

IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors

Supplement to IEEE Guide to the Installation of Overhead Transmission Line Conductors

Sponsor

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

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Abstract: General recommendations for the selection of methods and equipment found to be effective and practical for grounding during the stringing of overhead transmission line conductors and overhead ground wires are provided. The guide is directed to transmission voltages only. The aim is to present in one document sufficient details of present day grounding practices and equipment used in effective grounding and to provide electrical theory and considerations necessary to safeguard personnel during the stringing operations of transmission lines.

Keywords: conductor stringing, grounding, grounding equipment, grounding practices, overhead transmission line conductors, protective grounding

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Introduction

(This introduction is not a part of IEEE Std 524a-1993, IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors.)

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1. Overview

1.1 Scope

This guide provides recommendations for the selection of methods and equipment that have been found effective and practical for grounding during the installation of overhead transmission line conductors and overhead ground wires. This guide is directed at transmission voltages only. Installation of overhead conductors for distribution circuits generally involves similar conditions; however, the specific recommendations of this guide have not been developed to include all situations encountered at distribution voltages. The guide also includes a comprehensive list of definitions for equipment and tools used in effective grounding during the stringing operation.

1.2 Purpose

The purpose of this guide is to present in one document sufficient details of present day grounding practices and equipment used in effective grounding during installation of overhead transmission line conductors and ground wires, and to provide electrical theory and considerations necessary to safeguard personnel during the stringing operations of transmission lines.

1.3 Application

This guide is applicable to grounding used during construction of overhead transmission lines. Grounding practices for transmission line projects will be strongly influenced by available fault current and local soil and water table conditions. Methods that are currently employed are presented.

The practices that are described are to provide for a safe environment for the workers installing transmission line conductor and overhead ground wire from the initial setup to ready for service condition.

Requirements of national, state, or local regulations must be observed. This information is intended to be used in developing the appropriate grounding requirements, procedures, and selection of equipment by

methods engineers and construction personnel for the installation of overhead transmission line conductor projects.

1.4 Computer program

This guide includes a computer program for use in calculations of induced voltages and currents. A floppy disk is provided. Instructions for its use are included in annex B. The program, written in C, has been developed for both the disk operating system (DOS) and Macintosh.

1.5 Legal disclaimer

The support data for this guide were collected from a great number of sources and believed to be reliable and true. Care has been taken during the compilation and writing to prevent error or misrepresentation. The authors make no warranty with respect to the accuracy, completeness, or usefulness of the information contained in the guide, or assume any liabilities with respect to the applicability or use of any information, method, or process presented in this publication.

The use of trade names is for the information and convenience of the user of this guide and does not constitute an endorsement by the authors.

1.6 References

This guide shall be used in conjunction with the following publications:

IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in Substation Grounding (ANSI).¹

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

IEEE Std 524-1992, IEEE Guide to the Installation of Overhead Transmission Line Conductors (ANSI).

2. Definitions

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

Many of the terms have additional meanings and usages that are defined in IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms. An asterisk (*) following a definition indicates that the definition is identical to that which appears in IEEE Std 100-1992.²

2.1 anchor (conductor stringing equipment): A device that serves as a reliable support to hold an object firmly in place. The term anchor is normally associated with cone, plate, screw or concrete anchors, but the terms snub, deadman, and anchor log are usually associated with pole stubs or logs set or buried in the ground to serve as temporary anchors. The latter are often used at pull and tension sites (see anchor log in IEEE Std 100-1992). *Syn:* anchor log, deadman, snub.*

2.2 anchor site: The location along the line where anchors are installed to temporarily hold the conductors in facilitating splicing, pulling, or tensioning.

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

²Information on references can be found in 1.6.

2.3 ASTM: The American Society for Testing and Materials. Founded in 1898, the ASTM is a scientific and technical organization formed for the development of standards on characteristics and performance of materials, products, systems, and service; and the promotion of related knowledge.

2.4 AWG: American Wire Gage. Also known as the Brown and Sharp gage, AWG was devised in 1857 by J. R. Brown. This gage has the property such that its sizes represent approximately the successive steps in the process of wire drawing. Also, its numbers are retrogressive; a larger number denotes a smaller wire corresponding to the operations of drawing. These gage numbers are not arbitrarily chosen, but follow the mathematical law upon which the gage is founded.

2.5 body resistance: Determined from the ratio of voltage applied to current flowing in a human body, neglecting capacitive and inductive effects.

