IEEE Guide for Protective Grounding of Power Lines

IEEE Standards Board
Approved April 17, 1990

Sponsor
Transmission and Distribution Committee of the
of the
IEEE Power Engineering Society

Abstract: IEEE Std 1048-1990, IEEE Guide for Protective Grounding of Power Lines, provides guidelines for safe protective grounding methods for persons engaged in de-energized overhead transmission and distribution line maintenance. This guide compiles state-of-the-art information on protective grounding practices employed by power utilities in North America.

Keywords: Protective grounding, grounding practices, power lines, transmission lines, distribution lines.

ISBN 1-55937-035-1

Foreword

(This Foreword is not a part of IEEE Std 1048-1990, IEEE Guide for Protective Grounding of Power Lines).

Protective grounding methods have often not kept pace with their increasing importance in work safety as the available fault current magnitudes grow, sometimes to as high as 100 kA, and as rights-of-way become more crowded with heavily loaded circuits, leading to growing problems of electric or magnetic induction. This guide has, therefore, been prepared to compile state-of-the-art information on protective grounding practices currently employed by power utilities in North America.

At the time this guide was approved the membership of the Task Group of the Engineering in Safety, Maintenance, and Operation of Lines Subcommittee was as follows:

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The final conditions for approval of this guide were met on April 17, 1990. This guide was conditionally approved by the IEEE Standards Board on June 1, 1989, with the following membership:

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IEEE Guide for Protective Grounding of Power Lines

1. General

1.1 Scope

This guide aims to provide guidelines for safe protective grounding methods for persons engaged in de-energized overhead transmission and distribution line maintenance.

1.2 Purpose of Protective Grounding

The primary purpose of protective grounding is to limit the voltage difference between any two accessible points at the work site to a safe value.

1.3 References

This guide shall be used in conjunction with the following publications. For further information, consult the Bibliography in Section 10.

[1] ASTM F-855-1983, Specifications for Temporary Grounding Systems to Be Used on De-energized Electric Power Lines and Equipment.[1]

[2] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms, 4th ed. (ANSI).[2]

[3] Dalziel, Charles F., The Effects of Electric Shock on Man, *IRE Transactions on Medical Electronics* (PGME-S), May 1956.

1.3.1 Document in Preparation[3]

2 Definitions

Terminology for equipment and procedures associated with the installation of temporary grounding systems varies widely throughout the utility industry. Therefore, definitions have been included to provide a correlation between the terminology used in this guide and industry synonyms. Note that the synonyms are terms commonly used, although many are not necessarily good usage and should not be taken as equivalents to the guide terminology.

Many of the terms have additional meanings and usages that are defined in IEEE Std 100-1988 [2].[4]

1. ASTM publications are available from the Sales Department of the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

2. IEEE publications may be obtained from the IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331 or from the Sales Department, American National Standards Institute, 1430 Broadway, New York, New York 10018.

3. When the following document is completed, approved, and published, it will become a part of the references of this standard: P524A, proposed title: Guide to Grounding During the Installation of Overhead Transmission Line Conductors.

accessible voltage drop. Voltage difference between any two points accessible to workers at the work site.

anchor. A device that serves as a reliable support to hold an object firmly in place. The term is normally associated with cone, plate, screw or concrete anchors, but the terms *snub, dead man* and *anchor log* are usually associated with pole stubs or log set or buried in the ground to serve as temporary anchors. The latter are often used at pull and tension sites. (*See: anchor log*, IEEE Std 100-1988 [2].) *Synonyms: anchor log; dead man; snub*.

bonded. The mechanical interconnection of conductive parts to maintain a common electrical potential. (*See: bonding*, IEEE Std 100-1988 [2].) *Synonym: connected.*

bundle, two-conductor, three-conductor, four-conductor, multiconductor. A circuit phase consisting of more than one conductor. Each conductor of the phase is referred to as a subconductor. A two-conductor bundle has two subconductors per phase. These may be arranged in a vertical or horizontal configuration. Similarly, a three-conductor bundle has three subconductors per phase. These are usually arranged in a triangular configuration with the vertex of the triangle up or down. A four-conductor bundle has four subconductors per phase. These are normally arranged in a square configuration. Although other configurations are possible, those listed are the most common. *Synonyms: twin-bundle; tri-bundle; quad-bundle*.

clamp, grounding. A device used in making a connection between the electrical apparatus or conductors, and the ground bus, or grounding electrode.

conductor. A wire or combination of wires not insulated from one another, suitable for carrying an electric current. However, it may be bare or insulated. *Synonyms: cable; wire*.

de-energized. Free from any electrical connection to a source of potential difference and from electric charge; not having a potential different from that of the ground. The term is used only with reference to current-carrying parts that are sometimes alive (energized). (*See: dead*, IEEE Std 100-1988 [2].) To state that a circuit has been de-energized means that the circuit has been disconnected from all intended electrical sources. However, it could be electrically charged through induction from energized circuits in proximity to it, particularly if the circuits are parallel. *Synonym: dead.*

energized. Electrically connected to a source of potential difference, or electrically charged so as to have a potential different from that of the ground. (*See: alive*, IEEE Std 100-1988 [2].) *Synonyms: alive; current carrying; hot; live*.

equipotential. An identical state of electrical potential for two or more items.

fault (components). A physical condition that causes a device, a component, or an element to fail to perform in a required manner, for example, a short circuit, or a broken wire.

fault (current). A current that flows from one conductor to ground or to another conductor owing to an abnormal connection (including an arc) between the two.

ground (earth). A conducting connection, whether intentional or accidental, by which an electrical circuit or equipment is connected to earth, or to some conductive body of relatively large extent that serves in place of the earth.

ground grid (temporary). A system of interconnected bare conductors arranged in a pattern over a specified area and on or buried below the surface of the earth. Normally, it is bonded to ground rods driven around and within its perimeter to increase its grounding capabilities and provide convenient connection points for grounding devices. The primary purpose of the grid is to provide safety for workers by limiting potential differences within its perimeter to safe levels in case of high currents that could flow if the circuit being worked became energized for any reason, or if an adjacent energized circuit faulted. Metallic surface mats and grat-

4. The numbers in brackets correspond to those of the References in 1.3.

ings are sometimes utilized for this same purpose. When used, these grids are employed at pull, tension, and midspace splice sites. (*See: counterpoise; ground grid; ground mat*, IEEE Std 100-1988 [2].) *Synonyms: counterpoise; ground gradient mat; ground mat.*

ground, personal. A portable device designed to connect (bond) a de-energized conductor or piece of equipment, or both, to an electrical ground. Distinguished from a master ground in that it is utilized at the immediate site when work is to be performed on a conductor or piece of equipment that could accidentally become energized. *Synonyms: ground stick; working ground.*

ground rod. A rod that is driven into the ground to serve as a ground terminal, such as a copper-clad rod, solid copper rod, galvanized iron rod, or galvanized iron pipe. Copper-clad steel rods are commonly used during conductor stringing operations to provide a means of obtaining an electrical ground using portable grounding devices. *Synonym: ground electrode.*

ground, running. A portable device designed to connect a moving conductor or wire rope, or both, to an electrical ground. These devices are normally placed on the conductor or wire rope adjacent to the pulling and tensioning equipment located at either end of a sag section. Primarily used to provide safety for personnel during construction or reconstruction operations. *Synonyms: ground roller; moving ground; rolling ground; traveling ground.*

ground, structure base (temporary). A portable device designed to connect (bond) a metal structure to an electrical ground. Primarily used to provide safety for personnel during construction, reconstruction, or maintenance operations. *Synonyms: butt ground; ground chain; structure ground; tower ground.*

ground, traveler. A portable device designed to connect a moving conductor or wire rope, or both, to an electrical ground. Primarily used to provide safety for personnel during construction or reconstruction operations. This device is placed on the traveler (sheave, block, etc.) at a strategic location where an electrical ground is required. *Synonyms: block ground; rolling ground; sheave ground.*

induction, electrostatic (electric coupling). A common misnomer. There is no IEEE definition for *electrostatic*. The term *static* implies "at rest" or not varying with time. Therefore, this term may be construed to mean induced potential or current resulting from an object being placed in a dc electric field, but often the term is loosely used to include ac field effects.

induction (coupling). The process of generating time-varying voltages and/or currents in otherwise unenergized conductive objects or electric circuits by the influence of the time-varying electric and/or magnetic fields.

electric field induction (capacitive coupling). The process of generating voltages or currents or both in a conductive object or electric circuit by means of time-varying electric fields.

NOTES

1—*Electric field induction* is preferred over *electric induction* because the latter may be taken to mean electric flux density.

2—*Electric field induction* was formerly called *electrostatic induction*. This usage is deprecated because electrostatic fields are time invariant.

magnetic field induction (inductive coupling). The process of generating voltages and/or currents in a conductive object or electric circuit by means of time-varying magnetic fields.

NOTES

1—*Magnetic field induction* was formerly called *electromagnetic induction*. This usage is now deprecated because electromagnetic induction refers to combined electric and magnetic field effects.

