where the conductor touched is grounded at a remote point or touching at a remote point a conductor connected to the station ground grid. Here the voltage rise encountered due to ground fault conditions may be the full voltage rise of the ground grid and not the fraction of this total that is encountered in the usual touch contact. Transferred voltage is a special case of touch voltage.

Ungrounded system A system, circuit, or apparatus without an intentional connection to ground, except through potential-indicating or potential-measuring devices or other very high impedance devices. Though called ungrounded, this type of system is in reality coupled to ground through the distributed capacitance of its phase windings and conductors. In the absence of a ground fault, the neutral of an ungrounded system under reasonably balanced load conditions will usually be close to ground potential, being held there by the balanced electrostatic capacitance between each phase conductor and ground.

5.3 SYSTEM GROUNDING

A power plant electrical distribution system may be grounded in different ways, or it may remain ungrounded (no intentional electrical connection made between the system neutral and ground).

The primary reasons for connecting the neutral of a three-phase power system to ground are:

- To limit transient overvoltages during a phase-to-ground short circuit
- To provide a ground current return path for isolating faulted circuits

In power plants, the system ground is usually applied at the power source, that is, at the system transformer or generator.

TYPES OF SYSTEM GROUNDING

The following are the neutral grounding schemes used on power plant electrical distribution systems:

- Ungrounded
- Solidly grounded
- Resistance grounded
- Reactance grounded

Ungrounded System In an ungrounded, three-phase system (Figure 5-2a), the neutral point (if it exists) remains "floating," or ungrounded. In this system a single line-to-ground fault does not cause an outage. Hence, this system offers a high degree

The signal ground buses of the individual cabinets and the main instrumentation ground bus are interconnected radially with insulated (600-V) cable. It is preferable to provide separate grounding systems for the analog and digital systems. The equipment ground bus in each cabinet is connected to the local plant grounding system at convenient locations.

The computer cabinets may be isolated from the building structural steel by means of the computer room floor, but the cabinets are connected to the plant equipment grounding system. The computer signal ground bus is connected to the main instrumentation ground bus in the most direct manner. This connection may be run in metal conduit to provide physical protection and to minimize the introduction of noise.

The main instrument ground bus usually terminates in a junction box containing a copper bar that is insulated from the box. The box is installed at a location where there is direct access to the plant grounding electrode. The insulated cables from the analog and digital signal grounds, the computer signal ground bus, and the cable to the grounding electrode are bolted to the bus bar so that they can be readily removed to test for grounding system isolation.

Some manufacturers recommend that their equipment be grounded via a separate grounding electrode, one that is isolated from all other grounding electrodes. This approach is impractical for most power plant sites because it is difficult to find a location for an isolated electrode that is certain to remain isolated in the future. Also, long cable runs may be required to reach an isolated area. These long runs will introduce high impedances into the isolated grounding system at high frequencies and will increase the exposure of the system to electrical noise and transients.

5.6 STRUCTURE LIGHTNING PROTECTION

The purpose of a lightning protection system is to prevent or minimize damage to structures or equipment by providing a suitable path for the stroke current. Lightning protection systems are not intended to prevent lightning formation. This section presents an overview of the practical methods used in the design of lightning protection systems.

The following discussions on lightning formation and thunderstorm data illustrate the parameters important in the design of lightning protection systems and the degree of accuracy of the data available.

LIGHTNING FORMATION

A lightning stroke to earth begins when a separation of electric charge occurs within a storm cloud, producing a charge of one polarity distributed within the base of the cloud and a corresponding but opposite charge distributed on the surface of the earth under the cloud (Figure 5-8a). The stroke to earth starts with the development of a downward coronalike streamer from the cloud called a "stepped leader." This leader transports charge from the cloud toward the earth, following an unpredictable path in a series of hesitating steps. The leader velocity of propagation is about 100 ft/μs.