2.6 bonded (conductor stringing equipment): The mechanical interconnection of conductive parts to maintain a common electrical potential. *Syn:* connected.*

2.7 bullwheel puller (conductor stringing equipment): A device designed to pull pulling lines and conductors during stringing operations. It normally incorporates one or more pairs of urethane- or neoprene-lined, power-driven, single- or multiple-groove bullwheels where each pair is arranged in tandem. Pulling is accomplished by friction generated against the pulling line, which is reeved around the grooves of a pair of the bullwheels. The puller is usually equipped with its own engine which drives the bullwheels mechanically, hydraulically, or through a combination of both. Some of these devices function as either a puller or tensioner. *Syn:* puller.*

2.8 bullwheel tensioner (conductor stringing equipment): A device designed to hold tension against a pulling line or conductor during the stringing phase. Normally, it consists of one or more pairs of urethane- or neoprene-lined, power-braked, single- or multiple-groove bullwheels where each pair is arranged in tandem. Tension is accomplished by friction generated against the conductor which is reeved around the grooves of a pair of the bullwheels. Some tensioners are equipped with their own engines which retard the bullwheels mechanically, hydraulically, or through a combination of both. Some of these devices function as either a puller or tensioner. Other tensioners are equipped with only friction type retardation. *Syn:* retarder; tensioner.*

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

2.10 clipping-in (conductor stringing equipment): The transferring of sagged conductors from the travelers to their permanent suspension positions and the installing of the permanent suspension clamps. *Syn:* clamping-in, clipping.*

2.11 compression joint (conductor stringing equipment): A tubular compression fitting designed and fabricated from aluminum, copper, or steel to join conductors or overhead ground wires. It is usually applied through the use of hydraulic or mechanical presses. However, in some cases, automatic, wedge, and explosive type joints are utilized. *Syn:* conductor splice, sleeve, splice.*

2.12 conductor (conductor stringing equipment): A wire or combination of wires not insulated from one another, suitable for carrying an electric current. It may be, however, bare or insulated. *Syn:* cable, wire.*

2.13 conductor grip: A device designed to permit the pulling of conductor without splicing on fittings, eyes, etc. It permits the pulling of a continuous conductor where threading is not possible. The designs of these grips vary considerably. Grips such as the Klein (Chicago) and Crescent utilize an open sided rigid body with opposing jaws and swing latch. In addition to pulling conductors, this type is commonly used to tension guys and, in some cases, pull wire rope. The design of the come-along (pocketbook, suitcase, “4” bolt, etc.) incorporates a bail attached to the body of a clamp which folds to completely surround and envelope the conductor. Bolts are then used to close the clamp and obtain a grip. *Syn:* buffalo, Chicago grip, come-along, Crescent, “4” bolt, grip, Klein, pocketbook, “7” bolt, “6” bolt, slip-grip, suitcase.*

2.14 crawler tractor (conductor stringing equipment): A tracked unit employed to pull pulling lines, sag conductor, level or clear pull and tension sites, and miscellaneous other work. It is also frequently used as a temporary anchor. Sagging winches on this unit are usually arranged in a vertical configuration. *Syn:* cat, crawler, tractor, dozer.*

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

2.16 drum puller (conductor stringing equipment): A device designed to pull conductors(s) during stringing operations. It is normally equipped with its own engine which drives the drum(s) mechanically, hydraulically, or through a combination of both. It may be equipped with synthetic fiber rope or wire rope to be used as the pulling line. The pulling line is payed out from the unit, pulled through the travelers in the sag section, and attached to the conductor. The conductor is then pulled in by winding the pulling line back onto the drum. This unit is sometimes used with synthetic fiber rope acting as a pilot line to pull heavier pulling lines across canyons, rivers, etc. *Syn:* hoist, single drum hoist, single drum winch, tugger.*

2.17 dynamometer (conductor stringing equipment): A device designed to measure loads or tension on conductors. Various models of these devices are used to tension guys or sag conductors. *Syn:* clock, load cell.*

2.18 electric field induction (capacitive coupling): The process of generating voltages and/or currents in conductive objects or electrical circuits by the induction process that results from time-varying quasi-static electric fields.

NOTES

1—The term “electric field induction” is preferred over “electric induction” because the latter may be taken to mean electric flux density.

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

2.19 electromagnetic field induction (electromagnetic coupling): The induction process that results from time-varying electromagnetic fields.*

2.20 energized (conductor stringing equipment): Electrically connected to a source of potential difference, or electrically charged so as to have potential different from that of the ground. *Syn:* alive, current carrying, hot, live.*

2.21 equipotential (conductor stringing equipment): An identical state of electrical potential for two or more items.*

2.22 equipotential work zone (area, site): A work zone (area, site) where all equipment is interconnected by jumpers, grounds, ground rods, and/or grids that will provide acceptable potential differences between all parts of the zone under worst-case conditions of energization.

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

2.24 fault current (general): A current that flows from one conductor to ground or to another conductor owing to an abnormal connection (including an arc) between the two. A fault current flowing to ground may be called a ground fault current.*

2.25 finger line (conductor stringing equipment): A lightweight line, normally sisal, manila, or synthetic fiber rope, which is placed over the traveler when it is hung. It usually extends from the ground, passes through the traveler and back to the ground. It is used to thread the end of the pilot line or the pulling line over the traveler and eliminates the need for workers on the structure. These lines are not required if pilot lines are installed when the travelers are hung. *Syn:* layup line.*

2.26 grip, conductor (conductor stringing equipment): See 2.13, conductor grip.