2—*Magnetic field induction* is preferred over *magnetic induction* because the latter is reserved to mean magnetic flux density.

electromagnetic field induction (electromagnetic coupling). The induction process that includes both electric and magnetic fields.

isolated. (1) Physically separated, electrically and mechanically, from all sources of electrical energy. Such separation may not eliminate the effects of electromagnetic induction. (2) Not readily accessible to persons unless special means for access are used.

jumper. (1) A metallic wire connecting the conductors on opposite sides of a dead-end structure so that continuity is maintained. *Synonym: dead-end loop*. (2) A conductor placed across the clear space between the ends of two conductors or metal pulling lines that are being spliced together. Its purpose then is to act as a shunt to prevent workers from accidentally placing themselves in series between the two conductors.

line, pulling. A high-strength line, normally synthetic fiber rope or wire rope, used to pull the conductor. However, on reconstruction jobs where a conductor is being replaced, the old conductor often serves as the pulling line for the new conductor. In such cases, the old conductor must be closely examined for any damage prior to the pulling operations. *Synonyms: bull line; hard line; light line; sock line.*

overhead groundwire (OHGW) (lightning protection). Multiple grounded wires placed above phase conductors for the purpose of intercepting direct strokes in order to protect the phase conductors from the direct strokes. *Synonyms: earth wire; shield wire; skywire; static wire.*

resistance, body. Determined from the ratio of voltage applied to current flowing in a body, neglecting capacitive and inductive effects. That value impeding the current flow through the common body resulting from contact with an energized line.

sheave. (1) The grooved wheel of a traveler or rigging block. Travelers are frequently referred to as sheaves. *Synonyms: pulley; roller; wheel*. (2) A shaft-mounted wheel used to transmit power by means of a belt, chain, band, etc.

shock, primary. A shock of such a magnitude that it may produce direct physiological harm. Result of primary shock: fibrillation, respiratory tetanus, and/or muscle contraction.

shock, secondary. A shock of such a magnitude that it will not produce direct physiological harm, but it is annoying and may cause involuntary muscle reaction. Result of secondary shock: annoyance, alarm, and aversion.

static charge. Any electric charge at rest (e.g., charge on a capacitor), often loosely used to describe discharge conditions resulting from electric field coupling.

step potential. The potential difference between two points on the earth's surface separated by a distance of one pace (assumed to be one meter) in the direction of maximum potential gradient. This potential difference could be dangerous when current flows through the earth or material upon which a worker is standing, particularly under fault conditions. *Synonym: step voltage*.

stringing. The pulling of pilot lines, pulling lines, and conductors over travelers supported on structures of overhead transmission lines. Quite often, the entire job of stringing conductors is referred to as stringing operations, beginning with the planning phase and terminating after the conductors have been installed in the suspension clamps.

switching surge. A transient wave of over-voltage in an electrical circuit caused by a switching operation. When this occurs, a momentary voltage surge could be induced in a circuit adjacent and parallel to the switched circuit in excess of the voltage induced normally during steady-state conditions. If the adjacent circuit is under construction, switching operations should be minimized to reduce the possibility of hazards to the workers.

touch potential. The potential difference between a grounded metallic structure and a point on the earth's surface separated by a distance equal to the normal maximum horizontal reach, approximately one meter. This potential difference could be dangerous and could result from induction or fault conditions, or both. *Synonym: touch voltage.*

traveler. A sheave complete with suspension arm or frame used separately or in groups and suspended from structures to permit the stringing of conductors. These devices are sometimes bundled with a center drum, or sheave and another traveler, and used to string more than one conductor simultaneously. For protection of conductors that should not be nicked or scratched, the sheaves are often lined with nonconductive or semiconductive neoprene or with nonconductive urethane. Any one of these materials acts as a padding or cushion for the conductor as it passes over the sheave. Traveler grounds must be used with lined travelers in order to establish an electrical ground. *Synonyms: block; dolly; sheave; stringing block; stringing sheave; stringing traveler.*

3. Principles

3.1 Introduction

Voltage may appear at the work site due to accidental reenergization either through the isolating device or due to contact with another circuit, electric or magnetic induction from adjacent circuits, or a direct or indirect lightning stroke.

3.2 Voltages at the Work Site

When a grounded conductor becomes energized, the current flowing through grounded parts could result in potentially hazardous voltage differences between these parts if the protective grounding is inadequate. Figure 1 illustrates working positions aloft where abnormal voltages might appear. Figure 2 shows the step and touch voltages at the base of a line structure that could be of hazard to the groundman.

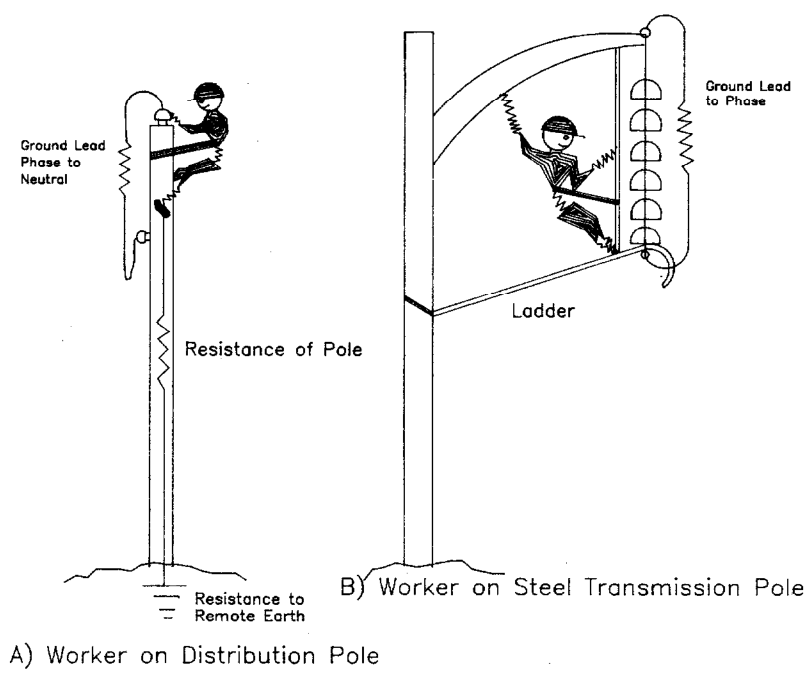

Figure 1 — Working Positions Aloft Where Abnormal Voltages Might Appear

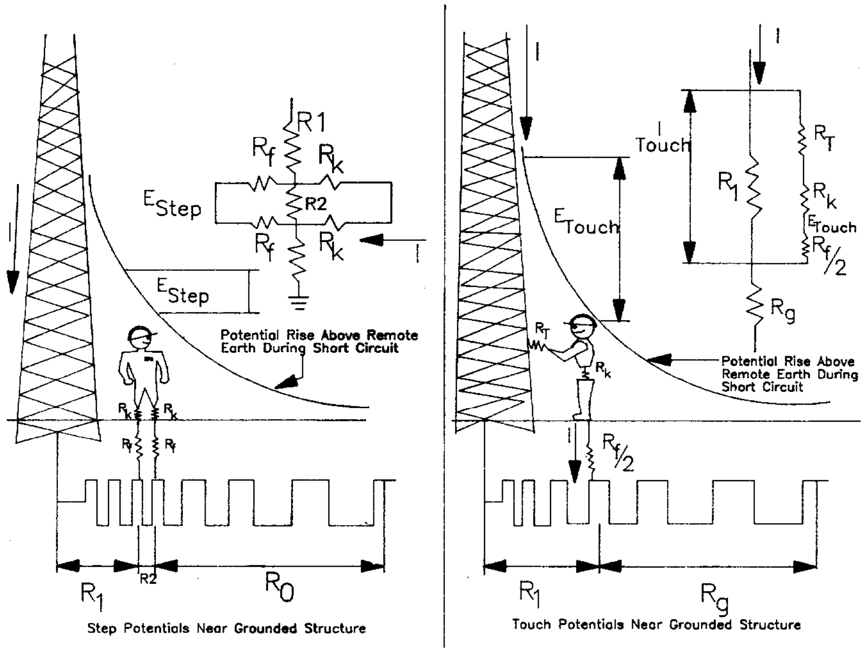

Figure 2 — Step and Touch Voltages at the Base of a Line Structure That Could Be of Hazard to the Groundman

Proper protective grounding will result in a safe working environment. Sufficiently low resistance grounds will limit excessive voltages in the work area aloft and proper work procedures will prevent exposure to step and touch potentials on the ground below the structure.

3.3 Safe Body Current Limits

Certain effects of frequency currents flowing in the human body have been fairly well defined and are summarized in Table 1. A person lightly touching a charged object might sense a faint tingling feeling in the finger tips when the current is within the touch perception threshold for the individual.

If a person grips a conductor that delivers a current at the touch perception level, the person would probably no longer feel anything, because the current spreads out over a larger contact area and is below the grip perception threshold.

If the current is increased gradually beyond a person's perception threshold, the current level begins to be bothersome and possibly becomes startling. At sufficiently large currents, the muscles of the hand and arm involuntarily contract. The maximum current a person can tolerate and still manage to release a gripped conductor is called the "let-go" threshold.

If a current somewhat above the "let-go" magnitude passes through the chest, it is possible that an involuntary contraction of the muscles will occur, which will arrest breathing as long as the current continues to flow (so called, "respiratory tetanus").

Currents flowing across the chest can disturb the heart's own electrical stimulation and cause it to assume an uncontrolled vibration called "ventricular fibrillation" and cease to beat (this is the most common cause of death by electrocution). The minimum body current to cause ventricular fibrillation for at least 0.5% of the adult population is determined by Dalziel's formula for adults weighing 50 kg (110 lbs) [3]:

$$I_{mA} = \frac{116}{\sqrt{t}} \qquad (1)$$

where

t = the duration of the current in seconds, provided it is in the range of 8.3 ms to 3 s. The constant, 157, is used for a utility worker weighing not less than 70 kg (154 lbs).

Although this relationship may be modified in the coming years, it is a well established one. The formula gives a current limit for assessing the safety of electrical systems, where it is generally the touch voltage that is known. To determine the safe touch voltage, the resistance of the person and the associated clothing, footwear, and grounding must be selected. Figure 3 illustrates the various series resistances that need to be considered.