As the tip of the leader approaches an object on the ground, an upward streamer develops from the

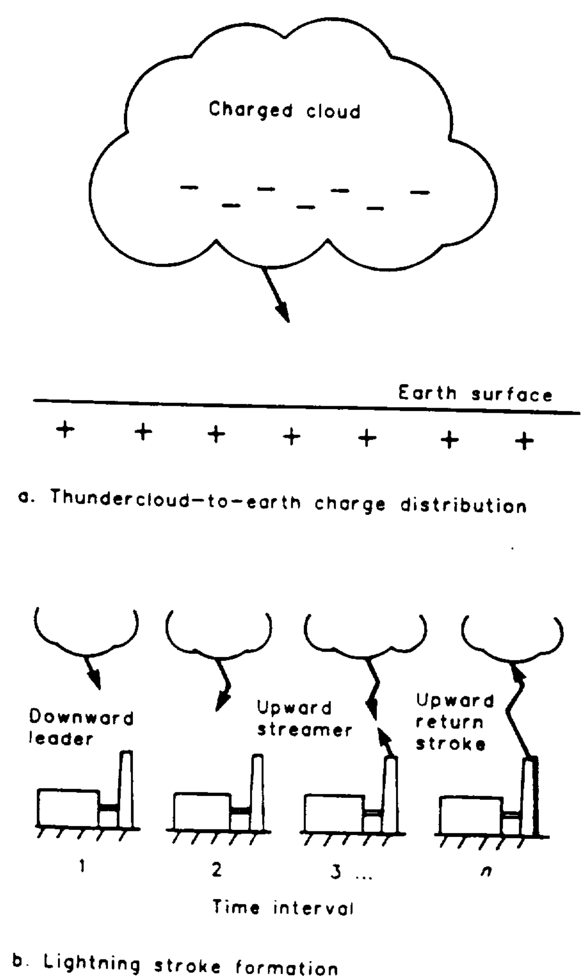


Figure 5-8 Lightning Formation

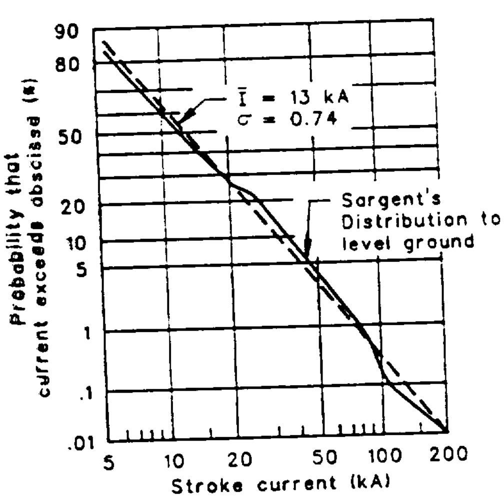
object and moves towards the descending leader (Figure 5-8b, time interval 3). The leader is directed towards this upward streamer, and when the two ionized paths meet, a conducting path is established between the object and cloud. Once the conducting path is established, a large current (return stroke) moves upward from the earth to equalize the charge within the cloud. The total elapsed time for a leader to complete its path from cloud to earth is less than 0.01 s.

The last step of the downward leader before establishment of the upward streamer is critical; at this point the stroke can be influenced to take a chosen path, thus providing protection to a given structure.

The electrical characteristics (polarity, crest magnitude, and waveshape) of stroke currents vary over wide ranges, which is typical of natural events. The return stroke current magnitude ranges from 2 to 200 kA, with some extremely intense strokes exceeding 300 kA. The current magnitude of an "average" stroke to level ground is about 13 kA (*10*). Figure 5-9 (*12*) shows a predicted frequency distribution of current magnitudes.

The waveshape of the return stroke current takes the form of an impulse as shown in Figure 5-10 (*13*). The current magnitude increases rapidly to its peak value in 1 to 10 µs.

This greatly simplified explanation of the lightning mechanism shows that any practical lightning protection system must deal with a large amount of energy in an extremely short period of time.



