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IEEE Guide for Protective Grounding of Power Lines

IEEE Power Engineering Society

Sponsored by the
Transmission & Distribution Committee

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IEEE Guide for Protective Grounding of Power Lines

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Approved 20 March 2003

IEEE-SA Standards Board

Abstract: Guidelines for protective grounding methods for individuals engaged in de-energized overhead transmission and distribution line maintenance are provided. This guide also provides information on the sizing and maintenance of protective ground sets. It is a compilation of information on protective grounding practices employed by North American power utilities.

Keywords: de-energized overhead line maintenance, protective ground set sizing, protective grounding, protective grounding practices, safety, testing and maintenance protective grounds

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Introduction

(This introduction is not part of IEEE Std 1048-2003, 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 right-of-ways become more crowded with heavily loaded circuits, leading to growing problems of electric or magnetic induction. This guide has compiled state-of-the-art information on protective grounding practices employed by power utilities in North America.

The revision of the guide was undertaken to add information on the electrical hazards related to electric utility vehicles working adjacent to power lines. Electrostatic induction develops a voltage on the vehicle, its magnitude depending upon the vehicle's insulation from ground, the separation distance, and the voltage and current on the adjacent line. The hazards may include both a transient discharge current as the vehicle is grounded through a person's body and a steady-state capacitive current that may flow through the vehicle. The revision discusses the advantages of isolating the worksite by barricading the vehicle to protect the public from the electrical hazards.

The revision also includes factors important in sizing protective grounds. These factors are based on a review of current practices, technical information, and safety criteria. The factors are intended to protect electrical workers during work on de-energized transmission and distribution lines.

The primary purpose of factors in sizing protective grounds is to ensure that protective grounds utilized during de-energized work on transmission and distribution lines are sized to adequately protect workers from injury or electrocution. Protective ground sizing is required for the maximum magnitude and duration of current that may flow in a grounding system at a worksite. The current may be of short duration from accidental energization of the line or may be due to continuous current from magnetic induction by nearby energized circuits.

This revision addresses the size of protective grounds to carry fault currents or induced current at the worksite for the full duration of current. Determination of fault current magnitude considering the ac and dc offset components and the effect of X/R (X is reactance and R is resistance) ratios is discussed. Primary and backup relaying times are discussed because both items are important considerations for sizing protective grounds. The determination of currents induced by nearby energized circuits is also discussed as an essential consideration for sizing protective grounds.

The material requirements for protective grounding sets are discussed in detail. Recommended materials, ratings, component design and shape, jacket material, resistance, mechanical stress considerations, and details of multiple grounding systems are also covered.

Finally, a discussion of the practical use of protective grounds is covered. The preferred practice is to use a single protective ground at a worksite. Because a single protective ground cannot always be accomplished, it is permissible to parallel more than one grounding cable. The precautions required for multiple protective grounds used in parallel are discussed. This guide concludes with a presentation of in-service maintenance, inspection, and testing guidelines.

This guide was developed through the collaborative effort of an international group of volunteers with expertise in many disciplines. While this guide represents a consensus among this volunteer group, it is not the only view on the issues addressed herein. As with any guidance, use of this guide and the procedures and positions herein does not provide proof of or guarantee safety. Use and compliance with this IEEE guide are wholly voluntary.

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Contents

IEEE Guide for Protective Grounding of Power Lines

1. Overview

1.1 Scope

This document provides guidelines for grounding methods to protect workers and the public from voltages that might develop in a jobsite during de-energized maintenance of overhead transmission and distribution lines.

1.2 Purpose

This document is intended to provide guidance for protective grounding in jobsites during de-energized maintenance of power lines. The primary purpose of protective grounding is to limit the voltage difference between any two accessible points at the worksite to an acceptable value. As an IEEE guide, the purpose of this document is to suggest approaches for protective grounding. This guide does not have mandatory requirements. Following the suggestions in this guide helps to mitigate risks, and users should take all reasonable steps necessary to minimize risks during de-energized maintenance of power lines.

2. References

This guide should be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ASC C2-1997, National Electric Safety Code® (NESC®).[1, 2]

ASTM B263-1999, Standard Test Method for Determination of Cross-Sectional Area of Stranded Conductors.[3]

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

ASTM F855-1997, Standard Specifications for Temporary Protective Grounds to be Used on De-Energized Electrical Power Lines and Equipment.

IEEE Std 516™-1995, IEEE Guide for Maintenance Methods on Energized Power Lines.[4, 5]

IEEE Std 524a™-1993, IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors: Supplement to IEEE Std 524-1992 (Reaff 1997), IEEE Guide to the Installation of Overhead Transmission Line Conductors.

OSHA 29 CFR 1910.269, Occupational Safety and Health Standard: Electric Power Generation, Transmission, and Distribution—Subpart R: Special Industries.[6]

3. Definitions

Terminology for equipment and procedures associated with the installation of temporary protective grounding systems varies widely throughout the 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.

3.1 accessible voltage drop: Voltage difference between any two points accessible to workers at the worksite.

3.2 bonded: The mechanical interconnection of conductive parts to maintain a common electrical potential. (*See:* **bonding,** *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B7][7].) *Syn:* **connected.**

3.3 bracket grounding: A grounding method where temporary ground sets are installed on both sides of the worksite. *Syn:* **adjacent structure grounding.**

3.4 bundle, two-conductor, three-conductor, four-conductor, and multiconductor: One phase of a circuit 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. *Syn:* **twin-bundle**; **tri-bundle**; **quad-bundle.**

NOTE—The supporting hardware may not maintain an effective bond between the conductors during faults.

3.5 clamp, temporary grounding: A device used in making a temporary connection between the grounding cable and the ground bus or grounding electrode and between the grounding cable and the transmission or distribution facility that is being grounded.

3.6 cluster bar and cluster support: A terminal that is temporarily attached to the structure to support (it may serve to establish an equipotential zone) and provide a bar that will accommodate at least two grounding clamps and may have terminals to accommodate grounding cables.

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[6] OSHA publications are available from the U.S. Department of Labor/OSHA, OSHA Publications, P.O. Box 37535, Washington, DC 20013-7535 USA (http://www.osha.gov/).

[7] The numbers in brackets correspond to the numbers of the bibliography in Annex A.

3.7 combination ground: A grounding method where temporary ground sets are installed on structures on both sides of the worksite, and with a ground set on the phase being worked on at the worksite.

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

3.9 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 earth.

The term is used only with reference to current-carrying parts that are sometimes energized (alive). (*See:* **dead,** *The Authoritative Dictionary* [B7].)

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

3.11 electromagnetic field induction (electromagnetic coupling): The induction process that includes both electric and magnetic fields and generates a circulating current between two grounded ends of a line due to the proximity of an adjacent or close energized and loaded line.

3.12 energized: Electrically connected to a source of potential difference, or electrically charged to have a potential different from that of the earth in the vicinity. (*See:* **alive,** *The Authoritative Dictionary* [B7].) *Syn:* **alive; current-carrying; hot**; **live.**

3.13 equipotential: An identical state of electrical potential for two or more items. For the purposes of protective grounding, a near identical state of electrical potential.

3.14 fault (components): A physical condition that causes a device, a component, or an element to fail to perform in a required manner.

3.15 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.

3.16 ground or grounded: 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, resulting in the circuit or equipment to be grounded. *Syn:* **ground (earth).**

3.17 ground grid (permanent): A system of interconnected bare conductors arranged in a pattern over a specified area and buried below the surface of the earth. It may be bonded to ground rods driven around and/or within its perimeter to decrease its resistance to remote earth. It provides convenient connection points for grounding devices. *Syn:* **counterpoise**; **ground gradient mat**; **ground mat.**

3.18 ground grid (temporary): Temporarily installed metallic surface mats or grating to establish an equipotential surface, which may be bonded to ground rods temporarily driven around and/or within their perimeter to increase the grounding capabilities and provide convenient connection points for grounding devices.

3.19 ground potential rise (GPR): The maximum voltage that a station ground grid (or isolated grounding installation) may attain relative to a distant point assumed to be at the potential of remote earth.

3.20 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. Ground rods may be used to establish permanent or temporary earth ground. *Syn:* **ground electrode.**

3.21 ground set: A system of ground clamps and covered cables suitable for carrying fault current. *Syn:* **grounding jumper.**

3.22 ground, traveling: A device used to connect a moving conductor or wire rope, or both, to an electrical ground. This device is attached to the traveler (e.g., sheave, block) at a location where an electrical ground is required. *Syn:* **block ground**; **rolling ground**; **sheave ground.**

NOTE—Primarily used to provide safety for personnel during construction or reconstruction operations.

3.23 indirect stroke: A lightning stroke that does not strike a transmission or distribution conductor or structure directly, but induces an overvoltage in them.

3.24 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.

3.25 jumper: (1) A permanent section of the circuit phase conductor(s) connecting a dead-ended circuit phase to a second dead-ended circuit phase or to equipment, so that continuity is maintained. *Syn:* **dead-end loop.** (2) A temporary conductor placed across the clear space between the ends of two conductors or metal pulling lines. (3) A conductive tool used to maintain electrical continuity across equipment, or a conductor that shall be opened mechanically to enable various operations of live-line work to be performed. *Syn:* **bypass.**

3.26 line, pulling: A synthetic fiber rope, wire rope, or existing conductor being removed, used to pull the new conductor. *Syn:* **bull line; hard line; light line; sock line.**

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

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

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

3.30 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.

3.31 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.

3.32 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.

3.33 step voltage: The potential difference between two points on the earth's surface separated by a distance of one pace (assumed to be 1 m 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. *Syn:* **step potential.**

3.34 stringing: The pulling of pilot lines, pulling lines, and conductors over travelers supported on structures of overhead lines.

NOTE—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.

3.35 switching overvoltage: A transient wave of overvoltage in an electrical circuit caused by a switching operation. When an overvoltage condition 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.

3.36 touch voltage: The voltage difference between a grounded metallic structure or equipment and a point on the earth's surface separated by a distance equal to one normal maximum horizontal reach, approximately 1 m. *Syn:* **touch potential**.

NOTE—This voltage difference could be dangerous and could result from induction or fault conditions.

3.37 transfer touch voltage: A special case of touch voltage where a conductive element, such as a vehicle, grounded to the structure, brings the potential from the structure to a point spanning more earth than 1 m. The transfer touch voltage increases as the distance from the grounded structure or equipment increases.