Table 1—Reactions to Power Frequency Currents

Threshold Reaction/Sensation	**Borderline Value (0.5% of Persons*) (mA)**		**Average Value (50% of Persons) (mA)**	
	Women	**Men**	**Women**	**Men**
Touch Perception	0.09	0.13	0.24	0.36
Grip Perception	0.33	0.49	0.73	1.10
Startle-Arm Contact	—	—	2.20	—
Let-go	6.00	9.00	10.50	16.00
Respiratory Tetanus	—	—	15.00	23.00
Ventricular Fibrillation	67†	100†	—	—

* 1% of persons for perception values
† Differences among men and women are due to body size differences.

Source: Mousa, Abdul M., New Grounding Procedures for Work on De-Energized Lines, *IEEE Transactions on Power Apparatus Systems*, vol. PAS-101, Aug. 1982, pp. 2668–2680.

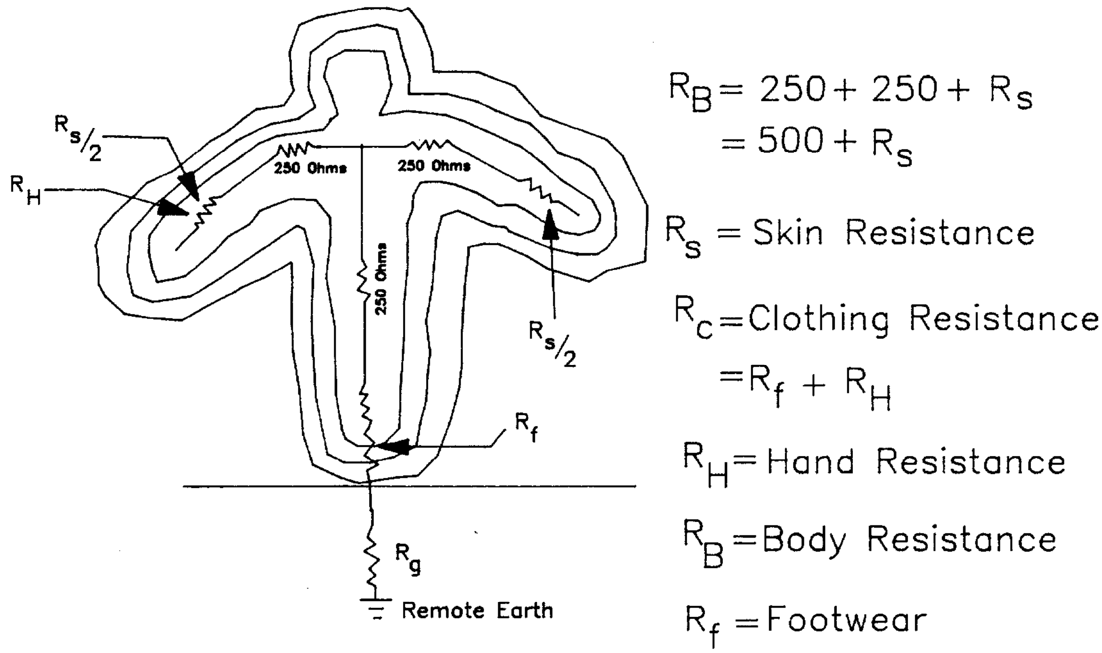

Figure 3 — Resistance of Person (Between Point of Contact and Remote Earth)

3.3.1 Body Resistance, R_b

The resistance of the human body consists of two resistances in series: the internal body resistance and the skin resistance. The internal body resistance is usually taken to be 500 Ω, although this subject is presently undergoing some thorough reevaluation. The skin resistance, R_s, in series with the body, is highly variable between persons and greatly reduced by various factors. For example, a soaked skin has less resistance than when dry. Some typical values of the total body resistance are given in Table 2. In addition, the body resistance depends on the applied voltage, as shown in Fig 4.

Table 2—Body Resistance in Ohms

Subject	Hand-to-Hand		Hand-to-Feet
	Dry	Wet	Wet
Maximum	13500	1260	1950
Minimum	1500	610	820
Average	4838	865	1221

NOTE—40 subjects tested.

Source: Dalziel, Charles F., The Effects of Electric Shock on Man, *IRE Transactions on Medical Electronics*, vol. PGME-S, May 1956.

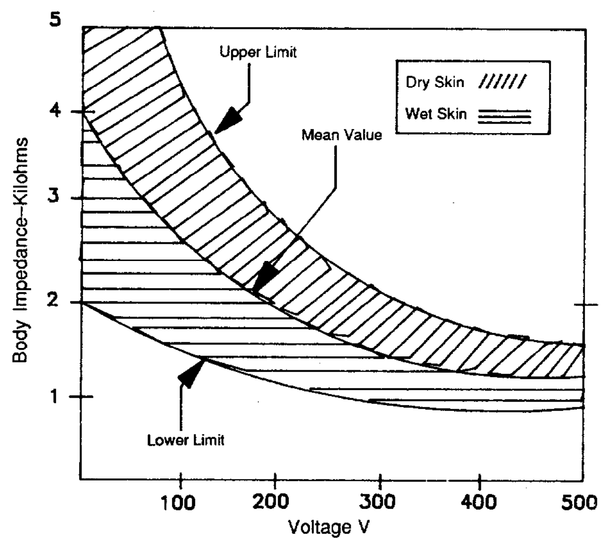

Figure 4 — Relation Between Body Impedance and Voltage

3.3.2 Clothing and Footwear Resistance, R_c

Although the clothing (for body contact) and glove (hand contact) resistance can naturally be quite substantial, they are generally neglected safety assessments. Electrical workers sometimes wear resistive footwear to reduce the severity of injury in case accidental contact is made. On the other hand, workers exposed to electric field from high-voltage equipment or lines, which can cause annoying spark discharges, may wear conductive footwear (boots or overshoes), which can have a resistance of less than 500 Ω.

3.3.3 Ground Resistance, R_g

The resistance of each foot to "remote earth" is generally taken to be $R_g = 3p_s$, where p_s = the ground resistivity. Typical values are given in Table 3.

Table 3—Derivation of Contact Resistance Between Each Foot and Ground (R_f) for Various Soil Composition

	Soil Composition			
	Wet Organic Soil	Moist Soil	Dry Soil	Bedrock
p_s (Ω-m)	10	100	1000	10 000
R (Ω) = $3 \cdot p_s$	30	300	3000	30 000

Source: Electrostatic Effects of Overhead Transmission Lines, Part I—Effect and Safeguards, *IEEE Transactions on Power Apparatus Systems*, vol. PAS-91, March/April 1972, pp. 422–426.

3.4 Fault Currents

System fault currents can flow in the protective grounds if

1) The grounded circuit is accidentally reenergized from its normal source voltage(s) (i.e., inadvertent reclosure); or
2) The grounded circuit is accidentally energized by another circuit (i.e., by sagging into another line or an energized line falling into the grounded circuit, or both).

The possibility that either one of these accidents could occur should be recognized before the de-energized work is undertaken, and the ampacity of the protective grounds should be selected to withstand the fault current that could be available from one or both kinds of source.

For proper selection of protective grounds, the nature of the fault current available must be known in

1) Magnitude
2) Duration
3) DC offset and magnetic forces

3.4.1 Magnitude

The maximum calculated fault current magnitude at a particular station is normally available from system planning data. Present day values range up to 70 kA for some systems.

Although the available fault current is seldom at its calculated maximum due to variations in system generating and loading patterns, the maximum value is usually taken for conservative calculations. Computer techniques are now also available to determine probability distributions of the fault current, such as shown in Fig 5. From this typical figure, it can be seen that the probability of the maximum fault current occurring is very small and it can be calculated that there is a 99% probability of not exceeding 60% of this value. Using such a probabilistic approach would, therefore, give much lower maximum fault current magnitudes.

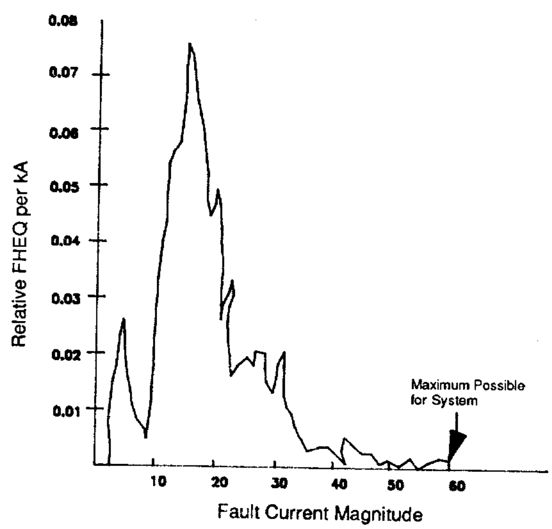

Figure 5 — Typical Fault Current Magnitude Probability Density Distribution

Figure 6 shows how line impedance decreases the fault current magnitude for a typical system, as the fault location moves away from the substation bus.

Because protective grounds may be installed from one phase to ground or between two or three phases and then to ground, the fault for which the grounds are selected can be either a line-to-ground, a phase-to-phase-to-ground, or a three-phase fault. The highest magnitude fault to be encountered by the grounding system must be considered.