SOURCE: G. W. Brown, "Joint Frequency Distribution of Stroke Current Rates of Rise and Crest Magnitude to Transmission Lines." In *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-97, no. 1. New York: Institute of Electrical and Electronics Engineers, January/February 1978, p. 53. © 1978 IEEE.

Figure 5-9 Distribution of Stroke Current Magnitude to Level Ground

THUNDERSTORM DATA

The frequency of occurrence of thunderstorms is usually measured as the mean number of calendar days per year during which thunder is heard by a local weather bureau observer. This statistic is called the isokeraunic level for a given geographic area. Thunderstorm data for the United States in Figure 5-11 (*8*) show large geographic variations in the frequency of thunderstorm days: central Florida has an isokeraunic level of 100, and the Pacific coast has a level of 0 to 5.

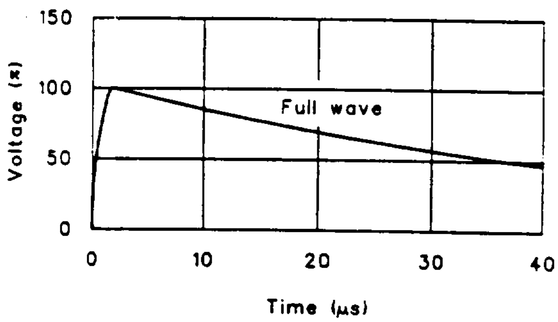
While the isokeraunic map provides a broad picture of storm frequency in a given area, it does not provide an accurate estimate of the number of lightning strokes to ground in a given locality—an important quantity in lightning protection design. Other problems exist with isokeraunic measurement: thunder can be produced by cloud-to-cloud discharges; the occurrence of lightning without thunder being heard is not recorded as a thunderstorm day; and multiple storms in a given day are not reflected in the statistics.

The degree of protection economically justifiable for a given installation should be based on storm severity in the locality and, in particular, on the number of strokes to ground in the area. Effective lightning location systems have been developed in recent years (*14*). These systems can accurately locate and plot ground stroke data for a given area, providing better data with which the engineer can work. Until their use is prevalent, however, the engineer must rely on local knowledge and judgment.

A research plan has been developed by EPRI that would improve our knowledge of the lightning mechanism and hence improve our lightning protection practices (*15*).

LIGHTNING PROTECTION PRINCIPLES FOR STRUCTURES

There are two generally accepted methods of protecting structures: the air terminal method and the mast or groundwire method. The air terminal method uses a network of bare grounded conductors (roof conductors) placed on the upper level of the structure. Vertical rods (air terminals) are attached to the roof conductors at appropriate intervals, as shown in Figure 5-12. This method depends on the proper positioning of the roof conductors and air terminals so that they can intercept the lightning stroke and provide a low-impedance path to the earth. Structural damage is avoided or minimized since the stroke energy



SOURCE: *IEEE Guide for Transformer Impulse Tests.* New York: Institute of Electrical and Electronics Engineers. 1968. IEEE Std. 93-1968. Figure I-1, p. 5. © 1968 IEEE.

Figure 5-10 Typical Stroke Current Waveshape

is channeled into the earth by the conductor and grounding systems.

