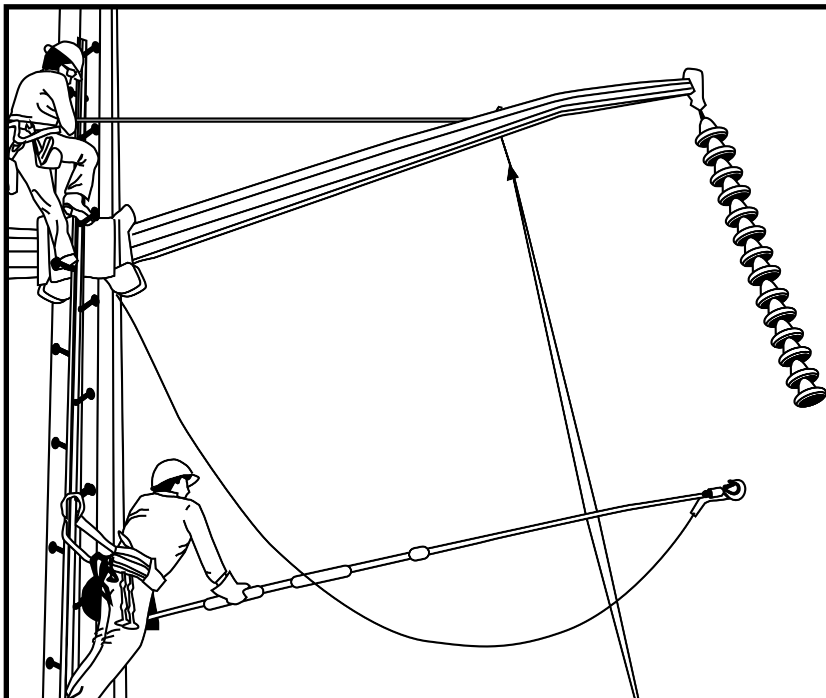
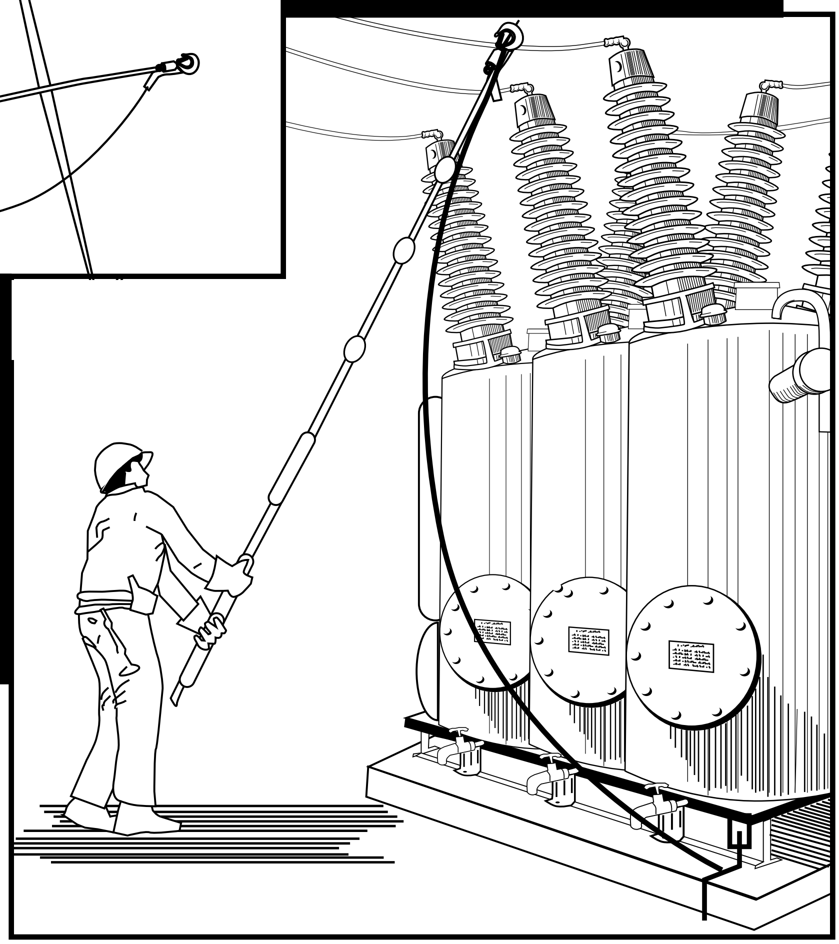
Chapter 1