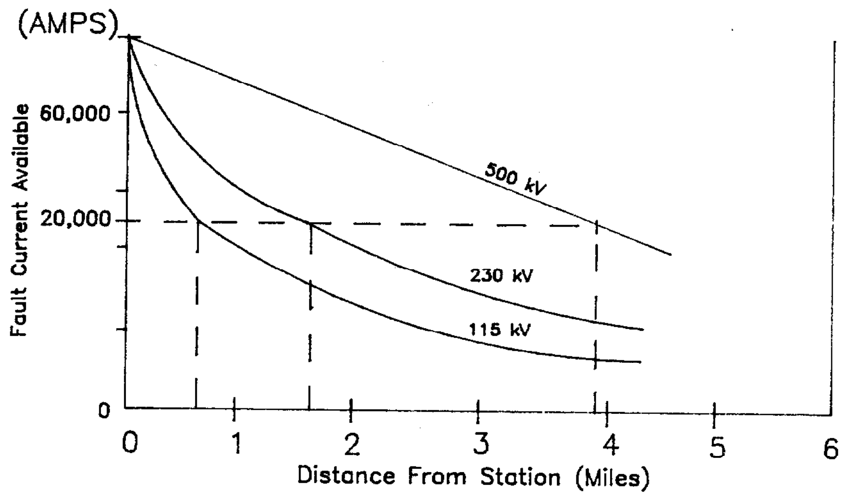

Figure 6 — Distance from Station (Miles)

3.4.2 Duration

Less readily available are the historical values of fault clearing time for the particular voltage level in the system. Clearing times for the secondary protection are often used for selection of protective ground size.

3.4.3 DC Offset and Mechanical Force

Occasionally, the fault current can have a magnitude, just after initiation, greater than the steady-state value that it reaches after several cycles, as shown in Fig 7. The mechanical forces acting on the ground leads during a fault are proportional to the square of the instantaneous current magnitude and, therefore, the maximum value (or dc offset) of the fault current is important in determining the adequacy of protective grounds. Some typical values of mechanical force are shown in Table 4.

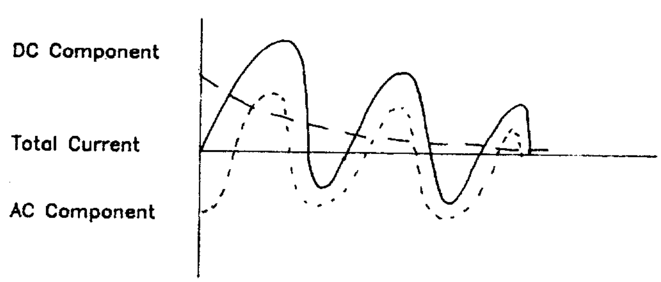

Figure 7 — Fault Current with a Magnitude, Just After Initiation, Greater Than Steady-State Value That it Reaches After Several Cycles

Table 4—Fault Current vs. Mechanical Force

Fault Current		Mechanical Force*
Steady State	**Peak**	
10 kA	12 kA	18 lb/ft
10 kA	20 kA	50 lb/ft
30 kA	40 kA	200 lb/ft
30 kA	60 kA	450 lb/ft

*For a 3 ft separation between conductors.

Although the peak forces are high, the destructive forces are manifested more as those required to stop a loose cable once the magnetic forces have accelerated it to a high velocity. The location of the cable in relationship to the working position should be considered. (See 6.5.)

3.5 Rating of Grounding Sets

The protective grounds are insulated conductors that must be capable of carrying the current and withstanding the mechanical forces for at least as long as the current lasts. In addition, the accessible voltage drop across the ground set cables (i.e., between connecting points) must not be hazardous. The rating of the grounding set thus depends on the following:

1) The current-carrying capacity of the cable
2) The current-carrying capacity of the cable clamps and their connection to the cable
3) How well it is connected at its ends (i.e., surface preparation and tightness)
4) The configuration it is being used in
5) The resistance of the complete grounding system

NOTE —Specifications for grounding cables, clamps, and ferrules are covered in ASTM F-855-1983 [1].

3.5.1 Cable Rating

The "melting characteristics" of some common copper cable sizes are shown in Fig 8. If the ground lead rating is exceeded during a fault, fusing of the copper increases the cable resistance, resulting in increased voltage drop across the grounding cables. Therefore, the cable size is usually selected so as to preclude fusing at the rated fault current magnitude and duration. For comparisons of grounding cable and jumper ratings between copper and aluminum cables, see ASTM F-855-1983 [1], Table 5.

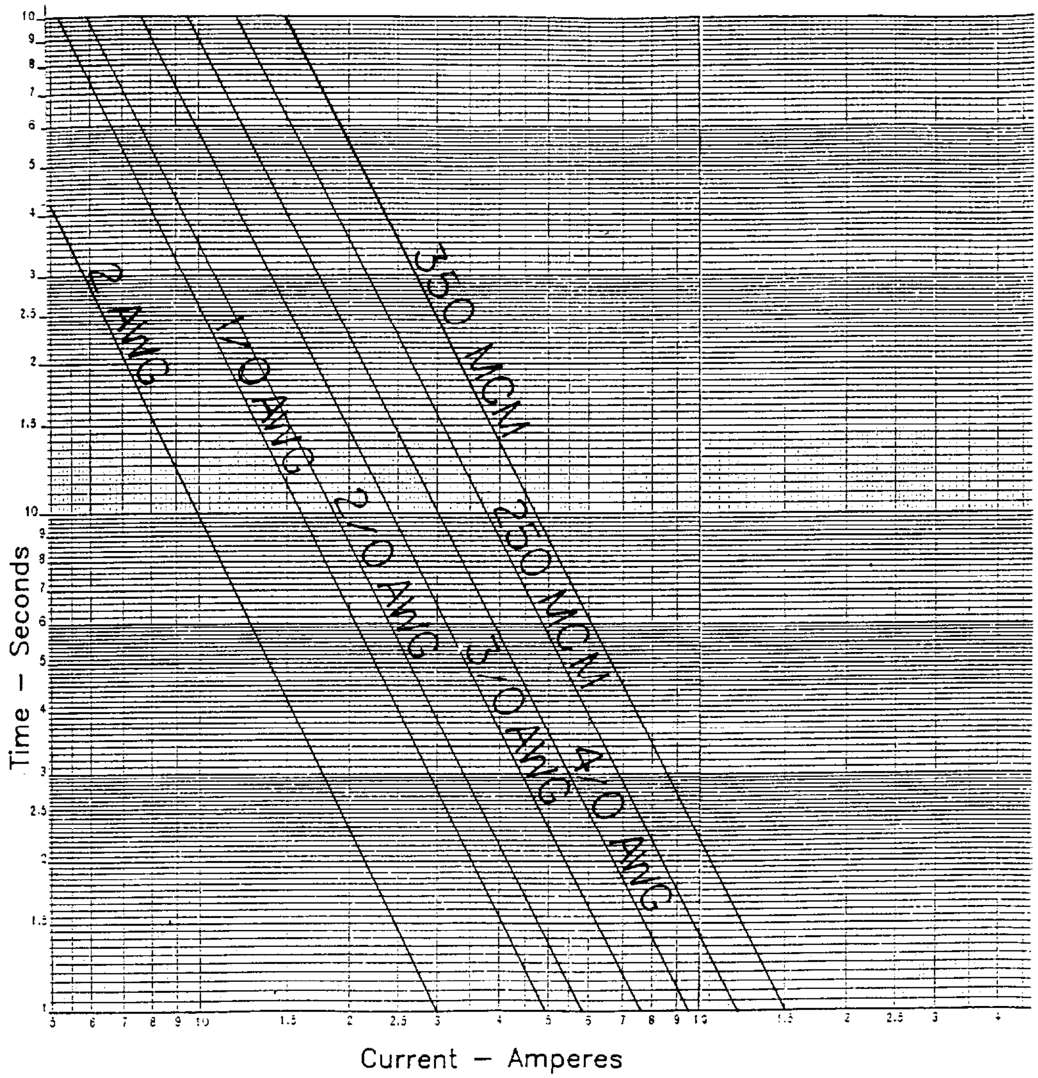

Figure 8 — Fusing Current vs. Time for Copper Conductors

Table 5—Distribution Line Grounding Practices

Protective Grounding	Figure	Power Company		
		A	B	C
Location				
At work site		X*	X	X
Bracketed		X	X	
Connection				
All phases on structure		X	X	
One phase only, if desired				X
Type of Ground Lead				
Cluster ground	12	X	X	X
Single ground leads	12, 13	X	X	
Pole band		X	X	
Ground Electrode				
Neutral		X	X	X
Neutral + driven ground			X	
Driven ground only		X		X
Guy anchor		X	X	X
Other			X	
Special Precautions				
Ground rod heating				
Ground mat				

*X = method used.

3.5.2 Clamp Rating

After a clamp is selected for a particular size of grounding cable, and a conductor size to which it is to be connected, it is common practice to test a sample of the complete grounding set at its intended rating. Of paramount importance is proper current transfer between the cable and the connecting point, and adequate mechanical strength under the most arduous combination of current dc offset and configuration of the fault current paths. Because the mechanical forces can lead to movement of the clamp, it is important that the clamp is so restrained at the connecting point that such movement does not result in the clamp being dislodged completely. Such a test might destroy the cable or clamps or both.

3.5.3 Clamp Connection

Provisions must be made in the work instruction for proper surface preparation at the connection points to ensure low contact resistance to prevent the clamps from being "blown off" by mechanical forces. Failure to remove the high-resistance oxide layer at the connection point can lead to excessive resistance heating and consequent melting at the connection, resulting in loosening and dislodging of the clamp. A brittle, corrosive layer could also cause the clamp to loosen. When tightening clamps, always follow the manufacturer's recommendations.

3.5.4 Circuit Configuration

The mechanical forces in the grounding cables are inversely proportional to the distance from a path of adjacent current flow. The proximity and configuration of other conducting paths that form the rest of the grounded circuit, therefore, play a role in the stresses imposed on the ground.

When a grounding set is tested, the current return paths can be defined, and it is recommended that the worst configuration likely to be encountered in the field be simulated for test purposes.

3.5.5 Resistance of Ground

In many cases, the two conducting parts that the grounding cable is connecting are simultaneously accessible by the worker, in which case the voltage difference between these two parts must be safe if a fault occurs. Dalziel's formula can be used to establish a safe voltage for the expected fault current magnitude and duration (see [3]).