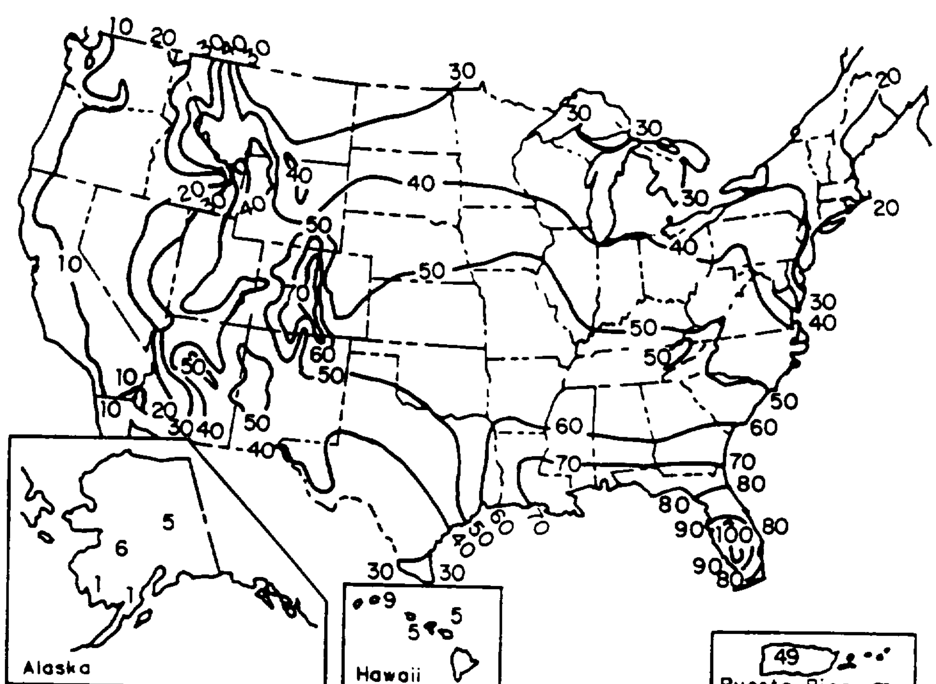
Roof conductors are placed at locations where point discharges are likely to develop in the presence of the strong electric field produced by the stroke. For a pitched roof a conductor is installed along the ridge; for flat roofs conductors are placed on the tops of parapets or on the edges of the roof to form a closed loop(s). For flat roofs with a large area, roof conductors and air terminals are located at intermediate intervals across the roof to provide protection for the entire area, as shown in Figure 5-12.

Guidance is available on the design details for roof conductor and air terminal systems (*16, 17*).

The roof conductors are connected to grounding electrodes by means of vertical cables (down conductors). These cables are run between the roof level and the earth on the inside or outside of the building walls. The down conductors should be installed in the most direct route between the roof and the earth in order to obtain the lowest surge impedance. If lightning protection conductors must be embedded in concrete, such as floor slabs, the conductors should be connected to the reinforcing steel at the top and bottom of the slab to prevent damage to the concrete when the conductor carries large stroke currents. The structural steel columns of a building can be used as down conductors if they provide a continuous and direct path to the grounding electrode.

The average distance between down conductors should be less than 100 ft, and at least two down conductors should be installed on any structure. Down conductors subject to mechanical damage from traffic should be enclosed for a distance of at least 6 ft above floor or grade level in a pipe of rugged plastic or nonmagnetic material.

Metallic objects, such as pipes, antenna supports, ladders, and ventilators, that project above the roof conductors should be connected (bonded) to the



SOURCE: *Transmission Line Reference Book, 345 kV and Above,* 2d ed. Palo Alto, Calif.: Electric Power Research Institute, 1982, p. 547.

Figure 5-11 Isokeraunic Map Showing Mean Annual Days of Thunderstorm Activity in the United States roof conductor system, since these objects are exposed to direct strokes. Metal objects that are located within 6 ft of the protection system should be bonded to the protection system to prevent arcing, unless they are connected to the plant equipment grounding system.

Experience has shown that structures that are fabricated entirely from steel of at least 3/16 in. in thickness and that are electrically continuous, such as tanks, are inherently self-protecting and need no lightning protection if adequately grounded. Grounded tanks containing flammable liquids or liquefied petroleum gas under pressure do not require lightning protection.

The air terminal method is also used to provide direct stroke protection to power plant chimneys made of reinforced concrete. The reinforcing steel must be electrically continuous and should be connected to the lightning protection system at the top and bottom of the chimney. Air terminals are uniformly distributed around the periphery at the top of the chimney and are interconnected with a ring of conductor. At least two down conductors, one on each side of the chimney, are used to connect the air terminals to the grounding system at the chimney base. The ground conductors are usually interconnected with a buried ring of conductor at the base and with a ring of conductor at the mid-height of the chimney if the height exceeds 200 ft. Bonding of metal parts attached to the chimney is done generally as described above for buildings.