3.38 worksite ground: A technique where the ground set is installed at the structure where the work is to be performed. *Syn:* **personal ground**; **ground stick**; **working ground**; **personal protective ground.**

4. Principles

4.1 Introduction

Voltage may appear at the worksite due to accidental energization either through the isolating device or due to contact with another energized circuit. Voltages or currents may be present due to electric or magnetic induction from adjacent energized circuits or due to a direct or indirect lightning stroke.

4.2 General

4.2.1 Voltages at the worksite

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 ground workers. Proper protective grounding will result in a reduced working hazard at the worksite. Sufficiently low-resistance ground leads will limit excessive voltages in the jobsite aloft, and proper work procedures will minimize exposure to step and touch voltages on the ground below the structure.

4.2.2 Body current limits

Certain effects of power frequency currents flowing in the human body have been well defined and are summarized in Table 1. A person lightly touching a charged object might sense a faint tingling feeling in the fingertips 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 gradually increases beyond a person's perception threshold, the current level begins to be bothersome and possibly becomes startling. At sufficiently large current, 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.

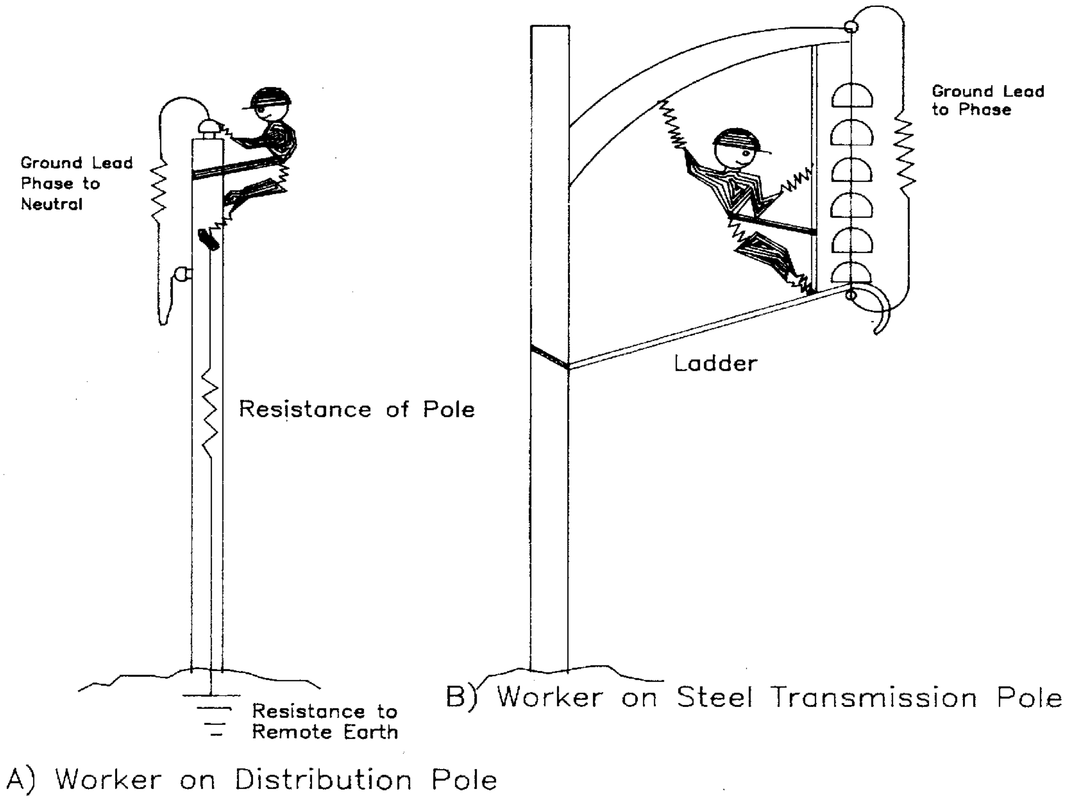
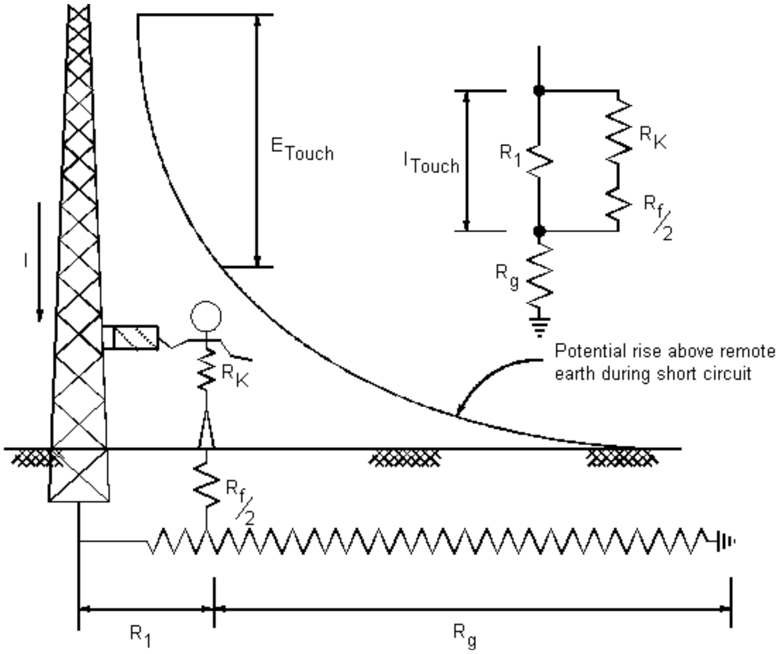


Figure 1—Working position aloft where abnormal voltage might appear

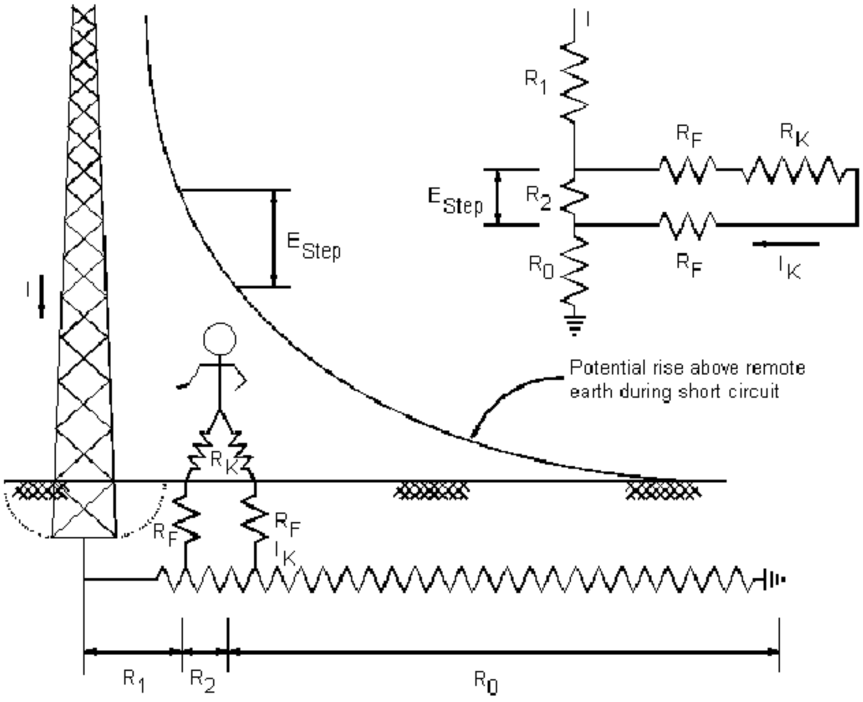
Table 1—Reaction to power frequency currents

Threshold reaction/sensation	Borderline value (0.5% of persons[a]) (mA)	
	Women	Men
Touch perception	0.09	0.13
Grip perception	0.33	0.49
Startle-arm contact	—	—
Let-go	6.00	9.00
Respiratory tetanus	—	—
Ventricular fibrillation[b]	67[c]	100[c]

[a] 1% of persons for perception values.
[b] A time-dependent function; see Equation (1).
[c] Differences among men and women are due to body size differences.



Touch voltage



Step voltage

Figure 2—Step and touch voltages at base of a line structure that could be of hazard to the ground worker

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. This contraction 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. This condition can cause the heart to assume an uncontrolled vibration called “ventricular fibrillation” and cease to beat. Ventricular fibrillation is the most common cause of death by electrocution. It has been found that 95.5% of the adult population weighing 50 kg or less will not experience ventricular fibrillation if the body current remains below that level determined by Dalziel’s formula, shown in Equation (1).

$$I_{mA} = \frac{116}{\sqrt{t}} \tag{1}$$

where

t is 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.

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 calculated. To determine the safe touch voltage, select the resistance of the person and the associated clothing, footwear, and grounding equipment. Figure 3 gives the series resistance for determining the safe touch voltages.

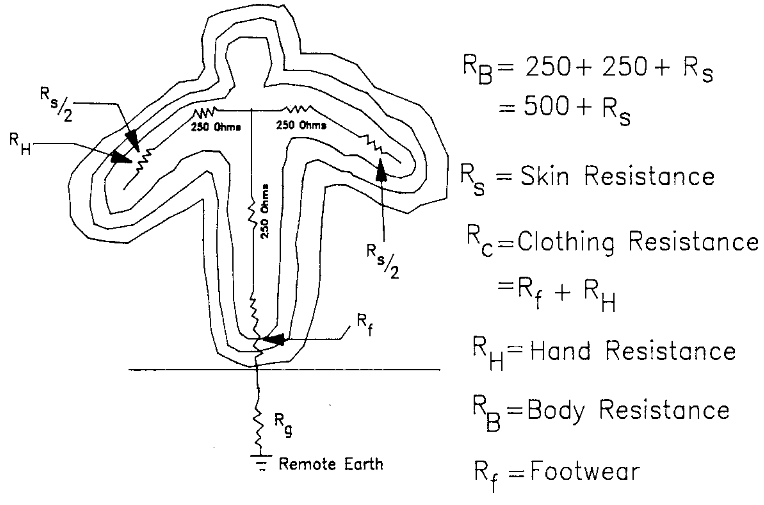


Figure 3—Resistance of person (between point of contact and remote earth)

4.2.3 Body resistance, R_b

The human body has two series resistances: the internal body resistance and the skin resistance. The total body resistance is usually taken as 1000 Ω for determining the body current limits, 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, wet skin has less resistance than dry skin. Table 2 gives typical values of the total body resistance. In addition, the body resistance depends on the applied voltage, as shown in Figure 4.