In most cases, however, the size of cable required to accommodate a given fault current will be of sufficiently low resistance per unit length that the voltage drop across the jumper is negligible, unless the cable is extremely long.

3.6 Induction Coupling

When an isolated line is located adjacent to one or more energized lines, it is subject to both capacitive and magnetic coupling from the live line(s), as illustrated in Fig 9.

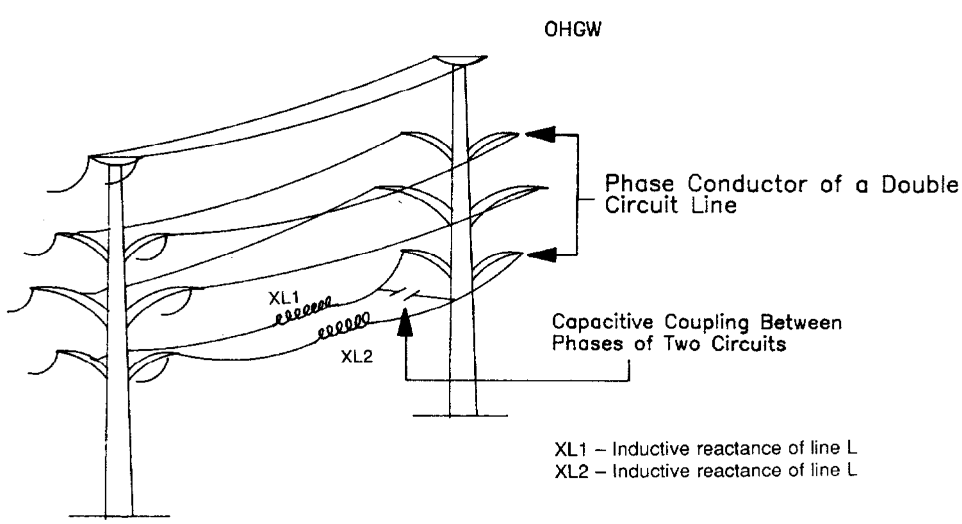

Figure 9 — Capacitive and Inductive Coupling Between Adjacent Circuits

3.6.1 Capacitive Coupling

Because of the capacitive couplings between each of the live conductors and each of the de-energized ones, a voltage is induced in the de-energized conductors. The induced voltage depends on the operating voltage and on the relative location of the live phases, and can be hazardous to workers. If the de-energized line were grounded at one point, the induced current that would flow is directly proportional to the exposed length of the two lines. Some values of capacitive, as well as magnetic, coupling are shown in Fig 10 for typical line configuration.

Connection of a single grounding cable to a line subject to capacitive coupling does not present any great difficulty. On the other hand, removal of such a ground can result in a long arc, which may be quite distressing to an unprepared person manipulating the grounding cable. Tests have shown that the length of the arc is quite unpredictable, depending on the initial current flowing, the voltage after the arc is extinguished, the prevailing weather, and the speed of withdrawal of the ground clamp.

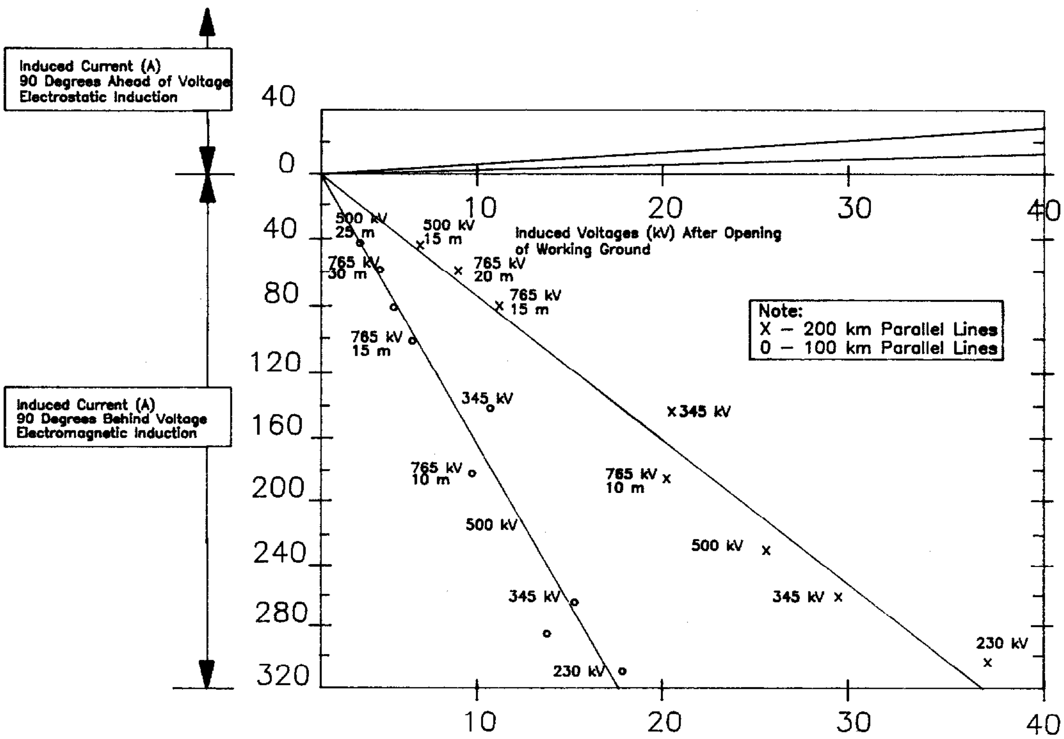

Figure 10 — Some Values of Capacitive, as Well as Magnetic, Coupling for Typical Line Configuration

3.6.2 Magnetic Coupling

Due to inductance between each of the live and each of the de-energized phases, a loaded live line induces a voltage in an adjacent parallel de-energized one. If the de-energized circuit is grounded at two locations either through line ground switches or protective grounds, a circulating current through the grounds that may be in the order of several hundred amps for long, closely coupled lines, will result. This can result in recovery voltages and currents that make it very difficult to remove the grounds and that may be disturbing to the worker. Switching devices and appropriate work methods should, therefore, be available to cope with such situations should they arise.

In addition to the problems of removal of grounding cables, the continuously induced currents that may flow in protective ground sets during the course of the work may give rise to possibly hazardous voltages due to variations in ground resistance.

The magnetically induced currents, being directly proportional to the current in the adjacent live circuit, can clearly be increased manyfold if the live circuit becomes faulted. Since the grounding sets themselves will be rated for the full fault current of the circuit on which they are being used, it is, however, unlikely that the current induced by a faulted adjacent line will exceed the ground's rating, even when the work is being conducted on a low-voltage line adjacent to a high-capacity one.

3.7 Lightning

Although work on lines is generally not done during a lightning storm, it is not possible to guarantee that lightning will not strike near or to the line. As a result, there will be a voltage surge traveling on the line in both directions, due either to all or part of the stroke current itself, or to induction from the stroke or from the shield wire. This steep-fronted wave will be attenuated as it travels on the line. Despite the attenuation, however, it is clear that the voltage remaining on the conductor, quite some distance from the stroke, may be hazardous.

Properly sized protective grounding cables will be able to withstand even the full current from the most severe lightning stroke. However, the voltages arising on the conductor being grounded and the step and touch potentials at the base of the structure may be hazardous at locations far from the incidence of the lightning stroke.

4. Grounding Practices

4.1 Introduction

This section describes the proven practices of many power companies regarding when grounding sets are used, where they are connected, how many are used, and what kind of ground electrode they are connected to. How protective grounds are actually installed, including the safety precautions taken, is described in Section 6, Work Procedures.

4.2 Theoretical Considerations

If the conductor that is being contacted by workers becomes energized for some reason, the voltage rise at the work site depends on a number of factors such as the following:

1) Fault current available at that location
2) The location of grounding sets relative to the work site and the fault current source
3) The number of phases that are grounded
4) The integrity of bonding between the conductor and the surface on which the worker is standing

A worker on the ground who happens to be touching grounded parts of the structure or conducting equipment attached to them, would be exposed to a voltage that depends on the method of connection to earth as well as on (1) and (2) above. Unfortunately, optimum conditions of (1) and (2) for the worker touching the conductor generally result in poor conditions for the worker on the ground, and vice versa.

4.2.1 Work-Site vs. Bracketed Grounding Sets

The decision to use work-site grounds (single point) or bracketed (adjacent structure grounds) involves evaluation of the electrical risk to all members of the crew and requires analysis of line design and permanent structure grounding practices of the utility.

In general, the use of work-site grounding sets will result in the minimum obtainable impedance path in parallel with the lineman's body, and thus, the minimum body intercept voltage (see Fig 11) for the lineman. Personnel at ground level may be subjected to higher step and touch potential than with bracketed ground sets depending upon design, i.e., the presence of overhead groundwire and tower grounding practice. However, personnel at ground level should normally be positioned in areas of low-voltage gradient while line work is in progress.