All materials, such as air terminals, conductors, and fittings, used on the upper 25 ft of a chimney should be suitable for the corrosive atmosphere. Lead-covered copper, Monel metal, and stainless steel materials are commonly used for this application.

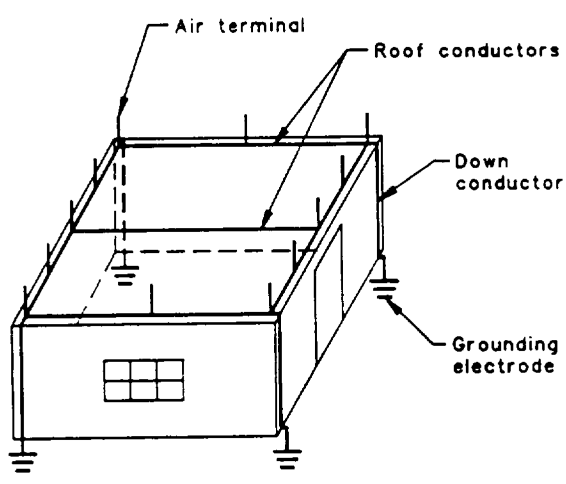


Figure 5-12 Structure Lightning Protection Using Air Terminals

The second method for providing lightning protection uses grounded mast(s) near the structure or equipment to be protected or grounded wires suspended over it. This method is used in cases in which it is desirable to prevent the stroke current from contacting any part of the structure or equipment, for example, buildings containing hazardous materials. The mast or ground wire approach is also used extensively to protect electrical substations, and a similar approach is used in transmission line design.

In the discussion on lightning formation at the beginning of this section it was mentioned that the last stage in the downward path of the stroke leader is important in the design of a protection system. Until this point is reached, the direction of the downward leader is not influenced by any object on the ground. At some distance above the earth (striking distance) the breakdown strength of the air gap between the stroke leader and an object on earth is exceeded; the upward streamer is formed and the leader is attracted to it. Figure 5-13 illustrates the significance of the striking distance in the following example. A stroke leader with a striking distance of *S* has progressed to point *A*. At this point a streamer could be initiated from the top of the grounded mast (point *B*) or from some object on the ground (point *C*), since distances *AB* and *AC* are the same as the striking distance *S*. Hence, the stroke path to ground would probably be completed through the mast or the stroke would hit the ground near point *C*. It is unlikely that the stroke path would be completed through point *D*, since the distance *AD* is greater than the striking distance *S*. Hence, the grounded mast shields point *D* from the direct stroke and would shield any object in the area *BOC* from a stroke with a striking distance equal to or less than *S*. It is postulated that the striking distance is not a constant for all strokes but is a function of the stroke intensity. Figure 5-14 (*18*) shows the relationship between the striking distance and stroke amplitude proposed by Golde. Note that the striking distance increases with increasing current magnitudes.

The vertical boundary of the protected area can be defined by a circular arc (*19*). If the plane defined by area *BOC* of Figure 5-13 is rotated through 360°, a conical surface is developed defining the zone of protection afforded by a mast of a given height. Figure 5-15a (*16*) shows the zone of protection for a single mast higher than 50 ft, and Figure 5-15b (*16*) shows the protected zone provided by two overhead ground wires higher than 50 ft. The zones of protection provided by masts or overhead ground wires that do not exceed 50 ft are shown in Figure 5-16 (*16*).