Table 2—Body resistance in ohms

Subject	Hand-to-hand		Hand-to-feet
	Dry (Ω)	Wet (Ω)	Wet (Ω)
Maximum	13 500	1260	1950
Minimum	1500	610	820
Average	4838	865	1221
NOTE—40 subjects tested (see Dalziel [B2]).			

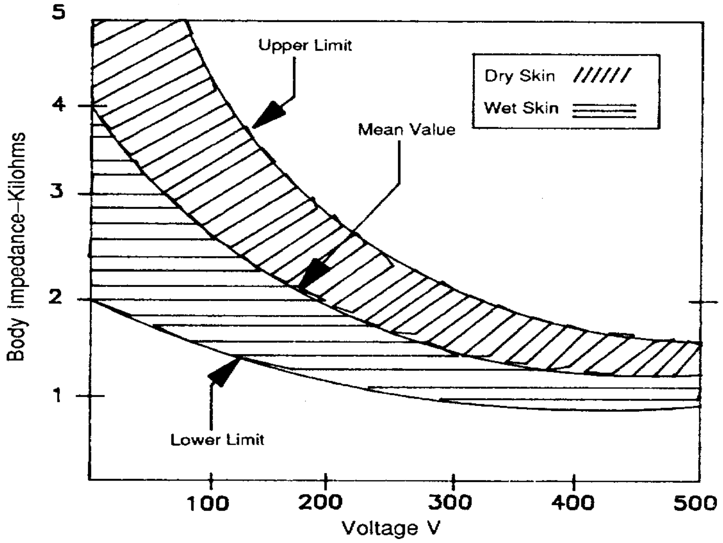


Figure 4—Relation between body impedance and voltage

4.2.4 Clothing and footwear resistance, R_c

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

4.2.5 Contact resistance, R_g

The resistance of each foot to "remote earth" is $R_g = 3p_s$, where p_s = the ground resistivity. Table 3 gives typical values (see "Electrostatic effects," Part I [B3]).

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) = $3p_s$	30	300	3000	30 000

4.3 Fault currents

System fault currents can flow in a protective ground if

a) The grounded circuit is accidentally reenergized from its normal source voltage(s) (e.g., inadvertent reclosure); or

b) The grounded circuit is accidentally energized by another circuit (e.g., by sagging into another line or an energized line falling into the grounded circuit, or both).

The possibility that an accidental energization of the isolated circuit could occur should be recognized, and the protective ground set sized to withstand the maximum fault current.

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

a) Magnitude and dc offset

b) Duration

4.3.1 Magnitude

The maximum calculated fault current magnitude at a particular station is normally available from system planning data. Present-day values may be higher than 70 kA for some systems.

Although the available fault current is seldom at the calculated maximum due to variations in system generating, loading patterns, and fault impedance, the maximum value is usually taken for conservative calculations. A probabilistic approach would, therefore, give much lower maximum fault current magnitudes.

Installation of protective grounds can be from one phase to ground or between two or three phases and then to ground. The highest magnitude fault to be encountered by the grounding system shall be considered.

The magnitude of the dc current ranges from zero to a magnitude equal to the crest ac.

Analytical studies indicate that when full dc offsets occur in locations with high X/R (X is reactance and R is resistance) ratios [such as close to a generating station (see Figure 5) or large transformer station], the short duration (6 to 60 cycle) fusing current ratings of grounding cables, calculated using Onderdonk's equation as considered in ASTM F855-1997[8], may not be appropriate. The additional heating from the dc component reduces the cable current-carrying capacity. With full dc offset, the current-carrying capacity of the cable shall have a rating of 71% of that with symmetrical current (see ASTM F855-1997).

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[8] For information on references, see Clause 2.

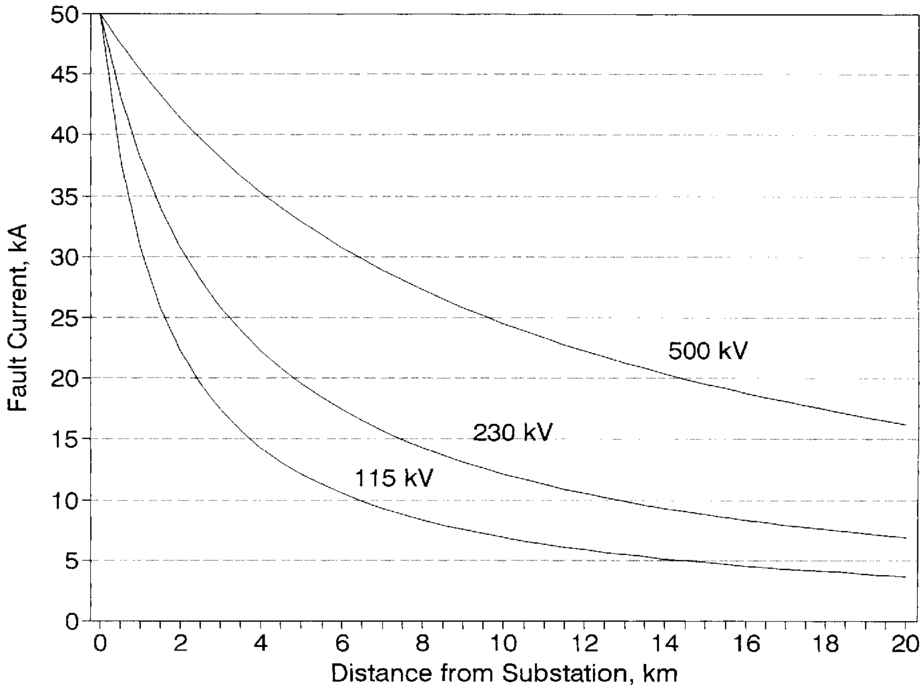

Figure 5—Distance from station

At or near large generating stations and substations, a large *X*/*R* ratio is likely because the impedance of the station is primarily inductive. Under most circumstances the *X*/*R* ratio does not exceed 35 to 40 within the substation. Several miles away from the station, the *X*/*R* ratio decreases because line resistance becomes the dominant factor. The line's *X*/*R* ratio typically ranges from 2 to 30 depending on the conductor size and configuration. A single small conductor line will have a low *X*/*R* ratio, while a bundled large conductor line will have a higher *X*/*R* ratio.

Occasionally, the fault current can have a magnitude, just after initiation, greater than the steady-state value it reaches after several cycles, as shown in Figure 6. The mechanical forces acting on the ground leads during a fault are proportional to the square of the instantaneous current magnitude. Therefore, the maximum value (or dc offset) of the fault current is important in determining the adequacy of protective ground systems. The forces for various fault currents are shown in Table 4. Equation (?), which calculates mechanical forces for fault currents not found in Table 4, can be found after Table 4.

When the mechanical 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 whip. The location of the cable in relationship to the working position should be considered (see 9.2.3).

4.3.2 Duration

The fault current duration is another critical factor when sizing a protective grounding system. The fault current duration is the time from fault initiation to clearing by the primary or backup relaying. The relay clearing time is the operating time of the relay plus the breaker operating time.

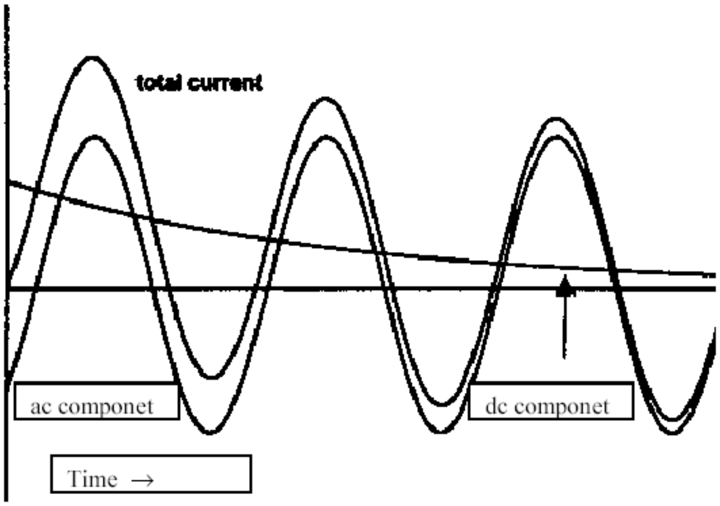

Figure 6—Fault current with a magnitude, just after initiation, greater than steady-state values that it reaches after several cycles

Table 4—Fault current versus mechanical force

Fault current			
Symmetrical root mean square (rms) (kA)	Symmetrical rms with dc offset (kA)	Instantaneous crest (kA)	Mechanical force[a] (N/m)
10	12	17	578
10	20	28.3	1780
30	40	56.6	7119
30	60	84.9	16 018

[a]For a 0.9 m separation between conductors.

$$F = \frac{(2ki^2L \times 10^{-7})}{d}$$

where

F is the force between two parallel conductors, each carrying current I, (N)
k is a shape factor, with $k = 1$ for round conductors
i is the instantaneous current (A)
L is the length of conductor (m)
d is the distance between the conductors (m)

4.3.2.1 Breaker reclosure considerations

If breaker reclosure should occur on the grounded line, the reclose current duration should be included in the total current duration used to size the grounding system. The time delay between the original circuit trip and the reclose will cause the cable to cool somewhat. Tests have indicated that the amount of this cooling does not result in significant increase in cable capability (see ASTM F855-1997).

4.4 Induction (coupling)

When a line is isolated from a source of potential and is next to one or more energized lines, it is subject to both capacitive and magnetic coupling from the live line(s), as illustrated in Figure 7.