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

NOTE—It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting body current to and from the earth (or the conducting body).*

2.28 ground grid (temporary) (conductor string equipment): A system of interconnected bare conductors arranged in a pattern over a specified area and on or buried below the surface of the earth. Normally, it is bonded to ground rods driven around and within its perimeter to increase its grounding capabilities and provide convenient connection points for grounding devices. The primary purpose of the grid is to provide safety for workers by limiting potential differences within its perimeter to safe levels in case of high currents which could flow if the circuit being worked became energized for any reason or if an adjacent energized circuit faulted. Metallic surface mats and gratings are sometimes utilized for this same purpose. When used, these grids are employed at pull, tension, and midspan splice sites. *Syn:* counterpoise, ground gradient mat, ground mat. (See counterpoise, ground grid, ground mat in IEEE Std 100-1992.)*

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

2.30 ground source: See 2.27, ground (earth).

2.31 ground stick, insulated: An insulated rod, fabricated from fiberglass reinforced plastic, with specialized connection hardware, operating mechanism, and of sufficient length to allow for safe gripping and installation of grounding clamps.

2.32 ground system (general): Consists of all interconnected grounding connections in a specific area. *Syn:* grounding system.*

2.33 grounded (conductor stringing equipment): Connected to earth or to some extended conducting body that serves instead of the earth, whether the connection is intentional or accidental.*

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

2.35 hoist (power line maintenance): An apparatus for moving a load by the application of a pulling force and not including a car or platform running in guides. These devices are normally designed using roller or link chain and built-in leverage to enable heavy loads to be lifted or pulled. They are often used to dead-end a conductor during sagging and clipping-in operations and when tensioning guys. *Syn:* chain hoist, chain tugger, coffin hoist.*

2.36 ICEA: The Insulated Cable Engineers Association. Founded in 1925, the ICEA is a professional society of insulated cable engineers to promote the reliability of covered and insulated conductors for the transmission and distribution of electric energy, control, and instrumentation of equipment and communications.

2.37 isolated (conductor stringing equipment): (A) Physically separated, electrically and mechanically, from all sources of electrical energy. Such separation may not eliminate the effects of electrical induction. (B) An object not readily accessible to persons unless special means for access are used.*

2.38 jumper (conductor stringing equipment): (A) The conductor that connects the conductors on opposite sides of a dead-end structure. *Syn:* dead-end loop. (B) A conductor placed across the clear space between the ends of two conductors or metal pulling lines that are being spliced together. Its purpose, then, is to act as a shunt to prevent workmen from accidentally placing themselves in series between the two conductors.*

2.39 magnetic field induction (inductive coupling): The process of generating voltages and/or currents in conductive objects or electric circuits by the induction process that results from time-varying quasi-static magnetic fields. NOTES: 1—"Magnetic field induction" was formerly called "electromagnetic induction." This usage is now depreciated because electromagnetic induction refers to the combined electric and magnetic field effects. 2—The term "magnetic field induction" is preferred over "magnetic induction" because the latter may be taken to mean magnetic flux density.*

NOTE—The fields in the vicinity of a transmission line can be adequately described as an electric field and a magnetic field. Electromagnetic may imply one or both of these fields. There should be no questions as to what is meant when the electric field or the magnetic field is discussed.

2.40 master ground (conductor stringing equipment): A portable device designed to short circuit and connect (bond) a de-energized circuit or piece of equipment, or both, to an electrical ground. Normally located remote from, and on both sides of, the immediate work site. The master ground is primarily used to provide safety for personnel during construction, and during reconstruction, it is used to provide safety for personnel during construction, reconstruction, or maintenance operations. *Syn:* ground set, ground stick.*

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

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

2.43 pilot line (conductor stringing equipment): A lightweight line, normally synthetic fiber rope, used to pull heavier pulling lines that, in turn, are used to pull the conductor. Pilot lines may be installed with the aid of finger lines or by helicopter when the insulators and travelers are hung. *Syn:* lead line, leader, P-line, straw line.*

2.44 pilot line winder (conductor stringing equipment): A device designed to payout and rewind pilot lines during stringing operations. It is normally equipped with its own engine, which drives a drum or a supporting shaft for a reel mechanically, hydraulically, or through a combination of both. These units are usually equipped with multiple drums or reels, depending upon the number of reels, pulled through the travelers in the sag section, and attached to the pulling line on the reel stand or drum puller. It is then rewound to pull the pulling line through the travelers.*

2.45 primary shock: A shock of a magnitude such that it may produce direct physiological harm. The results of primary shock are fibrillation, respiratory tetanus, and muscle contraction. (See [B21] and [B6].)