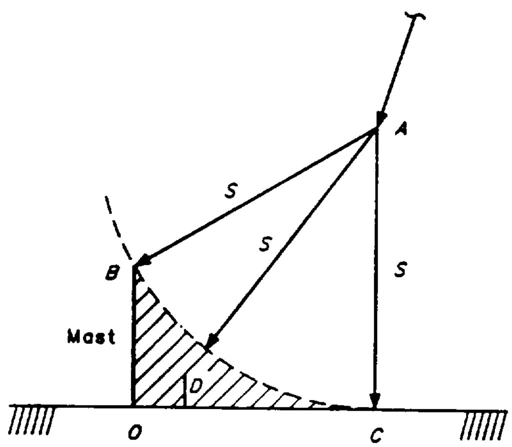
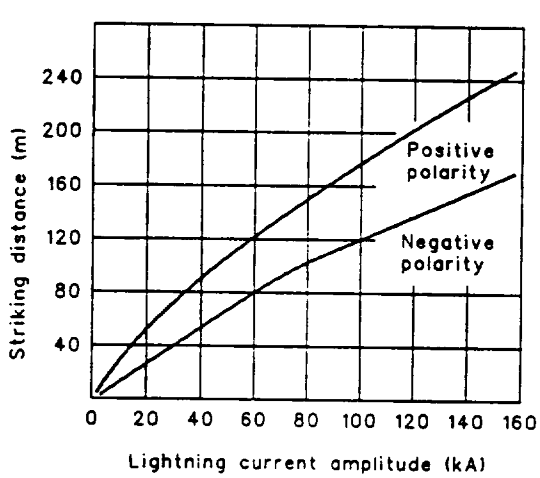


Figure 5-13 Shielding Provided by a Grounded Mast

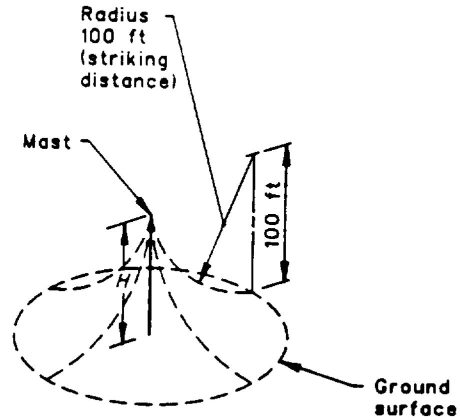
IMPULSE GROUNDING RESISTANCE

A lightning protection system must be connected to an adequate grounding system in order to be effective. Section 5.4 discusses the types of grounding electrodes generally used in power plant grounding systems and provides information for calculating the resistance to remote earth. It should be noted that these calculated values and most measured values are 60-Hz resistances (leakage resistances), whereas a lightning stroke in the grounding system encounters a surge impedance that is a function of the physical arrangement of the grounding electrodes, soil characteristics, and surge current magnitude and waveshape. The impulse resistance of ground rods is usually less than

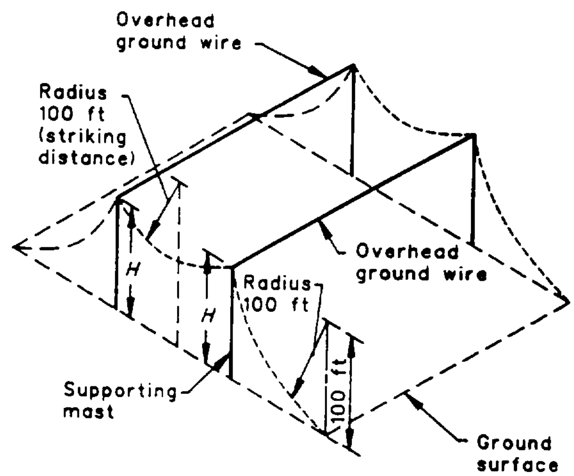


SOURCE: R. H. Golde. "The Lightning Conductor," *Journal of the Franklin Institute*, vol. 283, no. 6, June 1967, p. 461.

Figure 5-14 Postulated Striking Distance Versus Lightning Current Amplitude



a. Single mast



b. Overhead ground wires

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Figure 5-15 Zone of Protection for Mast Height *H* Exceeding 50 Ft

the measured 60-Hz resistance, as shown in Figure 5-17 (*8*). However, if a long length of buried wire (counterpoise) is used as a grounding electrode, the initial surge impedance may be many times greater than the leakage resistance. Figure 5-18 shows that a more effective impulse ground is obtained by using a number of short lengths of counterpoise arranged in a star (crowfoot) configuration (*20*). From a surge impedance standpoint, there is little to be gained from using more than four wires for the counterpoise or from using lengths longer than 250 ft.