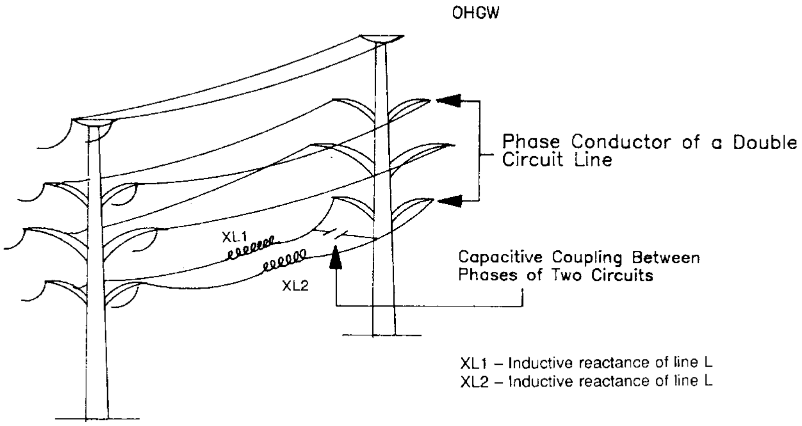

Figure 7—Capacitive and inductive coupling between adjacent circuits

4.4.1 Capacitive coupling

Due to the capacitive couplings between the live conductors and each of the isolated conductors, a voltage is induced in the isolated conductors. The induced voltage depends on the operating voltage and on the relative location of the live phases. The induced voltage may be hazardous to workers. If the isolated line is grounded at one point, current will flow. The induced current flow is directly proportional to the exposed length of the energized line and the isolated line. Some values of capacitive, as well as magnetic, coupling are shown in Figure 8 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. The arcing may be quite distressing to an unprepared worker manipulating the grounding cable. Tests have shown that the length of the arc on installing is quite predictable. However, the length of the arc at interruption can be considerably longer depending upon the arc current, the recovery voltage, as well as the prevailing weather and the speed of withdrawal of the protective ground.

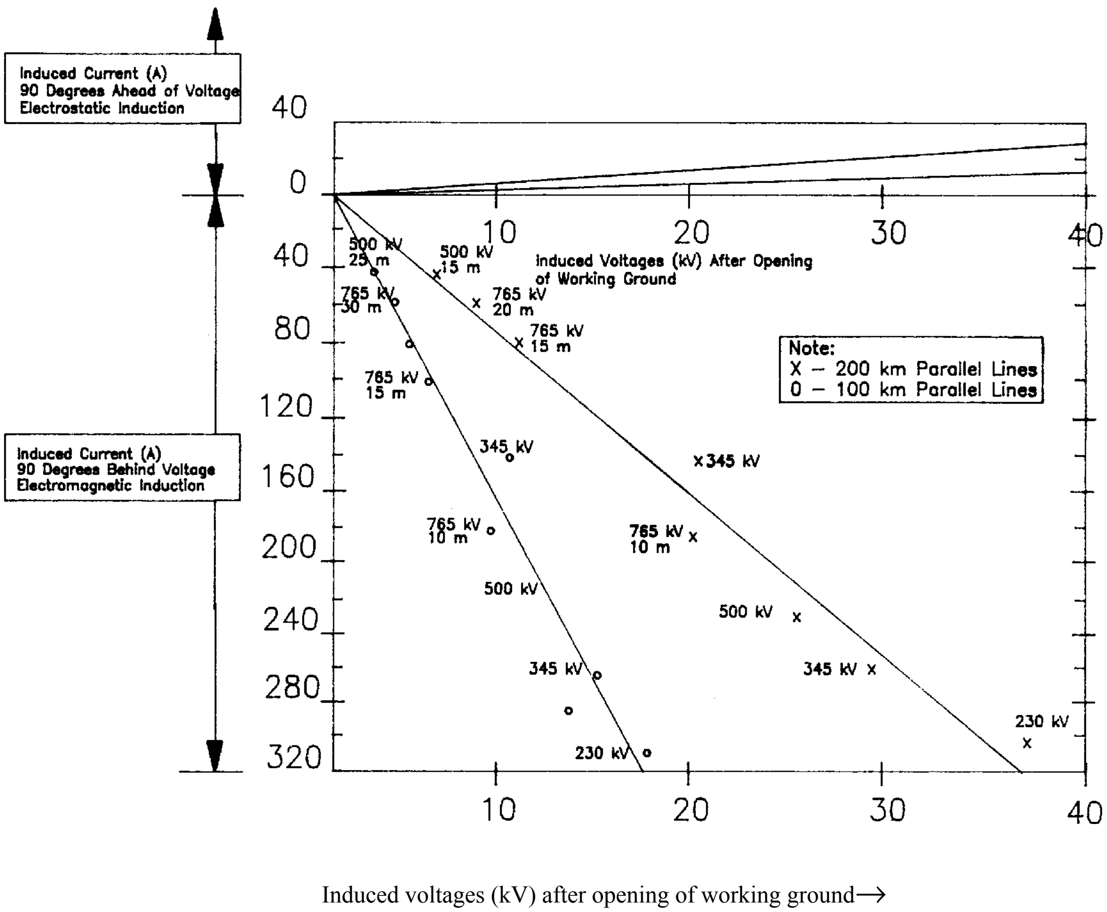

Figure 8—Some values of capacitive and magnetic coupling for typical line configuration

4.4.2 Magnetic coupling under normal conditions

Due to inductance of the lines, a loaded live line will induce a continuous circulating current in a parallel isolated and grounded line. The flux, which cuts the de-energized line conductors, is the vector sum of the fluxes developed around the three-phase conductors of the energized line. For flat configuration, all three conductors of the isolated line will be influenced by the same resultant flux of the live line. The resulting current in the isolated and grounded line will be of the same phase relationship although of different magnitude because of the difference in distance between the six conductors. When grounded to a cluster bar and then to earth, the earth cable will carry the arithmetic sum of the conductor currents. For double circuit vertical configurations, the resultant flux cutting each conductor of the isolated circuit will be about the same magnitude but of different phase relationship.

The magnitude of the current depends upon the spacing between the energized and isolated line, the load current flowing in the “live” circuit, and the location of the grounds on the isolated line and the coupling resultant flux.

Assume that station grounds are applied to the isolated line. The magnetically induced current will flow through the station grounds and earth to complete the loop. When a protective ground is installed at the worksite, the result is two loops. The current magnitude in the protective grounds at the worksite may vary between zero and twice the individual loop currents depending upon the phase relationship of the current in the two loops.

It is important to consider the continuous current flow in sizing the cable as it may approach the continuous rating of the cable.

4.4.3 Magnetic coupling during faults

The magnetically induced currents, being directly proportional to the current in the adjacent live circuit, can clearly be increased many fold if the live circuit becomes faulted.

4.5 Lightning

Although work on lines is generally not done when lightning is in the immediate area, it is not possible to guarantee that lightning will not strike near the line. The steep-fronted voltage surge from a lightning discharge to the line will be attenuated as it travels down the line. The voltage remaining on the conductor will depend on the lightning discharge voltage magnitude and the distance from the strike termination. If strike voltage exceeds the insulation level, the insulation will spark over, discharging the strike voltage to ground. If the insulation does not flash over, the lightning surge wave will travel down the line in both directions and will attenuate through the capacitance of the line; and the strike current will flow to ground through the portable protective grounds.

The strike current, while high in magnitude, is of a very short duration. The protective grounding cables, sized for fault current magnitudes and duration, will be able to thermally withstand lightning surge currents from the most severe lightning strike. However, the voltages arising on the conductor being grounded can be higher than expected, and once grounded the short-duration step and touch voltages about the grounded structure should be considered. These voltages will rapidly decrease with distance away from the structure.

Consideration shall be given to movement of the ground conductors due to the magnetic forces generated by the very high lightning current magnitude. The force is of very short duration, but can cause considerable movement of the conductor if it is too long.

5. Rating of grounding sets

5.1 Ground set components

Protective grounding sets are assemblies consisting of clamps, ferrules, and cable. The clamps and ferrules are manufactured using either aluminum alloy or copper alloy. The grounding cable is made from copper. The cable’s jacket may be made from polyvinyl chloride (PVC), silicon rubber, or other covering materials. The jacket is for mechanical protection of the copper strands.

All of the metallic components have an associated electrical resistance and a susceptibility to corrosion.

For illustrative purposes, take the conductivity for pure copper as a reference value of 100%. The other materials are measured relative to this value. For example, aluminum has a conductivity of 62% of copper. ASTM B105-2000 [B1] defines ten grades of copper alloy. Their conductivity varies from 8.5% to 85% of copper. The grounding set needs to have all parts with current capacity as great as that of the cable.

The protective grounds shall 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) shall not be hazardous. The rating of the grounding set thus depends on the following:

a) The current-carrying capacity of the cable
b) The current-carrying capacity of the clamps and their connection to the cable

c) How well the cable is connected at its ends (i.e., surface preparation and tightness)
d) The configuration in which the cable is being used
e) The resistance of the complete grounding system

NOTE—Specifications for grounding cables, clamps, and ferrules are covered in ASTM F855-1997.

5.1.1 Cable ratings

The “melting characteristics” of some common copper cable sizes are shown in Table 1 of ASTM F855-1997. If the ground lead rating is exceeded during a fault, fusing of the copper will result in the increase of the cable resistance and voltage drop across the grounding cable and rupture of the cable.

5.1.2 Cable material

The conductor shall consist of untinned annealed copper. It has been found that aluminum cables do not always give adequate performance during the life of grounding equipment and are not recommended. The use of copper cable only is specified by 35.1 through 35.1.4 of ASTM F855-1997. Copper provides maximum tensile strength, resistance to strand breakage during use, and minimum resistance to current flow. Aluminum connectors and cables exhibit a larger amount of “cold” flow than copper, and the aluminum components of any assembly will corrode.

5.1.3 Electrical resistance

The electrical resistance of conductors at 20 °C is specified in the respective specifications. Compliance at the time of manufacture can be checked by the test given in 2.1 of IEC 60227-2:2003-04 [B4] and IEC 60245-2:1998-03 [B5].

5.1.3.1 Resistance variations

For cables of the same material, cable resistance increases with length and decreases as the diameter increases. The diameter may vary by ± 5% during the manufacturing process. ASTM B263-1999 provides a method to accurately determine the cross-sectional area of a cable sample, and this method should be used in all measurements to assure accuracy.

5.1.3.2 Cable characteristics

Cable stranding is specified in 32.3 of ASTM F855-1997. Grounding cables are furnished in three types, with the type dependent upon both cable and protective jacket. Clause 35 of ASTM F855-1997 provides major characteristics of cables.

5.1.3.3 One cable

The preferred protective grounding system has one cable for each connecting leg.

5.1.3.4 Requirements for multiple cables

When it is essential that more than one cable be employed in the grounding assembly for each connecting leg (generally meaning that there are two or more cables), the requirements in 5.1.3.4.1 through 5.1.3.4.5 should be observed.