2.46 pull site (conductor stringing equipment): The location on the line where the puller, reel winder, and anchors (snubs) are located. This site may also serve as the pull or tension site (anchor) for the next sag section. *Syn:* reel setup, tugger setup.*

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

2.48 pulling vehicle (conductor stringing equipment): Any piece of mobile ground equipment capable of pulling pilot lines, pulling lines, or conductors. However, helicopters may be considered as a pulling vehicle when utilized for the same purpose.*

2.49 reel stand (conductor stringing equipment): A device designed to support one or more reels and having the possibility of being skid, trailer, or truck mounted. These devices may accommodate rope or conductor reels of varying sizes and are usually equipped with reel brakes to prevent the reels from turning when pulling is stopped. They are used for either slack or tension stringing. The designation of reel trailer or reel truck implies that the trailer or truck has been equipped with a reel stand (jacks) and may serve as a reel transport or payout unit, or both, for stringing operations. Depending upon the sizes of the reels to be carried, the transporting vehicles may range from single axle trailers to semi-trucks with trailers having multiple axles. *Syn:* reel trailer, reel transporter, reel truck.*

2.50 reel tensioner (conductor stringing equipment): A device designed to generate tension against a pulling line or conductor during the stringing phase. Some are equipped with their own engines, which retard the supporting shaft for the reel mechanically, hydraulically, or through a combination of both. The shaft, in turn, retards the reel. Some of these devices function as either a puller or tensioner. Other tensioners are equipped only with friction type retardation. *Syn:* retarder, tensioner.*

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

2.52 secondary shock: A shock of a magnitude such that it will not produce direct physiological harm, but may cause involuntary muscle reactions. The results of secondary shock are annoyance, alarm, and aversion (see [B21] and [B6]).

2.53 sheave (conductor stringing equipment): (A) The grooved wheel of a traveler or rigging block. Travelers are frequently referred to as sheaves. *Syn:* pulley, roller, wheel. (B) A shaft-mounted wheel used to transmit power by means of a belt, chain, band, etc. *

2.54 splice site: The location along the line where the conductors are temporarily anchored to join the conductors together to form a splice.

2.55 splicing cart (conductor stringing equipment): A unit which is equipped with a hydraulic pump and compressor (press) and all other necessary equipment for performing splicing operations on conductors. *Syn:* sleeving trailer, splicing trailer, splicing truck.

2.56 static charge: Any electric charge at rest, e.g., charge on capacitor. Static charge is often loosely used to describe discharge conditions resulting from electric field coupling.

2.57 step voltage (conductor stringing equipment): 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.*

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

2.59 structure base ground (conductor stringing equipment): A portable device designed to connect (bond) a metal structure to an electrical ground. It is primarily used to provide safety for personnel during construction, reconstruction, or maintenance operations. *Syn:* butt ground, ground chain, structure ground, tower ground.*

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

2.61 tension site (conductor stringing equipment): The location on the line where the tensioner, reel stands, and anchors (snubs) are located. This site may also serve as the pull or tension site for the next sag section. *Syn:* conductor payout station, payout site, reel setup.*

2.62 touch voltage (conductor stringing equipment): The potential difference between a grounded metallic structure and a point on the earth's surface separated by a distance equal to the normal maximum horizontal reach, approximately 1 m. This potential difference could be dangerous and could result from induction or fault conditions, or both. *Syn:* touch potential.*

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

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

3. Protective grounding principles

A grounding system shall be established at transmission line construction sites that will provide a safe environment for the transmission line construction workers. The grounding system and equipment to be used for each situation should be established by the user knowing the degree of exposure to electrical hazards and the soil conditions for that site. Generally, the most significant hazard results from work in proximity to energized lines.

The approach used within this guide is first to present methods of protecting personnel, develop electrical concepts, and describe hazards during transmission line construction. Then, in conjunction with the ASTM Standard No. F18.2, Protective Grounds, specific criteria and testing requirements of the grounding equipment to be met are discussed. Next, the application of methods and equipment to the process of grounding during the installation of overhead transmission lines is described. And finally, a floppy disk, documentation, and instructions on using the computer programs are presented to aid in determining appropriate grounding equipment and grounding systems for the various situations encountered during installation of overhead transmission line conductors.

All equipment, conductors, anchors, and structures within a defined work area must be bonded together and connected to the ground source. The recommended procedures of personnel protection are the following:

- a) Establishment of equipotential work zones
- b) Selection of grounding equipment for the worst-case fault
- c) Discontinuation of all work when the possibility of lightning exists which may affect the work site

In addition to the grounding system, the best safety precaution is to treat all equipment as if it could become energized.

4. Protection of personnel

The main concern of this guide is the protection of personnel from injury. The personnel at the work site must be protected against electric field coupling and magnetically induced voltages and currents caused by energized adjacent lines. Personnel must be protected from the hazards that result from accidental line energization or faults. Personnel protection can be achieved by placing adequate protective ground systems at the work area.

All appropriate line components and equipment within the work area should be bonded together to create an equipotential work zone. A non-conductive barrier (see figure 16) placed around the work area (includes the ground source) will reduce the exposure to touch and step voltages. Grounding equipment should be selected and installed in a manner that will minimize the likelihood of cables striking personnel during fault conditions.