The grounding system used for a structure lightning protection system should always be connected

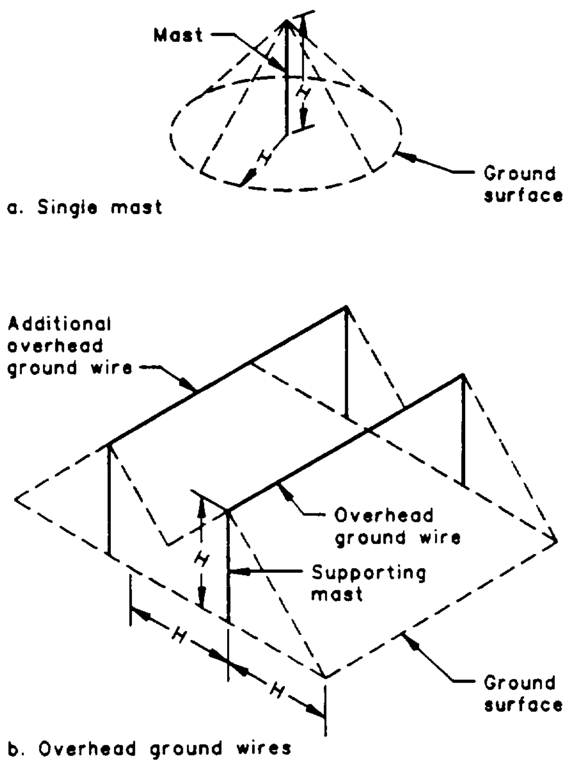

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Figure 5-16 Zone of Protection for Mast Height *H* Not Exceeding 50 Ft

to other plant grounding subsystems (equipment, surge protection, and so on). This is to ensure that all grounded parts will remain at approximately the same potential during a lightning stroke.

The grounding conductor used to connect a surge arrester to the ground electrode should be as straight and short as practicable to reduce its surge impedance, thus minimizing the voltage drop in the conductor when the arrester operates. A local grounding electrode should be provided for grounding surge arresters, and the local electrode should be connected to the station grounding system.

5.7 MATERIAL SELECTION AND SIZING

The grounding system is an important part of the electrical distribution system, and it should be designed, installed, and maintained with the same degree of care that is used for the insulated phase conductors. When grounding materials are selected and sized, it should be recognized that a large portion of the grounding system will not be readily accessible for inspection or repair after the installation is completed. Also, the grounding system in power plants is not always given the same degree of protection from physical damage and environmental effects that is provided for insulated conductors.

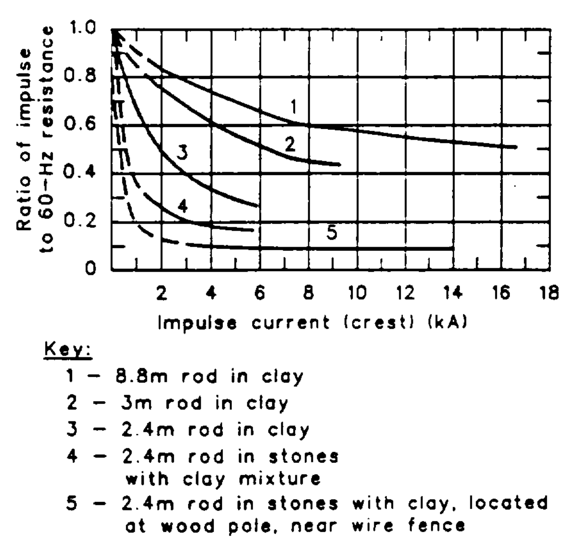
MATERIALS

When a material for a grounding system component is selected, the following characteristics should be evaluated:

- Electrical conductivity
- Fusing temperature
- Mechanical strength
- Corrosion resistance

One of the purposes of the grounding system is to interconnect various areas of the plant to minimize differences of potential between areas during ground fault conditions. If a grounding conductor with a relatively high electrical conductivity is used, conductor voltage drop will be reduced. The conductivity of materials used for grounding purposes is given in Table 5-6.