5.1.3.4.1 Length

The cables should be of equal length.

5.1.3.4.2 Cross section

The cables should be of equal cross section.

5.1.3.4.3 Material

The cables should be made from and with the same base material, stranding, lay distance, and other aspects of cable construction.

5.1.3.4.4 Connections

The same connecting parts and components should be employed.

5.1.3.4.5 Proximity

The items of the equipment employed should be fitted close together, with the cables laid or fixed to assure that they remain in parallel.

5.2 Grounding cable size

The grounding cable size to be used is determined by the cable current rating. A cable is rated according to its capability to conduct current for a specified time duration. Table 2 of ASTM F855-1997 lists both the withstand and ultimate capacity ratings of copper grounding cables subjected to a current level, with not more than 20% asymmetry. A 20% asymmetry translates into a maximum $X/R = 1.75$, seen only at a work-site some distance from the substation. See Appendix A of ASTM F855-1997 for calculations demonstrating the relationship between the asymmetry factor and the X/R ratio. Withstand rating represents a current that cables shall conduct without being damaged sufficiently to prevent reuse. The ultimate capacity represents a current that the cable is capable of conducting for a specified time but that will reduce the cable’s capability and that will prevent the cable from being reused.

The current-carrying capabilities of copper grounding cables are significantly affected by the dc; the worst-case dc offset (90º) for a 2/0 copper cable at 6 cycles is 45 000 A. For a dc offset of 45º, the capability is 57 000 A, and for a symmetrical current (0º offset) the capability is 62 000 A. The cable ratings were established based on the configuration in Figure 1 of ASTM F855-1997.

5.2.1 Rating of grounding cable

The user may use the withstand or ultimate capacity rating of the cable to select the size of the cable. A cable subjected to a fault current above the withstand rating shall not be reused.

5.2.1.1 Withstand capacity rating

Cable withstand ratings are based on performance in Table 2 and Table 3 of ASTM F855-1997 not exceeding 20% asymmetry factor. A cable subjected to fault current above the withstand rating should not be used. The withstand rating is a current that a cable can conduct without being damaged sufficiently to require destruction. Using the withstand rating rather than ultimate ratings will require larger cables.

5.2.1.2 Ultimate capacity rating

Table 1 of ASTM F855-1997 gives the ultimate current-carrying ratings for faults with 20% asymmetrical current. Table 2 of ASTM F855-1997 gives the ultimate current-carrying capacity with 20% or less asymmetrical current. Table 3 of ASTM F855-1997 gives the ultimate current-carrying capacity with differing asymmetrical current values. The different asymmetrical currents and associated dc offset values result from different circuit X/R values. When dc is not considered, the current capacities given in Table 2 of ASTM F855-1997 are less than the values in Table 3 of ASTM F855-1997.

NOTE—Using cable near its ultimate thermal capacity may result in mechanical failure of the assembly prior to expectations based upon heating alone. Use of the withstand cable rating is recommended.

Examples: When the X/R ratio or dc offset is unknown. Because the dc offset of the fault current declines rather rapidly with time, an assumption can be made to use an analogy between the value of the offset and time.

NOTE—The following examples require the use of ASTM F855-1997. All tables referenced are from ASTM F855-1997.

a) **Fault clearing time, $t < 6$ cycles:** Table 3a should be used because the 6 cycle time is considered the worst case. The worst case is considered because the needed clearing time is very short and any dc offset component is assumed not to decay with time.

   Example: From Table 3a, 2/0 copper with a clearing time of 6 cycles has a capacity of 45 000 A.

b) **Fault clearing time, $6 < t < 30$ cycles:** Table 3b should be used because the 15 cycle time is considered a midrange time. A midrange dc offset is considered because some compensation is provided by the decay of the subtransient component of ac.

   Example: From Table 3b, 2/0 copper with a clearing time of 15 cycles has a capacity of 38 000 A.

c) **Fault clearing time, $30 < t < 60$ cycles:** Table 3c should be used because the 45 cycle time is considered the long-range or best case. The dc offset is not considered because the relatively long allowed clearing time permits substantial decay of the subtransient component of ac to occur.

   Example: From Table 3c, 2/0 copper with a clearing time of 45 cycles has a capacity of 23 000 A.

The values in Table 3a, Table 3b, and Table 3c of ASTM F855-1997 were derived from a computer program (see IEC 61230:1993-09 [B6]). This computer program can be used to determine the grounding cable size requirements for known X/R ratios and fault-clearing time duration.

5.2.1.3 Mechanical consideration

The mechanical forces acting during a fault are proportional to the square of the fault current and can, therefore, be extreme at very high currents (e.g., above 50 000 A). These forces may cause the clamp to break or pull off the attachment.

These forces may also reduce the rated safe use time of the grounding set by an unknown and inconsistent amount. The conductor, heated by the fault current flow, may fail before reaching the fusing time associated with a particular current flow. The voltage drop caused by mutual inductance may also cause current imbalance in the multiple paths.

5.2.2 Clamp rating

Clamps for safety applications are characterized principally by their current/time ratings and general form. Also of importance are both the clamp's main and tap conductor size acceptances, jaw configuration, and the cable termination method. Of lesser importance is the material from which it is constructed and the method of installation.

For successful application of grounding cable sets, a clamp's rating should be for the maximum fault current for which it is to be used. This rating implies both electrical and mechanical capability. The electrical rating shall meet both the short-time fault and the continuous current requirements. The clamp shall be capable of carrying this current, for the specified time, without damage to itself or separating from the conductor.

If inadequately rated, the clamp may break or separate from the line due to the mechanical forces associated with the high current. An inadequately rated clamp may represent a high-resistance connection, causing the metal surfaces of both the conductor and clamp to soften and lose clamping force. Arcing and clamp separation can result.

The worker's risk of injury may be increased by inadequately sized or improperly applied equipment. Clamps are designed to accept one conductor only. Using a single clamp on multiple conductors will increase risk to the worker.

After a clamp is selected for a particular size of grounding cable and the conductor 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 are 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 restrained at the connecting point so that such movement does not cause the clamp to be dislodged completely. Such a test might destroy the cable or clamps, or both.

5.2.2.1 Clamps—aluminum alloy

Clamps made of aluminum alloy are lightweight and resistant to corrosion and have good current-carrying properties. Sufficient clamp size to allow dissipation of the heat generated during current flow shall be provided.

A tough, hard, invisible high-resistance oxide forms quickly on exposed aluminum. Once stabilized, this oxide prevents further oxidation. After a few hours the oxide film formed is too thick to permit a low-resistance contact without cleaning. Because the film is transparent, visual appearance is no assurance of a good contact.

In the presence of moisture, galvanic action occurs in aluminum-copper and aluminum-steel contacts. This activity causes pitting of the clamp and degrades its quality. The pitting and degrading quality of the clamp may not be a problem with protective ground cables, due to the temporary nature of their use. The use of anti-corrosion compounds, plated ferrules, or similar clamp and ferrule materials will reduce this effect and is strongly recommended

5.2.2.2 Clamps—copper alloy

Clamps made of copper alloy have high atmospheric corrosion resistance. Their tensile strengths are much greater than aluminum alloy. Copper alloy has a much higher density than aluminum alloy, resulting in heavier clamps for an equivalent size to aluminum. It is necessary to optimize the design of copper alloy clamps to balance the strength with the conductivity requirements. Oxides on copper and its alloys are conductive and are generally broken down by low values of contact pressure. Unless the corrosion is very severe, minimum cleaning is required to make a low-resistance contact. There is little electrochemical action between copper alloy clamps and copper ferrules. However, this activity is present when copper alloy clamps are mounted on steel parts for an extended time in the presence of moisture.

5.2.2.3 Resistance changes in use

In addition to cleaning, the clamp shall be tightened to the manufacturer's specifications. Both dirty surfaces and/or loose joints result in high-resistance connection. The heat generated from the flow of high fault current through an improper connection may result in softening of the metal surfaces at the jaw-conductor interface, with a loss of clamping force. The clamping force reduction increases the resistance further, generating more heat, until the clamp either falls or burns off the conductor. Dirty connections are a typical problem in field applications. Wire brushing and application of a joint compound prior to clamp installation are strongly recommended to ensure and maintain a clean electrical connection.

5.2.2.4 Electrical ratings

Ground clamp ratings for short-time and continuous current ratings are found in Table 1 of ASTM F855-1997. When there is a large dc offset (virtually full asymmetry), the initial peak current can be near to two times the rms symmetrical fault current, and magnetic forces can be up to four times as high. It should be noted that clamps rated in accordance with ASTM F855-1997 are rated for an asymmetry factor of only up to 20%. Many generating plants, substations, and other vicinities may have a much greater asymmetry factor than used in the table. These cases may require a higher rated clamp.

5.2.2.5 Mechanical stresses during faults

The clamps are subjected to very high mechanical loads during fault conditions, especially when large cable lengths are left mechanically unsecured. Under such conditions, large magnetic forces can accelerate the cables to high speeds, and the clamps are then called upon to absorb much of the kinetic energy. The mechanical adequacy of a given design and construction of clamp, for a given fault current, depends on the combination of cable type and length and the type of cable-to-clamp attachment (e.g., ferrule) with which it is to be used. For a given fault current magnitude and duration, a certain clamp may be entirely adequate mechanically for one application, but inadequate for another. At present, only full-scale fault current tests on the most adverse application of a clamp will allow determination of its mechanical acceptability.

5.2.2.6 Clamp form

Various forms of clamps are available, each suitable for either specific or multiple applications. Clamps are designed for use on various shapes of bus work, stranded or solid conductor, galvanized or tower steel, etc. Tests have shown that clamps that reduce the likelihood of clamp movement (e.g., some form of captive design) improve the overall performance under fault conditions.

5.2.2.7 Clamp size selection

The clamp should be selected so that the conductors for both the main and tap lines fall within the clamp’s acceptance range.

5.2.2.8 Jaw configuration

A clamp may have either smooth or serrated jaws. The smooth jaw design minimizes conductor damage. Using a smooth jaw clamp requires the use of a conductor cleaning tool, such as a wire brush, to ensure a low-resistance connection. The design of the serrated jaw clamp is to break through the normal surface corrosion or oxides of the conductor. Improper use of a serrated jaw clamp can damage the conductor. Further information about clamps may be found in 5.1 through 5.3 of ASTM F855-1997.