Personal Protective and Vehicle Grounding



August 1997

WESTERN AREA POWER ADMINISTRATION



DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

Power System Maintenance Manual

PERSONAL PROTECTIVE AND VEHICLE GROUNDING

AUGUST 1997

WESTERN AREA POWER ADMINISTRATION
POWER SYSTEM MAINTENANCE MANUAL
CHAPTER 1

Approved for Publication and Distribution

Dennis Schurman
Team Leader, Maintenance

Date

Preface

This chapter is issued by Western Area Power Administration (Western) and is designed to provide specific guidelines, instructions, procedures, and criteria for establishing and maintaining a personal protective and vehicle grounding program for maintenance and construction work on Western facilities. Procedures and guidelines supplement the requirements of Western's Power System Safety Manual. Corrections or comments concerning this chapter may be addressed to Western Area Power Administration, CSO Technical Support, A3940, P.O. Box 3402, Golden, CO, 80401-0098.

Disclaimer

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PROPOSED REVISION TO POWER SYSTEM MAINTENANCE MANUAL
PERSONAL PROTECTIVE AND VEHICLE GROUNDING, CHAPTER 1

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☐ Addition, ☐ Deletion, ☐ Rewording,
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Power System Maintenance Manual,
Chapter 1
Paragraph Number _________

SUGGESTED NEW WORDING:

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If additional space is needed, attach necessary pages.

Revision recommended by: ____ Mail Code: _________________
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Please return to: **Western Area Power Administration**
CSO Technical Support, Attn: A3940
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1. Overview

1.1 Scope
These guidelines and grounding procedures supplement the requirements of Western Area Power Administration's (Western) Power System Safety Manual. All Western and contractor maintenance and construction personnel working on electrically isolated transmission lines, substations, or equipment shall comply with these procedures. In the event of a conflict between the requirements contained in this chapter and those contained in the Power System Safety Manual, the Power System Safety Manual shall prevail.

1.2 Purpose
The purpose of this chapter is to establish clear and consistent guidelines and procedures for grounding electrically isolated transmission lines and equipment on Western facilities. Electrical theory and related applications to clarify the applicable personal protective and vehicle grounding requirements is given in detail in the Protective Grounding Engineering Guidelines [11].

1.3 Cancellation
This chapter supersedes Personal Protective Grounding, Chapter 1, Power System Maintenance Manual, January 1990.

1.4 Legal disclaimer
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1.5 Interpretations
The stated interpretations for the following words shall be applied throughout this chapter:

a) "May" - Permissive choice.

b) "Shall or Must" - Mandatory under normal conditions.

c) "Will" - Mandatory, but allowing the responsible employee or party some discretion as to when, where, and how.

d) "Should" - Advisory. "Should" statements represent the best advice available at the time of printing.

e) Male pronouns and related terms are used in reference to both male and female employees.

f) "grounding cables" or "protective grounds," when used by themselves, shall refer to both personal protective grounds and vehicle grounds.

g) "transmission," as used in this manual, also includes grounding practices for "distribution."

1.6 Responsibility. Each employee working on electrically isolated lines and equipment is responsible for knowing grounding requirements and for applying the proper grounding procedure(s). Managers and supervisors are responsible for ensuring that workers are knowledgeable and that they comply with these guidelines and grounding procedures.

1.7 Variances. Variances from the requirements of this chapter may be granted in accordance with paragraph 1.4 of the Power System Safety Manual.