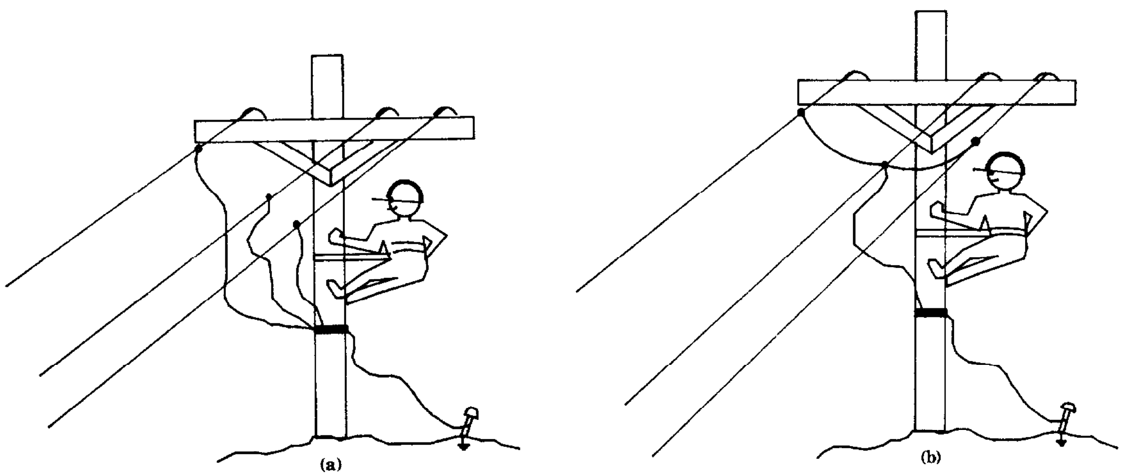

Figure 11 — The Minimum Obtainable Impedance Path in Parallel with the Lineman's Body, and Thus, the Minimum Body Intercept Voltage

Voltages that can be developed at the work site may come from several sources: first, at power frequency, from inadvertent clearance violation; and/or second, from accidental contact with another energized circuit. The magnitude and duration of these depends upon the system fault capacity and clearing time. A third source, while lower in magnitude, is continuous induction, magnetic or capacitively coupled. Impulse voltages from lightning may also appear at the work site and while the magnitude is large, the duration is very short.

With bracketed grounding sets, the conductors are shorted and grounded at adjacent towers on either side of the work site. With no overhead groundwire, most of the current will flow through the bracketed grounding sets and will result in increased voltage above remote ground. Its magnitude is determined by the current and the tower footing resistance. Since the work site tower is located at essentially remote ground, full tower rise voltage will appear between the work site tower and the conductor, and thus be applied to any lineman who has contact with both (see Fig 12).

When a shield wire is connected to each structure, current will also flow to earth through the work-site tower, but still a voltage will develop between the conductor and tower that could be hazardous to the lineman.

With work-site or single-point grounding, the lineman will be subjected to the minimum possible voltage between conductor and tower regardless of whether an overhead groundwire is used or not.

Ground personnel will be subjected to similar hazards on lines with overhead groundwire connected to all line structures whether single-point or bracketed grounding is used. Voltage gradients will be higher for single-point grounding on lines without overhead groundwire, but this hazard can be minimized by positioning of personnel away from the structure and will always be less of a hazard than that of the lineman using bracketed grounds.

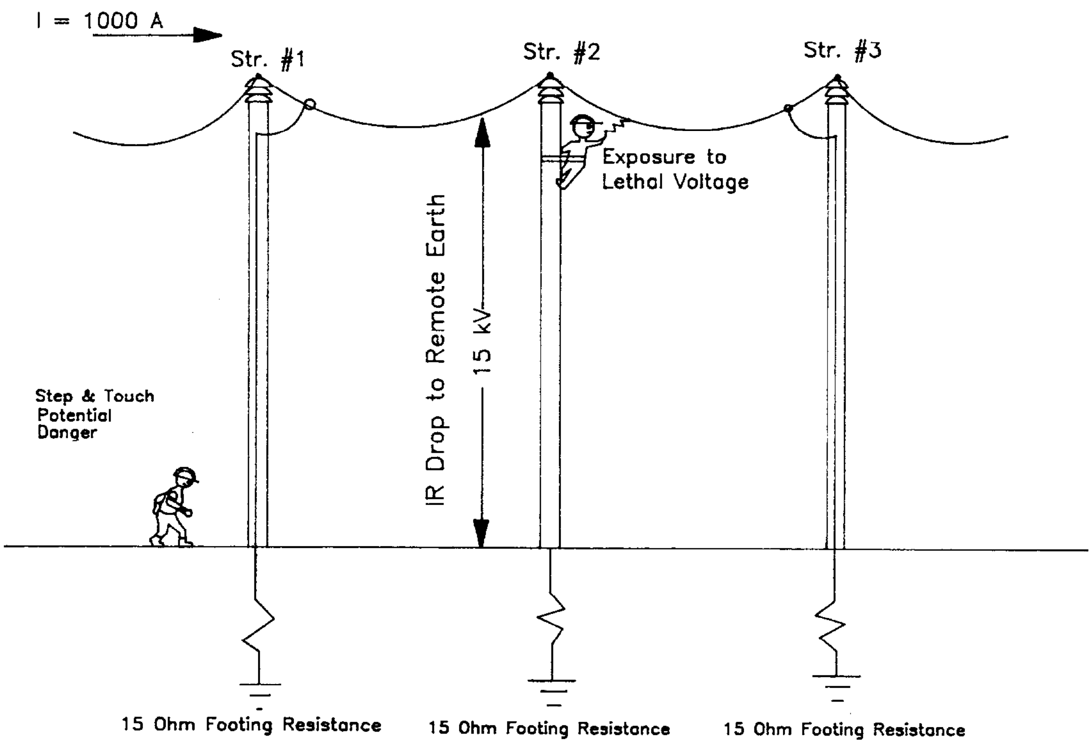

Figure 12 — Bracket Grounding

4.2.2 Single-Phase vs. Three-Phase Grounding

The magnitude of three-phase short-circuit currents may be higher than that of a single-phase short, especially when the ground resistance is high. In fact, the single-phase fault current of a three-phase distribution line, grounded only on one phase through a high-resistance ground, may be insufficient to cause the line circuit breaker to open. Protective grounds applied to all phases will therefore provide more certain, and generally more rapid, operation of breakers when ground resistance is high.

In addition, three-phase grounding also means that only a small part of the fault current of a three-phase fault would flow to ground at the structure, thereby reducing the step and touch potentials at the base of the structure. If ground resistances are low enough to ensure consistent fault clearing, and the step and touch potentials are within acceptable limits or can be guarded against, then grounding of only one phase of a three-phase line might be permitted. However, working clearances must always be maintained for the ungrounded phase conductors.

4.2.3 Bonding

In addition to the conductor being grounding at the work site, it may be bonded to the surface on which the worker is standing. Connection of a ground to a metal structure or the use of a pole platform, having a metal surface that is connected to the conductor, provides such bonding. In case of accidental reenergization, bonding maintains the worker at the same potential as the energized conductor.

Since the resistance of a wood pole may be as low as 2000 Ω per linear foot, the pole must be regarded as an electrical conductor from the point of view of shock hazard. Unfortunately, its resistance is too high to provide a good ground connection for a worker climbing it. For these reasons a collar, incorporating a grounding stirrup, is often clamped around the pole below the work position to provide a bond around the work area on the pole.

4.2.4 Ground Electrode

Protective grounds can be connected to the established ground of the structure, to another good ground electrode (i.e., a neutral conductor or a station ground), or to a temporary driven ground rod. In each case, the ground current, if the circuit is energized, will cause a voltage rise at the ground electrode proportional to its resistance to remote earth. The voltage rise is the step and touch potentials around the ground electrode (Fig 2), and may be hazardous to personnel in this area if suitable work methods are not adopted.

Use of an available shield wire as the ground electrode has merit since it distributes the current among a number of structures and so reduces the voltage rise at the base of the structure. It also generally provides a path of low resistance to remote earth.

Similarly, a neutral conductor is frequently used for its generally low resistance, compared with a driven ground. In the case of ungrounded poles, the common neutral ground can also eliminate the potential hazard of a voltage rise at the base of the pole. However, this voltage rise is then transferred to the grounded point if the common neutral is grounded away from the work site. Care must therefore be exercised that the worker on the pole is not exposed to any hazardous voltage between the phase and neutral conductors and any other grounded parts (i.e., guys) that may be within the worker's reach or even the (partly conductive) pole itself.

A temporary driven ground rod must be used if the structure's grounding is questionable. In the case of ungrounded poles, to avoid exposing the worker on the ground to the voltage rise at the ground rod, it is generally driven some distance away from the pole, and if possible, away from the work area because of its unknown ground resistance. If the structure is grounded, however, this practice can lead to a voltage difference between the structure ground and the driven rod when a ground current flows.

The latter is an example of the use of more than one ground electrode, which can pose a hazard if it is not recognized that any ground current flowing will divide between the electrodes and probably cause a difference in potential between them.

There may be a temptation to supplement an existing ground with a much lower resistance ground, such as a station ground grid, but the greater the difference in ground resistance of the two electrodes, the higher the voltage between them. This is particularly relevant when a continuous ground current is flowing, as in the case of induction from parallel lines.

When such a continuous current is flowing in a ground rod it should also be recognized that the current may be enough to cause drying out of the soil surrounding the rod, leading to a progressively high resistance, and associated voltage rise. A twenty-fold increase in resistance over about 5 min has been reported due to this effect. One power company uses a rule of thumb of 50 W/ft of buried ground rod as a limit above which the rod would start to heat considerably.

4.3 Distribution Line Grounding

There is often a wide variation in power company grounding practices. While these differences may stem from differences in "grounding philosophy," there are often significant local differences because of ground resistivities, system design, and general work procedures. These specific local conditions should not be overlooked when comparing a company's work procedures. Table 5 indicates if, and how, various power companies employ grounding practices on distribution lines.

4.4 Transmission Line Grounding

Various power company practices are shown in Table 6.