5.2.2.9 Corrosion effects

To prevent the possibility of corrosion and resulting loss of both electrical contact and mechanical strength, avoid directly fitting copper cables into aluminum alloy clamps. To prevent this, employ plated ferrules or a suitable contact aid. When employing these precautions, do not expose the grounding cable set to a corrosive atmosphere or excessive moisture.

5.2.2.10 Mounting methods

Clamps are designed with eyes (for installation with removable live-line tools) or with T-handles or are permanently mounted on insulated live-line tools.

Care should be used when using flat face clamps that are fitted with setscrews. The setscrew should be fully backed off prior to tightening the clamp jaws. The setscrew, if used, may then be tightened to the manufacturer's recommendations. Do not overtighten; otherwise the setscrew tip, rather than the larger surface jaw, may become the current path. Most setscrews are steel, resulting in poor conduction due to high resistance. The setscrew's poor conduction, combined with the small surface contact, can result in softening of the tip, loss of contact force, arcing, and loss of worker protection.

5.2.3 Clamp connection

Instruct workers in proper surface preparation at the connection points of grounding cable clamps to ensure low contact resistance. Low contact resistance will 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. The heating and melting will result 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 and do not overtighten.

5.2.4 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 testing a grounding set, 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.

5.2.5 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 shall be maintained at a safe level if a fault occurs. Dalziel's formula can be used to establish a safe voltage for the expected fault current magnitude and duration.

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

6. Grounding practices

6.1 Introduction

This clause describes the practices of many power companies regarding when to use grounding sets, where to connect them, how many are used, and the kind of ground electrode for connection of protective grounds. The installation of protective grounds is covered in Clause 8.

6.2 Theoretical considerations

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

a) Fault current available at that location

b) The location of grounding sets relative to the worksite and the fault current source

c) The number of phases that are grounded

d) 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 factor a), factor b), and factor c) listed in this subclause. Unfortunately, optimum conditions of factor a), factor b), and factor c) for the worker touching the conductor generally result in poor conditions for the worker on the ground, and vice versa.

Whenever fault current exceeds the rated current of the grounding cable system, additional protection is required. The preferred protection is a higher rated grounding cable system, with larger cable, terminal blocks (if used), ferrules (if used), and clamps. An alternative protection is parallel grounding cable systems. A practical size limitation for single-cable systems is reached when it becomes so heavy or awkward to install that the worker is reluctant to apply the system.

The protective grounding system shall not fail when subjected to the maximum fault current available at the work location, for the allowable time of fault current that may flow. This current may be the system fault current calculated for that location or from other sources such as an energized circuit falling into the isolated and grounded circuit being worked on.

6.2.1 Multiple grounding cables

Multiple grounding cables provide multiple paths for fault current flow. The multiple paths reduce the size requirement for an individual current path. However, unless the current paths have equal impedance, the fault current will not divide equally among the paths. For best matching of impedance for multiple current paths, cables of the same type, size, and length with identical ferrules and clamps should be used. An alternative to the use of two separate protective ground sets is the use of a clamp designed to accept two cables with ferrules. Extra care should be taken when using parallel ground cables because the cable manufacturing process can result in ± 5% variation in nominal cable size.

Extreme mechanical forces present under fault conditions may break the clamp, and then a worker would be left without protection. When practical, the individual cables of the ground cable system should be tied together. The tying together of the ground cables may be done by securing a rope to the top, or one end, of one cable and then winding it around the set and securing the rope at the opposite end. Also, dangerous voltage levels can develop across extremely small resistance during high current faults. Grounding cable systems with center splices to extend the length should be avoided because they increase the grounding cable resistance. This requirement is not intended to prohibit the use of cluster bar devices in a worksite protection scheme.

A critical time during the application of common connected parallel protective grounds is the application of the first grounding cable of each set. Prior to installation of the full set, the current path is severely undersized because the incomplete system is incapable of carrying the full fault current. Full worker protection is present only after installation of all parallel sets. This hazard can be minimized by proper circuit identification and the use of energized voltage detection devices.

6.2.1.1 Path impedance

To obtain approximately balanced currents through each protective ground cable, it is necessary to establish a nearly equal impedance path in each ground cable. The use of stranded conductors of identical size and length and the use of identical clamp types provide better control of path impedance. If multiple clamps are required, they should be alike. All clamps used should be alike and similarly installed. All torque values should be to the manufacturer's specifications.

For example, a 10% variation in cable impedance, i.e., a 10% excess in one cable and a 10% deficiency in the other, will result in unequal division of current. The path with the lower impedance will carry 11 000 A, while the cable with the higher impedance will have 9000 A for a 20 000 A available fault. Because all of these variations cannot be precisely determined, the use of a derating factor is necessary (see 6.2.2).

Factors causing unequal impedance include cable size, stranding, length, and placement. Connections of clamp to cable, cable to ferrule, and ferrule to clamp also affect the total impedance. Manufacturing tolerance of the grounding cable allows a variation in the cable's diameter. This diameter variation is a major factor in a cable's impedance variation. Impedance variations cause unequal division of current through the protective parallel paths. Because some unbalance is inevitable, covered cables should be used to prevent arcing or minor shocks to workers while near the worksite. Such a jacket also provides mechanical protection for the many small strands forming an extra flexible grounding cable.

6.2.1.2 Positioning

When using grounding cables in parallel, without a multicable clamp, connect the grounding clamps as close as possible on the part being grounded. The close proximity of the clamp connections is to ensure as balanced a current division as possible. Separation of the clamps may allow system conductor impedance to cause unbalanced current distribution in the parallel grounding cables.

6.2.1.3 Maximum grounding sets paralleled

More than two parallel protective grounding sets should be avoided if possible. The increased available fault current that makes paralleling necessary also creates other risk issues at the worksite. Extreme electromechanical forces are present as the current approaches 60 000 A. These forces may cause the clamp to break. These forces may also reduce the rated use time of the grounding system by an unknown and inconsistent amount. The conductor, heated by the fault current flow, may break before reaching the fusing time associated with a particular current magnitude. The voltage drop caused by mutual inductance may also cause current imbalance in the multiple paths.

It may be possible to reduce the protective ground system requirement from two cables to one cable by allowing an increased cable size, a reduction of the required protection time, or a combination of both. The appropriate source within the user's company should be consulted for resolution of these variations. If more than two grounding cables are required, custom-designed grounding cables with special installation techniques should be developed for that site. An alternative technique is the installation of rigid bus grounds.

6.2.1.4 Derating

To select the correct size cable, refer to Table 1 or Table 3a, Table 3b, and Table 3c of ASTM F855-1997. Each grounding cable used in a parallel scheme shall have its current-carrying value reduced by at least 10% if the cables are tied together or 20% if they are not tied together.

Example:

> Assuming an available maximum fault current of 56 000 A for a duration of 15 cycles and a dc offset of 45°

Solution 1:

One 4/0 AWG grounding cable:

From Table 3b, the maximum current for one 4/0 AWG grounding cable is 60 000 A for 15 cycles, which exceeds the required 56 000 A.

Solution 2:

Two 2/0 AWG grounding cables tied together (10% reduction):

Using two parallel 2/0 AWG grounding cables in lieu of one 4/0 AWG cable; from Table 3b, the maximum current for one 2/0 AWG grounding cable is 38 000 A for 15 cycles. Using two cables tied together, the maximum rating for the cable pair reduced by 10% each is

2 × (100% – 10%) × 38 000 or 2 × 0.9 × 38 000 A = 68 400 A, which exceeds the required 56 000 A.

Solution 3:

Two 2/0 AWG grounding cables not tied together (20% reduction):

Using two parallel 2/0 AWG grounding cables in lieu of one 4/0 AWG cable; from Table 3b, the maximum current for one 2/0 AWG grounding cable is 38 000 A for 15 cycles. Using two cables not tied together, the maximum rating for the cable pair reduced by 20% is

2 × (100% – 20%) × 38 000 or 2 × 0.8 × 38 000 A = 60 800 A, which exceeds the required 56 000 A.

Larger grounding cable systems or a custom-designed protective scheme is required when the maximum available fault current exceeds the capacity of the above solutions.

6.2.2 Station grounds parallel with protective grounding cables

Normally permanent station ground switches are not considered in the sizing of protective grounding cables because the protective grounding cable shall be capable of withstanding the total available fault current magnitude at the worksite in the event the cable is applied to an energized conductor. Where the de-energized line originates from a very high fault current station, station ground switches may be considered in sizing the grounding cable.

With station grounds closed and protective grounding cables in place, the current flow in the protective grounding cables will be reduced if the circuit is energized. However, the current magnitude flowing from sources other than re-energization is unknown.

Station grounds reduce the induced voltage that can appear on the de-energized line so that “buzzing” is more positive, but the ground system should always be sized for the possibility of full fault current flowing in the protective grounding cables.

The electrostatic voltage induced on a de-energized conductor is a function of the ratio of the capacitance between the conductor and the energized circuit and between the conductor and ground. With the ground switches closed, the voltage on the de-energized circuit is minimized to provide more assurance that the de-energized circuit is properly identified before grounding cable systems are applied.

6.2.3 Precautions

6.2.3.1 Cables subject to fault current

During a fault of high current, the cable can reach extreme temperatures, which can cause the jacket to burst into flames or melt. A by-product may be hazardous gases (e.g., chlorine) and highly corrosive gases (e.g., HC1, especially in the presence of moisture), depending on the chemical composition of the jacket material. The gassing of the jacket due to high temperatures poses a serious threat if it occurs in a confined area, such as an underground vault with a worker present. Adequate ventilation shall be provided.

6.2.3.2 Cable reuse

Cables that carry continuous current exceeding their continuous rating or that carry fault current that approaches or exceeds the withstand rating of the cable at power frequency shall NOT be reused.

Extreme temperatures also cause annealing in conductors. An annealed cable loses much of its tensile strength. It may fail due to breaking if reused.

6.2.4 Worksite versus bracket grounding sets

The decision to use worksite grounds (single point) or bracket (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 worksite grounding sets will result in the minimum obtainable impedance path in parallel with the worker's body, and thus, the minimum body intercept voltage (see Figure 9) for the worker.