2. References

This Chapter shall be used in conjunction with the most recent of the following publications:

[1] ANSI/IEEE-C2, *National Electrical Safety Code, The Institute of Electrical and Electronics Engineers, Inc., August 1989.*

[2] ASTM F 855, *Standard Specifications for Temporary Grounding Systems to be Used on De-energized Electric Power Lines and Equipment.*

[3] IEC Publication 479-1, *Effects of Current Passing Through the Human Body.*

[4] IEEE Paper 94 SM 607-2 PWRD, *Factors in Sizing Protective Grounds.*

[5] IEEE Standard 524a, *IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors.*

[6] IEEE Standard 1048, *Guide for Protective Grounding of Power Lines.*

[7] OSHA 1910, Code of Federal Regulations; Title 29-Labor; Subtitle B Regulations Relating to Labor; Chapter XVII *Occupational Safety and Health Administration, Department of Labor Part 1910, Occupational Safety and Health Standards.*

[8] OSHA 1926, Code of Federal Regulations; Title 29-Labor Subtitle B Regulations Relating to Labor; Chapter SVII *Occupational Safety and Health Administration, Department of Labor Part 1926, Safety and Health Regulations for Construction.*

[9] *Power System Safety Manual,* Western Area Power Administration.

[10] *Power System Operations Manual,* Chapter 1, *Power System Switching Procedures,* Western Area Power Administration.

[11] *Protective Grounding Engineering Guidelines,* Western Area Power Administration.

[12] *Standard Handbook for Electrical Engineers,* Thirteenth Edition, McGraw-Hill, Inc., 1983.

Copies of these publications or parts thereof may be obtained from CSO Technical Support.

3. Definitions

3.1 barricade. A physical obstruction such as tapes, cones, or A-frame type wood or metal structure intended to provide a warning about and to limit access to a hazardous area [7] [8].

3.2 barrier. A physical obstruction which is intended to prevent contact with energized lines or equipment or to prevent unauthorized access to a work area [7] [8].

3.3 bond. The electrical interconnection of conductive parts to maintain a common electrical voltage [1].

3.4 bracket grounding. Personal protective grounds placed on both sides of the worksite, normally on adjacent structures. In storm damage, placed as near as practical to the worksite. Synonym: adjacent structure grounding [6].

3.5 clearance. A statement with documentation from the Operations Supervisor to an authorized individual declaring that the equipment to be worked on has been electrically isolated from all sources of primary energy [10].

3.6 composite structure. A composite structure is a structure that is constructed of two or more different materials (i.e., wood poles with steel or fiberglass crossarms).

3.7 de-energized. De-energized is defined by ALL national and international standards and Federal OSHA as being "grounded, dead." This is not the interpretation used by some maintenance craft and operations personnel: therefore, "de-energized" is replaced in this text by "electrically isolated" or "electrically isolated and grounded." (PSSM: de-energized. Removed from its primary electrical source of energy by opening load current interrupting devices).

3.8 electrically isolated. Removed from all primary sources of electrical energy by opening switches, disconnectors, jumpers, taps, or other means of electrical supply. (PSSM: isolated. The current is isolated when all switches, disconnnectors, jumpers, taps, or other means through which known sources of electrical energy may be supplied to the particular lines and equipment have been opened on a de-energized electrical circuit or equipment).

3.9 energized. Electrically connected to a source of potential difference, or electrically charged so as to have a potential slightly different from that of the earth in the vicinity [1].

3.10 fault (current). A current that flows from one conductor to ground or to another conductor because of an abnormal connection (including an arc) between the two [1].

3.11 ground. 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 earth [1].

3.12 ground, protective. A portable cable assembly sized to carry maximum worksite anticipated fault current and anticipated continuous current from a grounded conductor, bus or piece of electrical equipment to ground or to connect a vehicle to earth or to a grounding system.

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

NOTE: stringing blocks with electrically conductive neoprene linings shall not be used to replace the grounding requirements of grounding stringing blocks [5].

3.14 grounding system. A system of personal protective and/or vehicle grounds that are connected together at the worksite to form an effective common ground.

3.15 ground, vehicle. See "ground, protective."

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

3.17 Isolated (physical). The use of barriers or barricades to prohibit workers and the public from approaching grounded systems.

3.18 jumper. (1) A metallic wire connecting the conductors on opposite sides of a deadend structure so that continuity is maintained. Synonym: deadend loop. (2) A conductor placed across the clear space between the ends of two conductors or metal pulling lines that are spliced together to act as a shunt capable of carrying continuous current to prevent workers from accidentally placing themselves in series between the two conductors.