Table 6—Transmission Line Grounding Practices

Protective Grounding	Figure	Power Company					
		A	B	C	D	E	F
Location							
At work site		X*	X	X	X	X	
Bracketed		X	X				X
Connection							
All phases on structure		X			X	X	X
One phase only, if desired		X†	X	X			
Phase-to-metal structure					X		
Phase-structure-phase-structure-phase	14, 16	X		X	X		
Phase-phase-ground	15						
Phase-phase-ground-shield wire	15						
Pole band	14, 16	X		X			
Other							
Ground Electrode							
Shield wire			X	X‡	X		
Shield wire + driven ground			X	X	X		
Driven ground only		X	X		X	X	
Guy anchor		X	X	X	X	X	
Other							
Special Precautions							
Ground rod heating			X				
Ground mat			X	X		X	
Removal of grounds in presence of induction			X	X	X	X	
Supplementary grounding near high-fault locations			X	X	X	X	
Ground current measurement						X	
Touch voltage measurement						X	

*X = method used.
†Only on 500 kV with station switch closed.
‡Only as a last resort on rock.

5. Power Line Construction

Grounding practices during construction should follow the same principles as outlined for de-energized maintenance activities. Ground points should be selected to provide a minimal resistance path to remote earth. All equipment should be kept in excellent condition. All surfaces to which grounding clamps are connected should be cleaned to ensure proper contact. Frequent inspection of all components is essential.

Grounding methods and procedures when stringing overhead groundwire are the same as those for conductors as detailed in P524A (see 1.3.1).

6. Work Procedures

6.1 Introduction

Typical operating procedures prior to and at the conclusion of de-energized work are outlined in this section.

6.2 Voltage Detection Methods

Voltage detection is the process of sensing voltage on a line to determine whether or not the line voltage is present and is used only for confirmation of isolation and only after standard clearance procedures are complete.

6.2.1 Buzzing

Buzzing is a process performed by linemen to ensure that features being worked on have been isolated. Buzzing is a method of determining circuit deenergization by audible means. Buzzing may be accomplished with the use of a variety of tools and devices such as live line tools, noisy testers, and voltage detectors.

6.2.2 Live Line Tool Method

Buzzing a circuit through the use of a live line tool is one of the simplest methods. This process involves nothing more than touching the metal cap at the end of a live line tool to the conductor. If the voltage is high enough to produce a buzzing sound, the circuit is considered energized. If the opposite is true and the buzz is not heard, the line is to be considered isolated.

6.2.3 Noisy Tester Method

The noisy tester operates using the same concept as the hot stick method. A noisy tester is an instrument attached to the end of a live line tool, which is used to produce a buzzing sound to indicate an energized line. The noisy tester resembles a two-pronged metal fork with a ball attached to one end of a prong. The other prong is sharpened to a point. By touching the ball to the conductor, the lineman produces a corona on the pointed end. If the corona can be heard, the line is to be treated as an energized circuit.

6.2.4 Voltage Detectors

Voltage detectors perform the same function, only with more accuracy and reliability. There are three types of detectors in common use: the neon indicator, the hot horn or noisy tester, and the multiple range type.

Voltage detection is used to provide an indication of voltage levels and isolation of a line. Voltage detection should be used only as a secondary confirmation of isolation and only after standard work procedures, e.g., dispatcher communication, tag out procedure, and visually open gaps.

6.2.4.1 Neon Indicator

The neon indicator is held at the end of a hot line tool and positioned in the electric field produced by the conductor and produces a clear visual indication of an energized circuit. Neon indicators should be tested prior to and after each use.

6.2.4.2 Hot Horn or Noisy Tester

The noisy tester voltage detector (NTVD), not to be confused with the noisy tester buzzing device, alerts personnel of voltage by means of alarm. It is often used to check areas in the underground, around switchgear, substations, and overhead lines. Many NTVD's will give a signal despite the type of voltage in the line. Other types of NTVD's are equipped with two pitches to differentiate between the line and electromagnetically induced voltages. This detector is battery operated, with either 4.5 V or 9 V depending upon the voltage detector, and is positioned at the end of a live line tool. Operation of the NTVD depends on the specific manufacturer. Typically, however, all that is involved is turning on the device and placing the detector in the electric field of the conductor. (See Table 7 for distances to ensure safe and accurate results.)

The NTVD should not be touched to conductors energized at 33 kV and above.

Table 7—Noisy Tester Voltage Detector—Detection range

Distance from Conductor	kV on Conductor
1 in	4
4 in	13
12 in	26
1.5 ft	33
3 ft	110
6 ft	230

Most NTVD's are supplied with test and disconnect switches. The instrument should be checked before and after each test to ensure proper and accurate usage.

6.2.4.3 Multiple Range Voltage Detector (MRVD)

The MRVD is essentially a multiple range field intensity meter. The MRVD is operated by means of a selector switch, which enables the user to vary kilovolt ranges. The lineman can then use the MRVD to *approximate* line-to-line voltage by hanging the steel contact hook into a single phase. The MRVD is not a voltmeter. The MRVD uses field strength to estimate line-to-line voltage, whereas the voltmeter uses the actual voltage and difference in potential to determine the voltage reading. Therefore, the MRVD is not an accurate instrument and all readings should be regarded as estimates. If the interpretation of the meter reading is questioned, assume the line is energized and take necessary safety precautions, i.e., always assume the circuit is live until proven otherwise. Like the NTVD, the MRVD is battery operated and equipped with an internal battery circuit and a test button. The MRVD should be checked before and after each test.

6.3 Advantages and Disadvantages of Voltage Detectors

Each voltage detector has its advantages and disadvantages. It is left up to the users to determine which detector will be most appropriate for their purposes.

6.3.1 Neon Indicator

The advantage to using the neon indicator type voltage detector is that it provides a good visual indication; however, the detector is limited in its application uses and may light up due to induced voltage from a nearby line.

6.3.2 Noisy Tester Voltage Detector

The following are the advantages to using an NTVD:

1) It is not necessary to make contact with the line to receive an approximation of the voltage.
2) The NTVD is one of the simplest devices to use.
3) It is less expensive and lighter in weight than the MRVD.

Its disadvantages are that it is limited to a maximum of about 250 kV and also that it does not give any specific indication of estimated voltage.

6.3.3 Multiple Range Voltage Detector

There are many advantages to using an MRVD. First, the MRVD provides a more reliable indication between energized and de-energized lines than do other voltage detectors. It also enables the user to provide a more specific approximation of the voltage on the line. Lastly, on certain types of MRVD's the operating voltages may be as high as 550 kV. The MRVD, nevertheless, is not without its disadvantages. In order to operate the MRVD, the instrument must come in contact with the conductor. The MRVD is also heavier and more costly than other voltage detectors. Another distinct disadvantage to the MRVD is that it is affected by various factors. For instance, if the device is close to a ground, or to another energized conductor, the reading will register higher than the actual voltage on the measured conductor. The opposite will be true if the MRVD is near a jumper or equipment operating at the same phase voltage.

6.4 Cleaning Conductor and Ground Connections

6.4.1 Purpose

The purpose for cleaning the conductor and ground connection is to limit the voltage drop across the connection. Special attention should be paid to the connections between the cable and ferrule, and the ferrule and grounding clamp. These are considered to be the weak points in the grounding set cables in terms of current-carrying capacity.

6.4.2 Equipment and Method

Conductors and ground connections may be cleaned by one of two methods: wire brushing or self-cleaning clamps.

6.4.2.1 Wire Brushing

Some lines must be cleaned by the use of wire brushes. The wire brush is easily attached to a live line tool. When a brush is required to clean an aluminum conductor, an inhibitor should be used. The effects of wire brushing will virtually disappear after 20 min.

If self-cleaning clamps are not used, the clamp jaws and the conductor surfaces should be cleaned immediately before attachment.

6.4.2.2 Self-Cleaning Clamps (SCC's)

SCC's are simply ground clamps with serrated jaws to provide additional corrosion penetration. SCC's can be used on ground-to-conductor connections to ensure a good connection. To use an SCC, simply tighten the SCC lightly onto the conductor, rotate the clamp a few degrees in each direction, and secure the clamp. As with any type of clamp, the jaws should be cleaned after use, and worn parts should be replaced as deemed necessary by the user.

6.4.3 Weathering Steel and Painted Steel Tubular Structures

For weathering steel and painted steel tubular structures, special precautions shall be heeded. The protective oxide on weathering steel, which is highly resistive, should not be removed. In this particular situation, grounding is best accomplished by welding a copper or steel bar to the structure on which the ground end clamp can be attached or a stainless steel nut into which a threaded copper stud can be inserted.

6.5 Ground Installation Using Live Line Tools

When placing grounds, some type of insulating tool or material shall be used in case some component involved in the grounding is "hot." In most cases, live line tools are a natural choice.

6.5.1 Tools

The principal tool used for grounding application is the live line tool.

6.5.2 Methods of Use

After installing the ground end first, a live line tool is used to hold the conductor-end of the groundwire when connecting it to the conductor. This will prevent any shock hazard to the worker in case the conductor is at a different potential than the ground.

6.5.3 Voltage Ratings of Tools

Live line tools are to be of adequate length and rated for the voltage on the line in question.

6.5.4 Problems of Control

When applying heavy grounding cables, a worker may have difficulty in controlling them. To help, a co-worker may assist with an additional live line tool or a "shepherd hook" with a nonconductive rope and pulley.

6.6 Placing of Grounds

Grounds should be placed either at the work site or at a distance as close as possible to the work location. (See Section 4, Grounding Practices.) If the situation arises such that the installation of a ground is not practical or would create an unsafe condition, the ground should not be installed and line worked as if it were energized.

6.6.1 Safety

One precaution to keep in mind when placing a ground is that the grounding set should be installed close to the work location, but not so close as to be disturbed during work. Before working on or coming within minimum working distance of high-voltage lines or equipment, those parts to be worked on must be placed at ground potential. Minimum work distances as established by governing agencies should be observed when installing grounds.

It is also recommended that personnel installing the grounds use live line tools and, according to individual company rules, eye protection against intense rays from electric arcs, sparks, and possible molten metal during the arcing period when connecting the ground cable to the conductor. Always remember that all conductors and equipment should be treated as energized until tested and grounded.