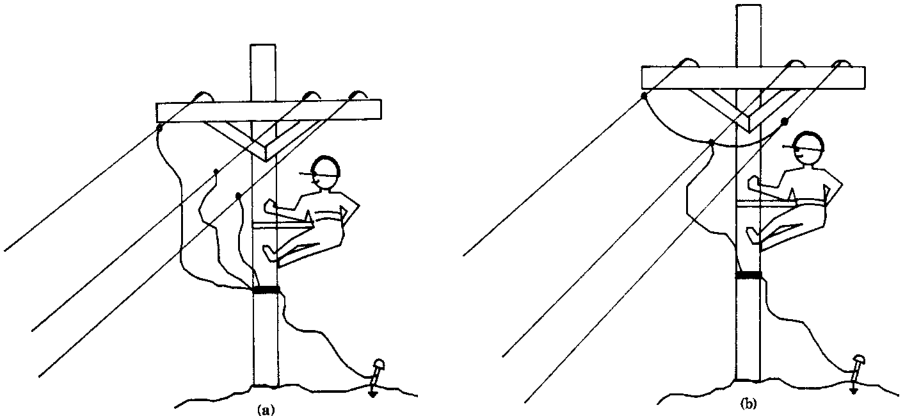

Figure 9—The minimum obtained impedance path in parallel with the worker's body and, thus, the minimum body intercept voltage

With bracketed grounding sets, the conductors are shorted and grounded at adjacent towers on both sides of the worksite. With no overhead ground wire (OHGW), 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. Because the worksite tower is located at essentially remote ground, full tower rise voltage will appear between the worksite tower and the conductor and thus be applied to any worker who has contact with both (see Figure 10).

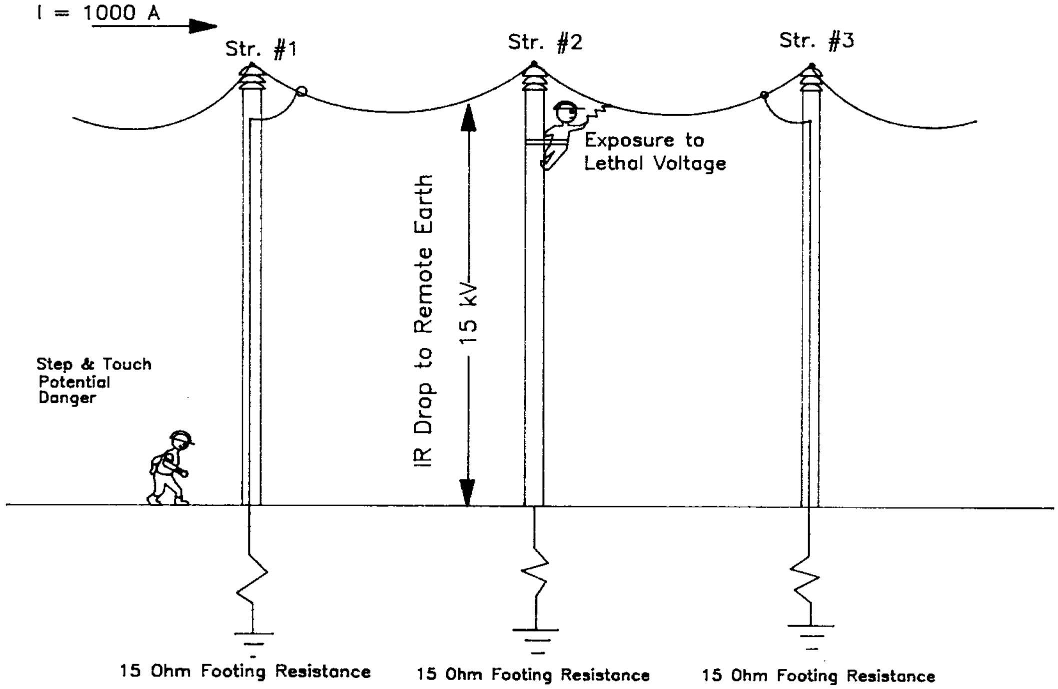

Figure 10—Bracket grounding

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

With worksite grounding, personnel at ground level may be subjected to higher step and touch voltage than with bracketed ground sets depending upon design, i.e., the presence of OHGW 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.

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

With worksite grounding, the worker will be subjected to the minimum possible voltages between conductor and tower regardless of whether an OHGW is used.

Ground personnel will be subjected to similar hazards on lines with OHGW connected to all line structures whether worksite or bracketed grounding is used. Voltage gradients will be higher for worksite grounding on lines without OHGW, but this hazard can be minimized by positioning personnel away from the structure and will always be less of a hazard to workers in contact with the conductors than the use of bracket grounds.

6.2.5 Single-phase versus three-phase grounding

The magnitude of three-phase short-circuit currents may be higher than the magnitude of a single-phase short, especially when the ground resistance is high. 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 provide more certain, and generally more rapid, circuit breaker operation when ground resistance is high.

Three-phase grounding 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 voltages at the base of the structure. If ground resistances are low enough to ensure consistent fault clearing, and the step and touch voltages 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 shall always be maintained for the ungrounded phase conductors.

6.2.6 Bonding

In addition to the conductor being grounded at the worksite, 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 re-energization, bonding maintains the worker at the same potential as the energized conductor.

Because the resistance of a wood pole may be as low as 6700 Ω/m, the pole should 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 cluster bar, incorporating a grounding stirrup, is clamped around the pole below the work position and used to provide a bond around the jobsite on the pole.

6.2.7 Ground electrode

Protective grounds can be connected to the established ground of the structure, to another good ground electrode (e.g., a neutral conductor or a station ground), or to a temporary driven 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 produces the step and touch voltages around the ground electrode (see Figure 2 in 4.2.1) and may be hazardous to personnel in this area if suitable work methods are not adopted.

Use of an available OHGW (see 12.3) as the ground electrode has merit because 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. It should be recognized that, where the current flows, there will be a voltage rise at every connection to earth.

Similarly, a neutral conductor is frequently used for its generally low resistance, compared with a driven ground rod. 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 worksite. Care should 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 (e.g., guys) that may be within the worker's reach or even the (partly conductive) pole itself.

A temporary driven ground rod should 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 jobsite 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. Tying the two electrodes together with a ground cable can mitigate this difference in potential.

There may be a temptation to supplement an existing ground with a much lower resistance ground, such as a ground grid, but the greater the difference in ground resistance of the two electrodes, the higher the voltage between them. The higher voltage 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 higher resistance.

6.3 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 resistivity, system design, and general work procedures. These specific local conditions should not be overlooked when comparing a company’s work procedures.

7. 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 OHGW are the same as the methods and procedures for conductors as detailed in 1.3.1 of IEEE Std 524a-1993.

8. Work procedures

8.1 Introduction

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

8.2 Voltage detection methods

Voltage detection is the process of sensing voltage on a line to determine whether the line voltage is present and is used only for confirmation of isolation and only after standard clearance procedures are complete.

8.2.1 Buzzing

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

8.2.1.1 Live-line tool methods

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. Buzzing method is not reliable at voltages of 69 kV and below.

8.2.1.2 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 and 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 worker produces a corona on the pointed end. If the corona can be heard, the line is to be treated as an energized circuit.

8.2.1.3 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).

8.2.1.4 Neon indicator

The neon indicator is held at the end of a live-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.

8.2.1.5 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 an audible alarm. It is often used to check areas in the underground and around switchgear, substations, and overhead lines. Many NTVDs give just one type of signal regardless of the type of voltage in the line. Other types of NTVDs 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 5 for distances to ensure safe and accurate results).

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

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

Table 5—NTVD detection range

Distance from conductor	kV on conductor
25.4 mm	4
101.6 mm	13
305.0 mm	26
457.0 mm	33
0.92 m	110
1.83 m	230

8.2.1.6 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 worker can then use the MRVD to approximate line-to-line voltage by hanging the steel contact hook onto 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.

8.3 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.

8.3.1 Neon indicator

The advantage to using the neon indicator 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.

8.3.2 NTVD

The following are the advantages to using an NTVD:

a) It is not necessary to make contact with the line to receive an approximation of the voltage.
b) The NTVD is one of the simplest devices to use.
c) 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 that it does not give any specific indication of estimated voltage.

8.3.3 MRVD

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 MRVDs 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 should 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 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.

8.4 Cleaning conductor and ground connections

8.4.1 Purpose

The purpose of 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 between the ferrule and grounding clamp. These connections are considered to be the weak points in the grounding set cables in terms of current-carrying capacity.

8.4.2 Equipment and method

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

8.4.2.1 Wire brushing

Some lines should be cleaned by the use of wire brushes. The wire brush is 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 an aluminum conductor will virtually disappear after 20 min if the inhibitor is not used.

8.4.2.2 SCCs

SCCs are ground clamps with serrated jaws to provide additional corrosion penetration. SCCs 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.

8.4.3 Metal structures

8.4.3.1 Steel pole structures

Steel poles are considered as structures with slip joint sections and bolted crossarms. Joint resistance should be measured on selected structures after installation and periodically as maintenance personnel deem necessary. Surface contacts where personal protective grounds are to be attached should be cleaned prior to cable attachment to ensure a proper bond.

8.4.3.2 Weathering steel pole structures

The protective oxide on weathered 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 welding on a stainless steel nut into which a threaded copper stud can be inserted. Weathering steel poles should be constructed with bonds between crossarms and poles and between slip joints to ensure the electrical continuity. If bonding straps are not part of the structure, measures should be taken to ensure protection from induced and fault currents.

8.4.3.3 Painted steel tubular structures

For painted steel tubular structures, special precautions should be used to provide a low-resistance ground path. Jumpers should be used around joints or other painted surfaces to provide a current path. The same procedures outlined in 8.4.3.1 should be followed.

9. Grounding procedures

When placing grounds, some type of insulating tool or material should be used. In most cases, live-line tools are a natural choice.

9.1 Preliminary

Grounds should be placed either at the worksite or at a distance as close as possible to the worksite. If a situation arises where the installation of a ground is not practical or would create an unsafe condition, the ground should not be installed, and the line should be worked as if it were energized.

Before working on or coming within minimum approach distance of high-voltage lines or equipment, the parts to be worked on shall be placed at ground potential. Minimum work distances as established by governing agencies should be observed when installing grounds.

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 re-energization or lightning stroke, and it cannot be restored to original capacity, it should be destroyed.

9.1.1 Methods of use

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

9.2 Installation procedure

When installing 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.