3.19 spiking. Mechanically or hydraulically driving a grounded pin into an insulated power cable to assure it is electrically isolated before the insulation is opened.

3.20 step voltage. The potential difference between two points on earth's surface separated by a distance of one pace (assumed to be 1 m (3.3 ft) in the direction of maximum potential gradient). This potential difference could be dangerous when current flows through the earth or material upon which the worker is standing, particularly under fault conditions. Synonym: step potential [6].

3.21 touch voltage. The potential difference between a grounded metallic structure and a point on earth's surface separated by a distance equal to a person's normal maximum horizontal reach, approximately 1 m (3.3 ft). This potential difference could be dangerous and could result from induction, fault currents, or both. Synonym: touch potential [6]

3.22 transferred touch voltage. The voltage difference between points on a surface connected by a conductive element which increases touch voltage greatly as the distance from the source increases. Synonym: transferred touch potential [6].

3.23 worksite. The immediate work area. On transmission lines, the area is normally in the vicinity of a structure.

4. Basic criteria for safe grounding

Western is committed to providing its employees with a safe working environment. However, the employees must be aware of possible hazards and avoid, or at least minimize, exposure to them.

The purpose of protective grounding is to prevent accidental death or injury to workmen from electrical shock (For additional information regarding the electrical shock hazard, refer to Protective Grounding Engineering Guidelines [11]).

The primary use of protective grounds is to provide minimum risk for personnel while they are working on electrically isolated lines, buses, or equipment. This is accomplished by reducing voltage differences at the worksite (voltage across the worker) to the lowest practical value in the event that the equipment or line being worked is accidentally energized. Another function of protective grounding is to protect against induced voltage from adjacent parallel energized lines or equipment.

Voltage differences may appear at the worksite because of induction from adjacent circuits, static charge, lightning, or accidental energization. If the line, bus, or equipment becomes energized, potentially hazardous voltage differences could result. Protective grounds will limit excessive voltage differences in the work area aloft, and proper work procedures will reduce exposure to step, touch, and transferred touch voltages on the ground. The most important rule in safe grounding is to ensure that the worker is never in series with a grounding system component (see figure 1). Installing protective grounds is considered to be live work as a circuit is considered to be energized until grounded. Figure 2 depicts the voltage rise curve used to demonstrate step and touch voltages. As the distance from the contact between the fault and the earth increases, the amount of resistive soil in between also increases. Western's staged fault tests show that the voltage rise reaches near maximum (100 percent) at approximately 10 m (32 ft 10 in) (point B in the figure) and about 50 percent of the maximum at 0.5 m (1 ft 8 in) to 1.2 m (3 ft 1 in) (point A in the figure).