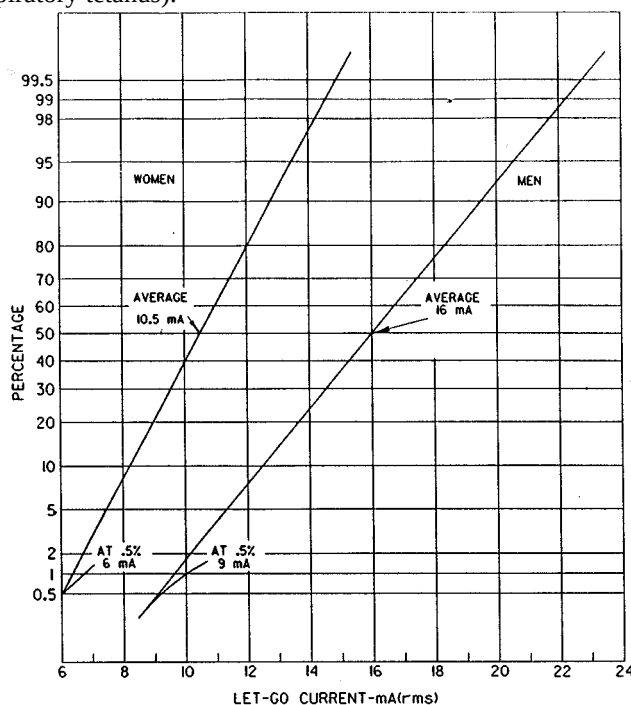
4.1 Physiological reactions

Shock currents can be classified according to the degree of severity of the shock they produce. Primary shock currents can produce direct physiological harm. Secondary shock currents do not produce direct physiological harm but are annoying and may cause involuntary muscle reaction. Both primary and secondary shock currents can be either steady-state or transient in nature. While large charges produced by lightning strokes can cause primary shocks, the transient current effects are a product of time and current magnitude and may or may not produce direct physiological harm.

The effect of ac and dc currents is given in table 1. With increasing shock currents, the control of the muscles in which the current flows becomes increasingly difficult. "Let-go current" is the value of current at which a human holding an energized conductor cannot control his/her muscles enough to release the conductor. The "let-go current" depends on the type of current, dc or ac. Figures 1 and 2 show the distribution curve of "let-

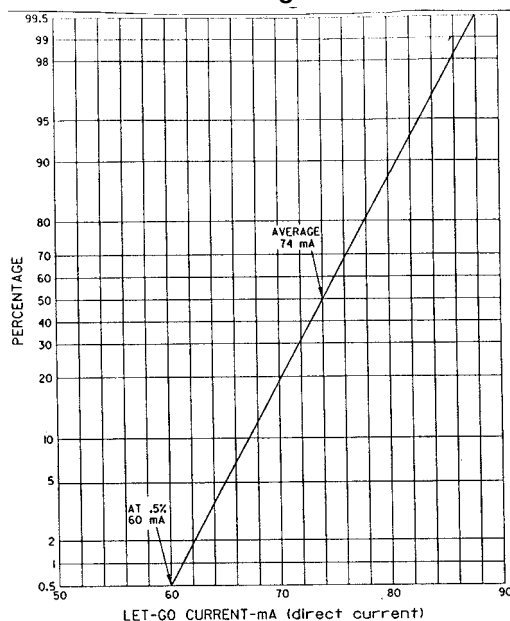
go current” for ac current at 60 Hz frequency and dc current [B4]. Figure 1 shows a “let-go current” of 9 mA for men and 6 mA for women. The “let-go currents” are chosen as those corresponding to 99.5% probability of not losing muscular control.

Currents above the “let-go current” shall be avoided since prolonged muscle contraction in the chest area can lead to suffocation (respiratory tetanus).



NOTE—Data from test results of 28 women and 134 men.

Figure 1—Distribution curve of let-go values of alternating currents



NOTE—Data from test results of 28 men.

Figure 2—Distribution curve of let-go values of direct currents

Table 1—Effects of ac and dc current

Effects	Current (mA)			
	Direct current		60 Hz rms	
	Men	Women	Men	Women
No sensation on hand	1.0	0.6	0.4	0.3
Slight tingling—"threshold of perception" level	5.2	3.5	1.1	0.7
Shock; uncomfortable, but not painful; muscular control not lost	9.0	6.0	1.8	1.2
Painful shock; muscular control not lost—"safe let-go" level for 99.5% of persons tested	62.0	41.0	9.0	6.0

The goal of protective grounding is to avoid adverse physiological effects.

Charles Dalziel [B4] carried out extensive research on the magnitude of current flow and the related effects on human participants. He investigated a time-current relationship of this primary shock, given by the following equation:

$$I = (K/\sqrt{T}) \text{ A} \quad (1)$$

where

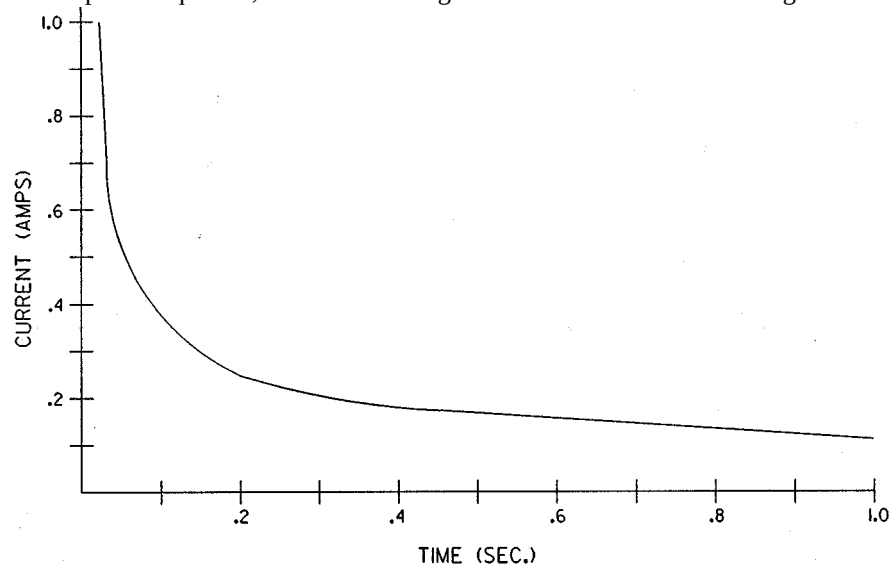
I is the ventricular fibrillation current in amperes

T is the time duration of current flow in seconds

K is an empirical constant

for a probability of 0.5% of ventricular fibrillation, $K = 0.116$.

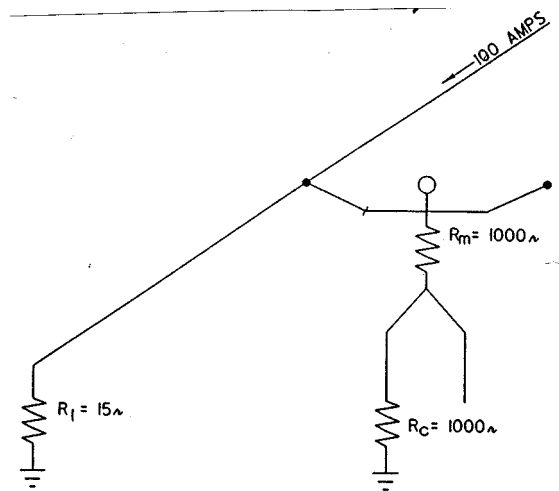
Using Dalziel's empirical equation, the curve relating current and time is shown in figure 3.

**Figure 3—Plot of Dalziel's empirical equation**

Example

Assume the following situation depicted in the figure below:

- a) During stringing of a transmission line, the brakes fail on the tensioner, the guard structure collapses and the line under construction is accidentally energized by a distribution line.
- b) The resistance of the ground at the tensioner end is $15\ \Omega$.
- c) The fault current is 100 A.
- d) Voltage across man is approximately $V_m = I \cdot R_1 = 100 \cdot 15 = 1500\text{ V}$.
- e) The contact resistance plus the body resistance of the man is $1000\ \Omega$ plus $1000\ \Omega = 2000\ \Omega$. Man is standing on the ground and is not protected by a ground.
- f) Current through man, $I_m = V_m/R_m = 1500/2000 = 0.75\text{ A}$.



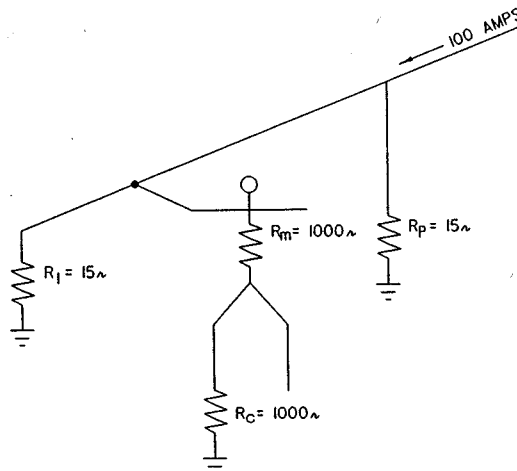
- g) Using Dalziel's electrocution formula

$$I = 0.116/\sqrt{T}$$

$$T = (0.116/I)^2 = (0.116/0.75)^2 = 0.024\text{ s}$$

Therefore, for a possible fatal shock it would take only 1/40 s.

Assume the same conditions above with the addition of a personal ground.



- h) $V_Y (100)(15/2) = 750 \text{ V.}$
- i) $V_m/R_m = (750)/(2000) = 0.375 \text{ A.}$
- j) $T = (0.116/I_m)^2 = (0.116/0.375)^2 = 0.096 \text{ s}$

From the above information and examples of accidental contact with an energized circuit, it is obvious that the results can be hazardous even from a momentary contact, when the worker is not adequately protected from electrical shock. It also shows that for a ground-level work site, application of personal grounds does not necessarily establish a hazard-free equipotential zone for the worker. Precautions such as the following must be exercised to avoid problems from such hazardous conditions:

- a) Use of insulated mats
- b) Use of conductive mats (grids)
- c) Use of properly rated gloves
- d) Use of properly rated insulated hot sticks
- e) Use of barricades
- f) Staying on properly grounded and bonded equipment

It can also be shown that some situations can develop secondary shock current values. This secondary shock hazard provides justification for requirements such as use of safety belts when working on towers.