9.2.1 Structures

9.2.1.1 Lattice structures

When grounding cables 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 grounded end clamps may be connected directly to the tower structural members.

9.2.1.2 Painted and galvanized steel pole structures

Painted and galvanized steel pole structures usually do not have bonds between the crossarm and pole or between pole slip joints. Joint contacts are deemed sufficient for electrical contact.

9.2.1.3 Composite and concrete structures

Structures of mixed materials or structures with concrete poles should have personal protective grounds installed similar to the grounds for wood structures.

9.2.1.4 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 be positioned any higher than the level of the phase for safety and convenience reasons. Generally speaking, the methods used to ground wooden structures are similar to the methods used for metal structures. One major difference, however, is the procedure concerning pole grounding cables, which are not present on metal structures. Pole ground wires 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 they are still in place; some pole ground wire 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 is required.

9.2.2 Length of grounding cables

Grounding cables 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, the grounding cable should not be coiled or wrapped around metallic objects because coiling tends to reduce the current capability of the cable. The grounding cable should be as short as possible to reduce the risk of excessive motion.

9.2.3 Problems of control

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

9.3 Removing grounds

9.3.1 Method

Grounding shall be removed in reverse order of application, i.e., the connection to the de-energized line shall be removed first and the connection of the grounding cable at the ground end shall be removed second. 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.

9.3.2 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 cable 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.

10. Vehicles and equipment—methods of protection—workers and public

10.1 Methods

Three basic methods are used, separately or in combination, to provide personal protection for the public and workers standing and working near energized facilities (see "Methods for protecting employees" [B8]).

a) *Grounding equipotential zones.* All equipment is electrically interconnected by bonding cables and grounded to a system neutral, system ground, and/or grids that provide negligible potential difference across the zone.
b) *Insulation.* Workers are insulated by gloves, footwear, mats, platforms, insulated booms, etc., suitable for the voltage resulting from maximum fault currents and the voltage available at the worksite.
c) *Isolation.* Isolation may be provided by physical restraints such as barricades or barriers. No one should be inside the isolating perimeter unless protected by method a) or method b). Isolation, if properly used, provides a positive means of protecting the public. With respect to the step voltage hazard, the isolation distance may vary from a few meters to 9.5 meters or more depending on the available fault current and voltage.

If the isolation method is combined with the use of ground rods, the determination of where to place the isolation perimeter shall take into account the location of the ground rods. The voltage gradient in the ground radiating from the ground rod may be large when accidental contact is made, and the ground connection should also be isolated. Barricading these points should be considered.

The protection system chosen shall be adequate for the hazard that exists.

10.2 Vehicle grounding

10.2.1 Aerial devices

Equipment that could make contact with an energized facility or could become energized during the work process should be grounded with protective grounding sets capable of carrying the full fault current magnitude for the time required to clear the fault [i.e., method a) in 10.1]. Isolation [i.e., method c) in 10.1] is usually employed to keep both workers and the public away from possible exposure to step and touch hazards.

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

Workers on the ground should be aware of the step voltage hazards near the vehicle chassis as well as the structure and ground electrode. IEEE Std 524a-1993 indicates a different method of bonding depending on the type of aerial device in use (see 1.4.1 in that standard.)

10.2.2 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 jobsite or that the vehicle be isolated from contact.

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

Vehicles that cannot possibly make contact with facilities that are or may be energized may be grounded with a discharge (static) ground cable.

10.2.3 Vehicles connected to station service

Vehicles that may be energized from a station service source should be grounded with cables capable of carrying the possible current.

11. Maintenance

11.1 Inspection and maintenance of protective grounds

In order to ensure the capability of the grounding cables to conduct the maximum local fault current and protect the line worker, proper maintenance of the ground cables is a necessity. Maintenance of ground cables shall include, but not be limited to,

a) Visual inspection of the cable and clamps.
    1) Check the cable for cracks or broken insulation.
    2) Check for broken cable strands, particularly in the area of the ferrule.
    3) Check the clamps for sharp edges, cracks, splits, or other defects. The clamp shall be replaced if found defective.
    4) Verify that the clamps operate smoothly and are free of excessive looseness.
    5) Verify that the connection between the clamp and the ferrule is clean and tight.
b) Resistance measurement (see IEEE Std 524a-1993). The resistance of the main contact to the attached cable shall be less than the resistance for an equal length of maximum size cable(s) for which the clamp is rated.
c) Grounding cables with clamps on insulated live-line working tools. To verify the integrity of insulated rods, see IEEE Std 516-1995.

Maintenance intervals shall depend upon exposure, manner of use, individual company policy, and field inspection.

11.2 Testing

11.2.1 Component design tests

Component design tests are specified by ASTM F855-1997 or IEC 61230:1993-09 [B6].

11.2.2 Periodic tests

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

11.2.2.1 Millivolt testing

Millivolt testing has been shown to be a reliable method for detecting problems at the ends of protective ground cables. A dc of 25 A is recommended. It should be as “smooth” or ripple-free as possible to measure the resistive component only. If there is substantial current variation, as in half-wave rectified dc, circuit inductance will affect the readings and make duplication difficult.

Problems confined to the central cable portion are not typically seen by this method. If broken strands exist, they may be in physical contact with other strands and thereby mask the problem.

At this time no millivolt limits used as pass/fail criteria can be given. If a user maintains a series of test values, a trend line can be developed. Table 6 shows some typical values that will assist in developing useful failure criteria. The following values were recorded using 25 A, half-wave rectified dc to test "old" 2/0 protective grounding sets.

Table 6—Typical range of values for protective ground testing

Conductor-clamp contact	Clamp to ferrule	Ferrule to cable
A-B and G-H	B-C and E-G	C-D and F-E
35.0–40.0 mV[a]	1.0–2.5 mV	0.2–0.22 mV

[a] If the clamp-to-conductor values are in this range, tighten the clamp, as values less than 10 are desired. Also, these values will be changing, and studies are still ongoing to determine more accurate values.

Figure 11 shows a practical method for testing portable grounding cables without clamps. To test clamp to clamp, move the current and potential leads to include the clamps. Potential leads shall not contact the current leads.

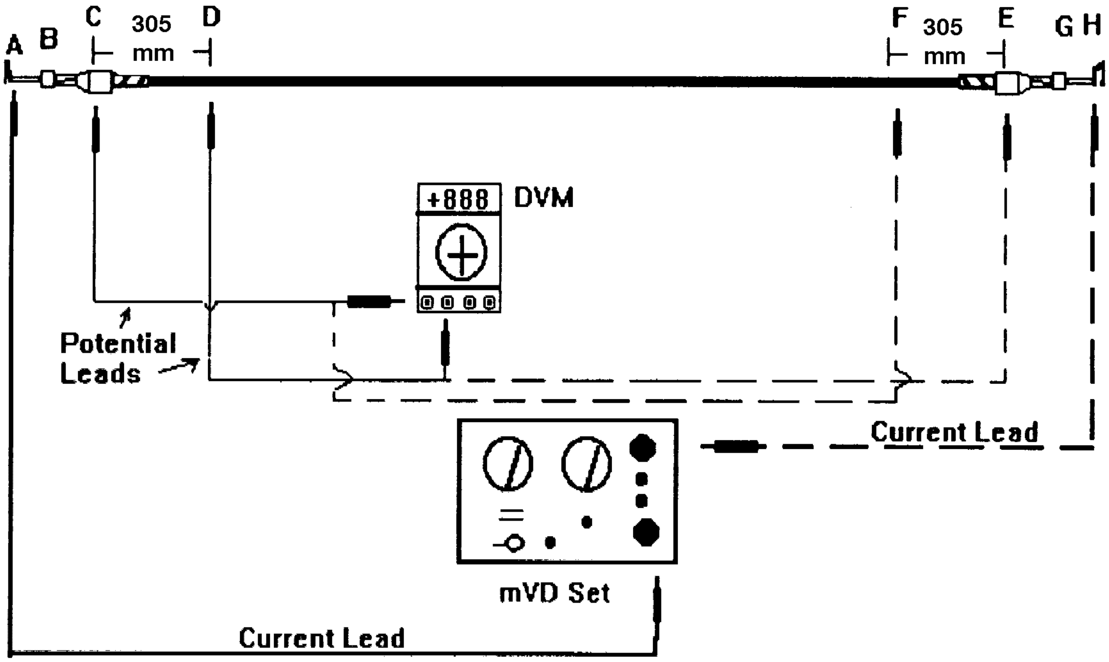

Figure 11—Protective ground testing arrangement

11.2.2.2 High current testing

High current testing has been shown to be a reliable method for detecting high-resistance connections on ground cable ends. This test method involves loading the grounding set proportional to the withstand current rating of the ground set. The voltage drop across the set is recorded and then multiplied by the ratio of the withstand current rating to the applied loading current. If this calculated voltage drop is less than the maximum allowable value for the grounding set rating, the assembly can be considered safe for continued use. Using Dalziel's formula (see Dalziel [B2]), determine the maximum voltage drop for the ground set (see 4.2.2). For the following example, 75 V is used and is the recommended voltage drop (30 cycle) for a human at fibrillation.

11.2.2.2.1 Example

The 30 cycle fault current withstand rating of 1/0 AWG copper cable is 15 000 A. Loading a 1/0 AWG copper protective ground to 750 A provides a ratio of maximum to applied current of 20.0. If the recorded voltage drop across the protective ground is 2.4 V, the calculated voltage drop for the grounding jumper under maximum fault conditions is $2.4 \times 20 = 48$ V. The calculated voltage of 48 V is less than the established 75 V maximum allowable voltage drop so that the portable protective ground successfully passes the high current test.

12. Ground electrodes

12.1 Pole grounds

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

12.2 System neutral

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

12.3 OHGW

A continuous OHGW may be used for transmission line ground application if electrically connected to the structure or structure ground and if of adequate current-carrying capability.

12.4 Ground rods

Ground rods may be used for certain independent applications midspan or to supplement the grounding at a structure when driven to achieve a low ohmic resistance, a normal length of 1.5 m to 2.5 m.

12.5 Measuring devices

The most common instruments used for measuring earth 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.

Clamp-on ground resistance testers may be used to measure ground rod and small grid resistance without the use of auxiliary ground rods. Clamp-on ground resistance testers are used in multigrounded systems without disconnecting the ground under test.

Annex A

(informative)

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A.1 For further reading

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

[10] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[11] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

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