All components of the grounding system must withstand the temperatures generated by the maximum ground fault condition that occurs during



SOURCE: *Transmission Line Reference Book, 345 kV and Above,* 2d ed. Palo Alto, Calif.: Electric Power Research Institute, 1982, p. 559.

Figure 5-17 Impulse Current Resistances of Various Ground Rods high temperatures, the maximum allowable temperature of the grounding components should be reduced accordingly.

5.8 APPLICABLE CODES AND STANDARDS

Power plant grounding systems are usually designed in accordance with a design criterion that is either developed at the beginning of a project or based on existing utility standards. The criterion establishes the basis for the design and helps to ensure uniformity of design within a plant or system. The following codes and standards are commonly used, where applicable, as input to design criteria and company standards:

- *National Electrical Code* (*NEC*) American National Standards Institute (ANSI)/National Fire Protection Association (NFPA) 70-1984
- *National Electrical Safety Code* (*NESC*) IEEE Standard C2-1984
- *Lightning Protection Code* NFPA 78-1983
- *Installation Requirements for Lightning Protection Systems* Underwriters' Laboratory (UL) Standard UL96A-1983
- *Recommended Practice for Grounding of Industrial and Commercial Power Systems* IEEE Standard 142-1982
- *IEEE Guide for Safety in Substation Grounding* IEEE Standard 80-1986
- *IEEE-recommended Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System* IEEE Standard 81-1983
- *IEEE Guide for Determining the Maximum Electric Power Station Ground Potential Rise and Induced Voltage From a Power Fault* IEEE Standard 367-1979

The applicability of these documents to power plant grounding installations is discussed in this section.

NEC (ANSI/NFPA 70-1984)

This code is an advisory document approved jointly by ANSI and the NFPA. It has been adopted in whole or in part by many regulatory agencies. Article 250 of this code pertains to the grounding of electrical systems and equipment.

The *NEC* is not intended to apply to utility installations used for the generation, transmission, or distribution of electrical energy in cases in which these installations are under the exclusive control of the electrical utility. Generally, these facilities are not accessible to the public and are designed, constructed, operated, and maintained by experienced personnel. However, the *NEC* is intended to apply to utility installations used for other purposes, such as office buildings, warehouses, garages, machine shops, and recreational buildings that are not an integral part of a generating plant. These buildings are more readily accessible to persons who may not be familiar with the hazards associated with electrical systems and equipment.

NESC (IEEE Standard C2-1984)

Section 9 of the *NESC*, a guide standard published by the IEEE, covers grounding methods for electric utility supply and communication facilities. The rules given in Section 9 are applicable to generating stations.

LIGHTNING PROTECTION CODE (NFPA 78-1983) AND *INSTALLATION REQUIREMENTS FOR LIGHTNING PROTECTION SYSTEMS* (UL96A-1983)

These codes establish the same basic requirements for structure lightning protection systems, and they are used as a basis for designing power plant structures whenever a lightning protection system is needed to meet government or insurance requirements. Tall, nonmetallic stacks at fossil fuel stations usually need lightning protection systems because of insurance requirements. For nuclear stations the reactor containment, nonmetallic stacks, and tall cooling-tower structures are normally equipped with lightning protection systems.

RECOMMENDED PRACTICE FOR GROUNDING OF INDUSTRIAL AND COMMERCIAL POWER SYSTEMS (IEEE Standard 142-1982)

This standard provides an overall but concise discussion of the major topics associated with power plant grounding.

IEEE GUIDE FOR SAFETY IN SUBSTATION GROUNDING (IEEE Standard 80-1986)

This document provides guidance in the design of substation grounding grids; it primarily addresses design considerations for outdoor installations. It

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