4.2 Body resistance

For determination of the potential differences, which should not be exceeded in safe work sites, an effectively correct value of body resistance shall be utilized. Values for applicable body resistance vary from 100 Ω through values of several thousand ohms when thick calluses are present on skin surfaces. By use of Ohm's law we can see that the most critical body currents for a given voltage will occur when low body resistance is used. However, a body resistance of 1000 Ω is recommended by and is adopted for calculations in this guide.

4.3 Step voltage

With an overhead transmission line, ground-fault current (I_e), initiated by breakdown or flashover of an insulator string enters the earth through the footing of steel towers or through any other object connected to ground. Assuming the ground is homogenous, the current spreads uniformly in all radial directions. The current produces substantial voltage gradients, as shown in figure 3. If a man is walking as in figure 4 in the neighborhood of a faulted transmission tower, voltage is impressed on each foot. This voltage is called step voltage and is given by the line integral of the voltage gradient over the step width S between his feet at a distance X from the faulted tower footing [B8],[B9]. S is usually assumed to be 1 m.

$$V_s = \int_x^{x+s} E_{dx}$$

where

$$E = \rho(I_e/2\sqrt{\pi}x^2) \text{ and}$$

ρ = resistivity of earth

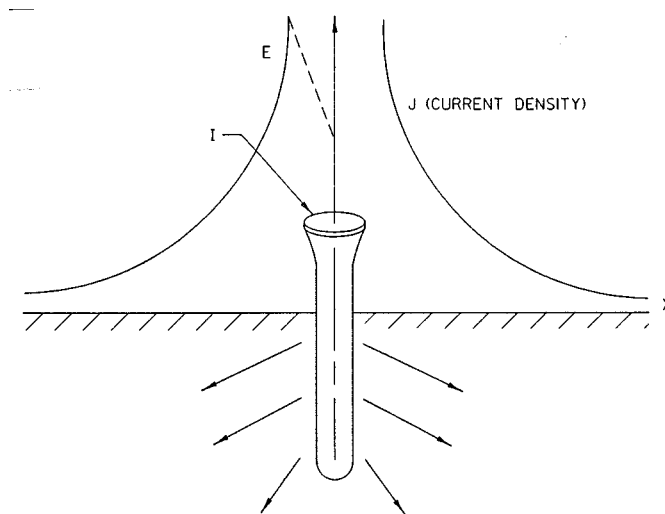


Figure 4—Physical representation of voltage gradients near a ground rod

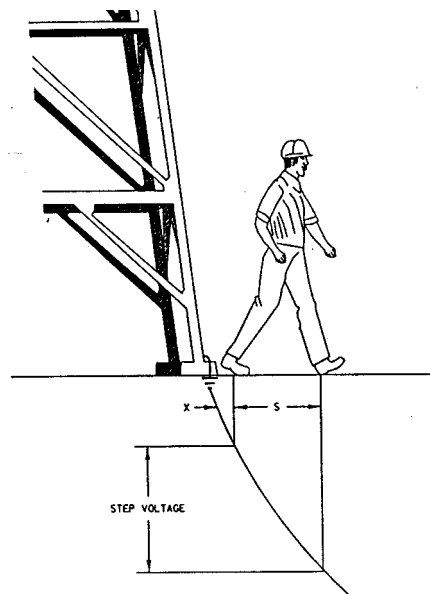


Figure 5—Physical representation of step voltage

This simple model assumes uniform soil resistivity and that the current in the grounding electrodes is equally divided and discharges into earth uniformly along the length of each electrode. It is cautioned that simplified formulas can fail to accurately predict the results, sometimes within an order of magnitude, in most cases where the soil structure and grounding configuration is complex [B14].

The step voltage V_s is equaled to the gradient of $V(s,x)$ multiplied by the distance S between a person's feet in the direction of the gradient.

The body current i_B passing through a person's legs is given by

$$i_B = V_s / (R_b + R_c)$$

where

- R_b is the body resistance, including the resistance of the shoes, and the skin on the feet and body itself
 R_c is the contact resistance between a person's feet and the ground, for a homogenous soil [B9]

IEEE Std 80-1986 gives an expression of the contact resistance R_c if the soil has two layers and the top layer is thin.

The step voltage depends not only on the ground current and the distance from the ground source, but also on the step width and the resistivity of the grounds, and increases with both these values.

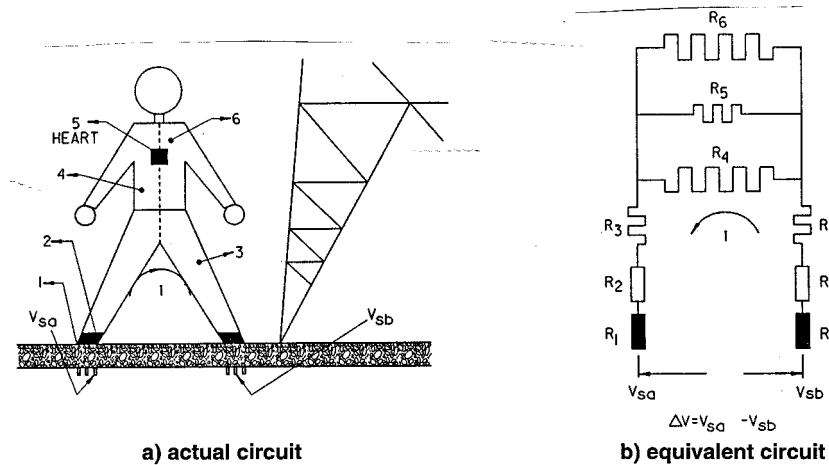


Figure 6—Schematic representation of step voltage [B14]

