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IEEE Guide for Protective Grounding of Power Lines

IEEE Power Engineering Society

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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 work-site 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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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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²The NESC is available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331 US (<http://standards.ieee.org>).

³ASTM 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 516TM-1995, IEEE Guide for Maintenance Methods on Energized Power Lines.^{4, 5}

IEEE Std 524aTM-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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⁶OSHA 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/>).

⁷The 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.

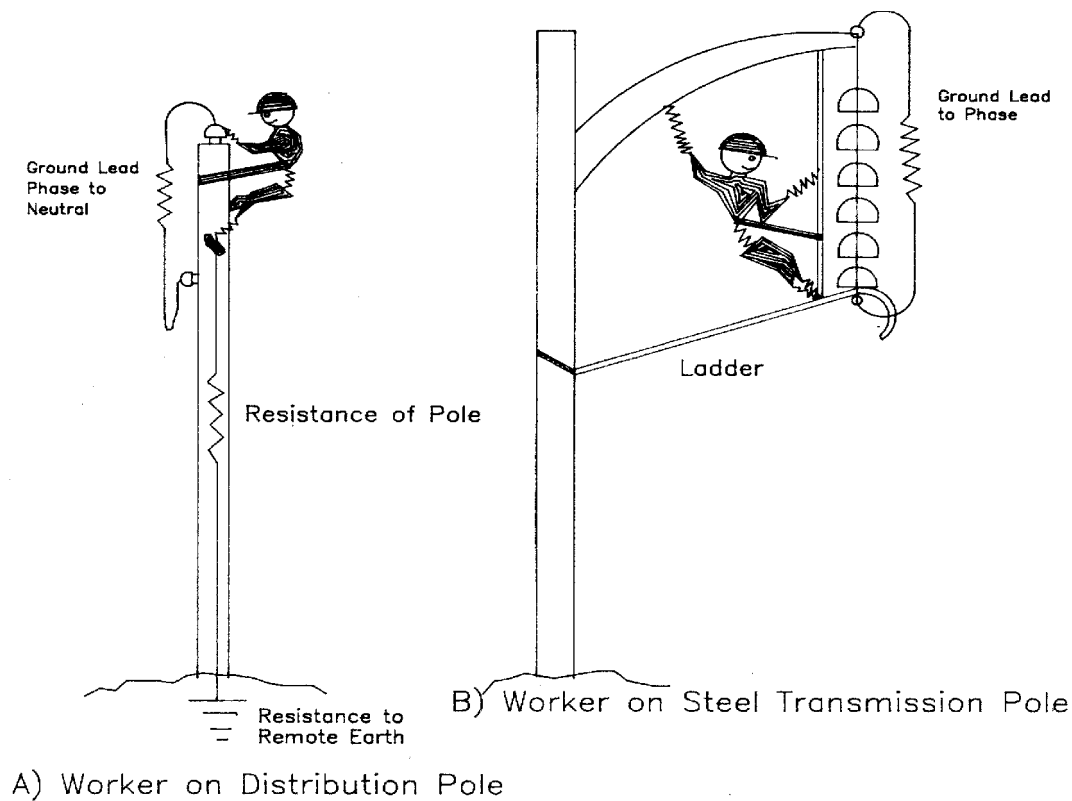


Figure 1—Working position aloft where abnormal voltage might appear

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

^a1% of persons for perception values.

^bA time-dependent function; see Equation (1).

^cDifferences among men and women are due to body size differences.