If a grounding set in service is subjected to rated current, through accidental reenergization or lightning stroke, and it cannot be restored to original capacity, it should be destroyed.

6.7 Methods of Use

When placing a grounding cable, the ground end is always connected first, followed by the connection of its opposite end to a clean metallic surface to provide a good connection to ground. The connection of the ground to the phase should be done quickly and positively using an insulated tool or live line tool to minimize the arcing period and potential harm to personnel. Grounding procedures for metal transmission-line structures and wooden structures are similar; however, they are not identical.

6.7.1 Metal Structures

When grounding conductors supported by metal towers, a grounding-cluster support may be used. The grounding-cluster support ensures the adjacency of the ground terminals, and consequently provides a low-resistance connection. The ground end clamps may be connected directly to the tower structural members. On low-voltage lines, linemen may ground the phases from a position near or at the level of the conductors.

6.7.2 Wooden Structures

Grounding-cluster supports should be used on wooden structures for the same reason as for metal structures. The grounding-cluster supports, however, should not positioned any higher than the level of the phase for safety and convenience reasons (see Fig 13). Generally speaking, the methods used to ground wooden structures are similar to those used for metal structures. One major difference, however, is the procedure concerning pole grounding conductors that are not present on metal structures. Pole groundwires should be checked and inspected before installing the ground to ensure continuity.

These wires should be checked for cuts and damages, and also to determine whether or not they are still in place. Some pole groundwires may not have sufficient capacity to carry fault currents. If any doubts exist concerning the fault current capability of the pole grounds, the use of a temporary ground rod and down ground are required.

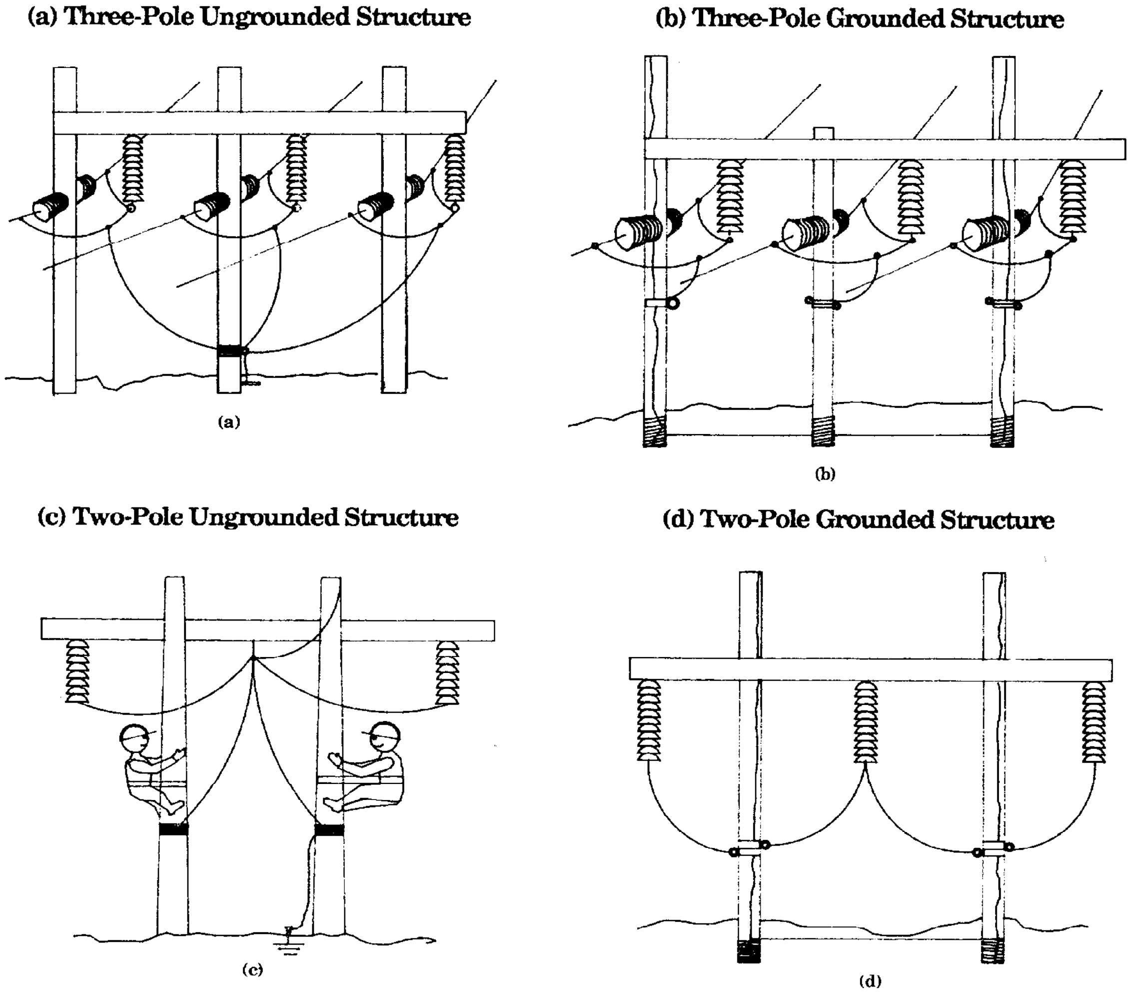

Figure 13 — Grounding Cable Installation

6.8 Length of Grounding Conductors

Ground conductors are often tied to the structure or tower leg to prevent excessive motion and subsequent harm to personnel and equipment if fault current were to pass through them. It is recommended that excess slack in the grounding cable be secured. However, it should not be coiled or wrapped around metallic objects since that tends to reduce the current capability of the cable.

6.9 Removing Grounds

6.9.1 Method

Grounding cables must be removed in reverse order of application, i.e., the connection to the de-energized line must be removed first and the disconnection of the grounding cable at the ground end must follow. If removing the ground by live line tools is too difficult, a second ground adjacent to the first may be installed. The first ground may then be removed by hand and the second by means of live line tools.

6.9.2 Precautions

Several safety precautions should be considered when removing a ground, such as using live line tools for disconnecting grounds. In the initial step of removal, an arc may develop, with the length dependent upon the induced voltage of the line. Also, the linemen should avoid handling the ground lead while the conductor end is being removed. After disconnecting the ground lead from the de-energized line, it should be isolated from nearby lines and buses before disconnecting the ground end to avoid producing any accidental induced voltage.

7. Grounding Practices—Vehicles and Equipment

7.1 Aerial Devices

While working from a platform on an aerial device, an equipotential zone for the worker should be obtained by bonding the platform or boom or both to the de-energized circuit. It is also recommended that the vehicle chassis be connected to the common temporary or permanent ground electrode when possible, or that the vehicle be isolated from contact.

Workers on the ground should be aware of the step potential hazards near the vehicle chassis as well as the structure and ground electrodes. P524A indicates a different method of bonding depending on the type of aerial device in use (see 1.3.1).

7.2 Equipment—Diggers, Cranes, and Other Work Vehicles

When using any equipment to perform work on de-energized circuits, it is recommended that the equipment chassis be bonded to the common temporary or permanent ground electrode to establish an equipotential work area or that the vehicle be isolated from contact.

Workers and operators should be aware of the step potential hazards near the equipment as well as the structure and ground electrodes.

8. Equipment

8.1 Introduction

This section describes the temporary grounding system used for personal protection while working on de-energized power lines.

8.2 Application and Use of the Protective Grounding System

8.2.1 Clamps

Before each use, grounding clamps should be physically inspected and sized for the object with which the connection is to be made. Each clamp jaw should be cleaned before use.

8.2.2 Cable

Grounding cable should be physically inspected before each use and be found free of any defects that would prohibit proper operation. The cable should be of desired length, and tied off with suitable slings if the cable is of extra length or if the cable has to pass near energized conductors or close to any mechanical hazard.

8.2.3 Connections

The object(s) to which the clamp is to be connected should be clean and be able to accept the clamp. When SCC's are to be used, the clamp rotation, when lightly installed, will suffice in lieu of cleaning. Most vehicles that require grounding have a lug or loop welded or connected to the frame. A good low resistance is required between the frame of the vehicle and ground.

8.2.4 Installation

The ground connection must always be made first and removed last. The clamps should be tightened appropriately on the ground or conductor or both. When tightening clamps, always follow the manufacturer's recommendations. Should a short circuit occur, the item to which the clamp is connected should not be damaged. A good electrical joint between the conductor and clamp is vital.

8.2.5 Configuration

When short-circuiting grounds are installed, a wye or star connection scheme is desirable. This arrangement balances the voltage in the work site to a considerable degree.

8.3 Testing

8.3.1 Component Design Tests

These are specified by ASTM F-855-1983 [1].

8.3.2 Periodic Tests

Each grounding set should be physically (visually) inspected before each use. Periodic electrical tests can also be used.

9. Ground Electrodes

9.1 Pole Grounds

Pole grounds are usually of a size considerably smaller than the personal protective ground and should be supplemented for current-carrying capacity for all transmission and substation applications. Pole grounds are satisfactory for distribution application if electrically connected to the system neutral and if of adequate capacity.

9.2 System Neutral

The system common neutral may be used for distribution grounding applications.

9.3 Overhead Groundwire (OHGW)

The OHGW may be used for transmission line ground application if electrically connected to the structure or structure ground.

9.4 Ground Rods

Ground rods may be used for certain independent applications midspan when driven to achieve a low ohmic resistance, a normal 5 to 8 ft length.

9.5 Measuring Devices

The most common instruments used for measuring ground resistance use the reference method requiring driven rods placed remotely from the point of reading. When there is a possibility of circulating currents due to induced voltage, care should be taken to monitor a driven ground rod, i.e., the ground area around the rod. The earth should not be allowed to bake or dry out due to the current flow.

10. Bibliography

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