4.4 Touch voltage

The potential differences described in 4.3 make it such that a person could be standing with both feet on a single equipotential line. Under such conditions that person would not have a resultant current flow from foot-to-foot. However, as illustrated in figure 7, it can be seen that a person may touch a piece of construction equipment that is not at the same potential as the person's feet.

The body current i_B passing through a person's arm to leg is given by the following equation:

$$i_B = V_s / (R_b + R_c)$$

where

- R_b is the body resistance, including the resistance of the shoes, and the skin on the feet and body itself.
 R_c is the contact resistance of a person's hand and feet

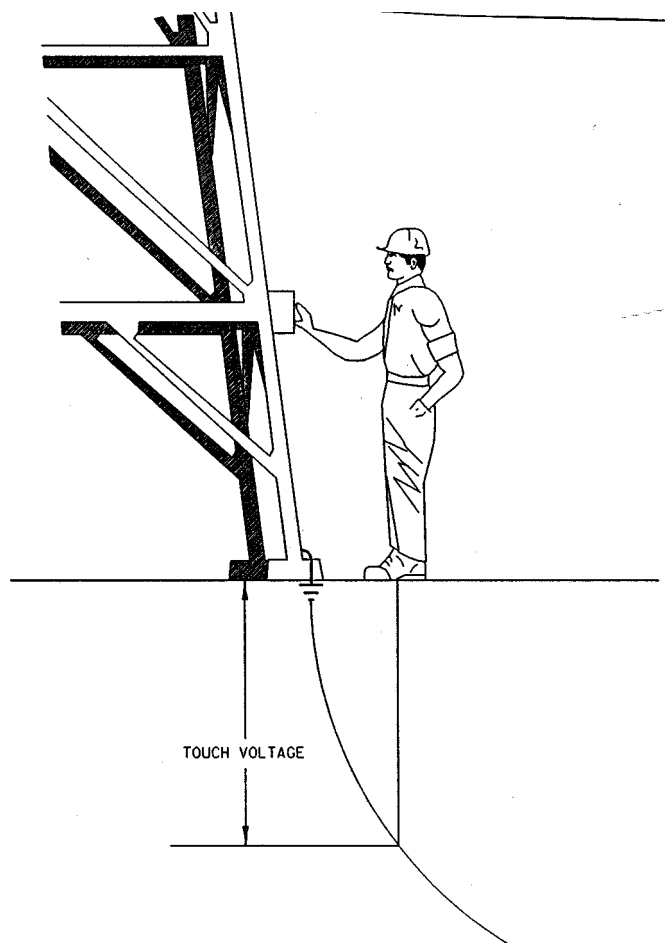


Figure 7—Physical representation of touch voltage

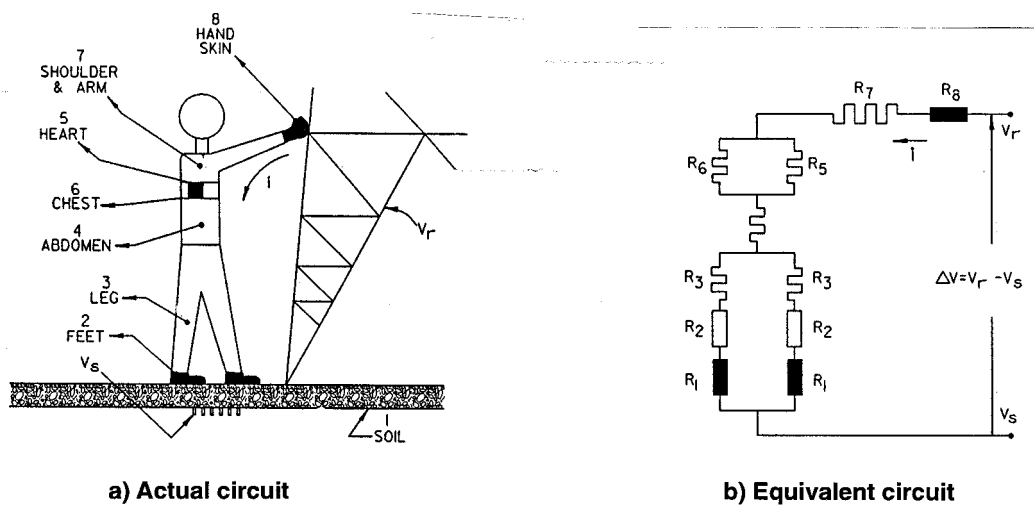


Figure 8—Schematic representation of step voltage