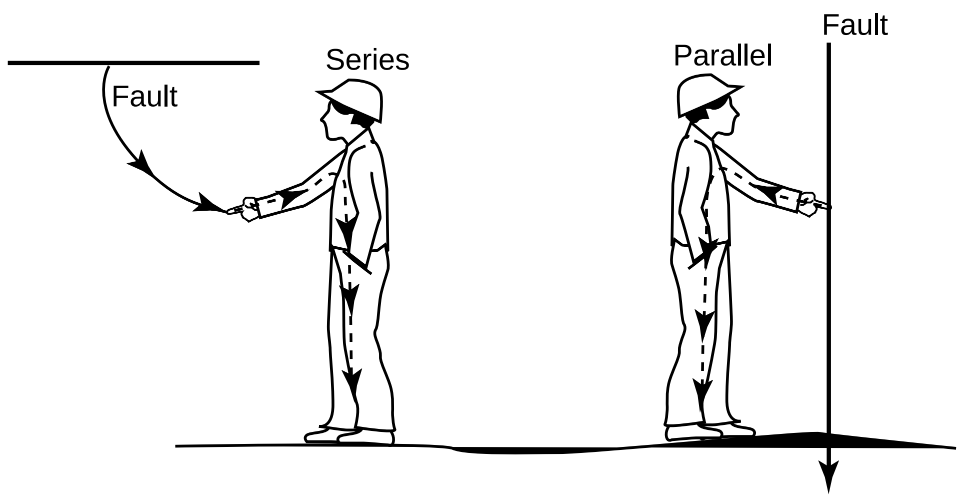


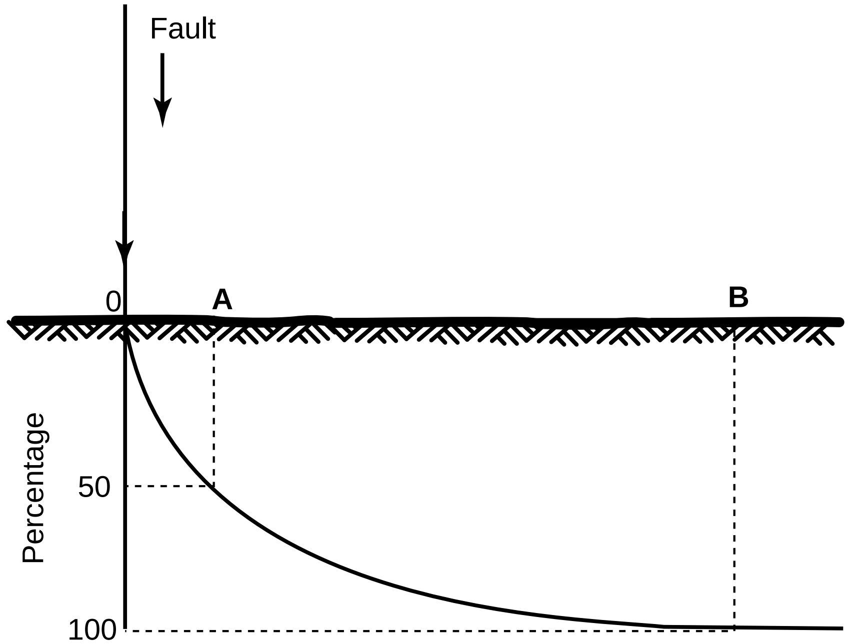
Figure 1
Current Path

Step, touch, and transferred touch voltages occur where there is a difference in potential between two points (see figure 3). These voltages are the result of energization of a grounded conductive object, either by accidental energization (i.e., fault) or through continuous induced current. Protection against step and touch voltages may be accomplished in three ways (see figure 4):

a) Equipotential is obtained by keeping the person and reaching activities confined to an equipotential surface.

b) Insulation is obtained by using insulated platforms, footwear, gloves, etc. insulated for the maximum anticipated fault or induced current at the worksite.

c) Isolation is accomplished by limiting or restricting the approach distance to grounding systems (i.e., barricading or fencing). Barricading is the most efficient way to protect the public from step and touch voltages at a temporary worksite.



NOTE: The distance from the fault to points A and B depend on fault magnitude and soil resistivity.

Figure 2
Voltage Rise Curve

To minimize the exposure to hazardous levels of step, touch, and transferred touch voltages on transmission line systems, persons not involved in the work activity should stay a minimum of 3 m (10 ft) from the grounding system (i.e., structures, vehicles, guy wires, and ground rods). The minimum distance may increase with new system designs with greater fault capability. The dangers associated with step and touch voltages may be substantially reduced by wearing insulated footwear.

Further information regarding ground fault currents and step, touch, transferred touch voltages is available in the Protective Grounding Engineering Guidelines [11].

In summary, whenever working on electrically isolated lines or equipment, employees should:

a) Review the job procedures, the Job Hazard Analysis (if required), and the protective grounding requirements before beginning work,

b) Review the applicable list of maximum anticipated fault currents to determine the size and number of protective ground cables to be used [11].

c) Visually inspect the protective grounding cable(s) for defects.

d) Buzz the circuit or equipment before installing the grounding cable(s) to verify that the circuit has been electrically isolated (PSSM: de-energized).

e) Never place themselves in series with an electrical circuit when installing or removing protective grounding cables.

f) Install the protective grounding cables to the grounding system first; then, using a hotstick that does not violate the minimum approach distances of the voltage being worked (see Paragraph 8),

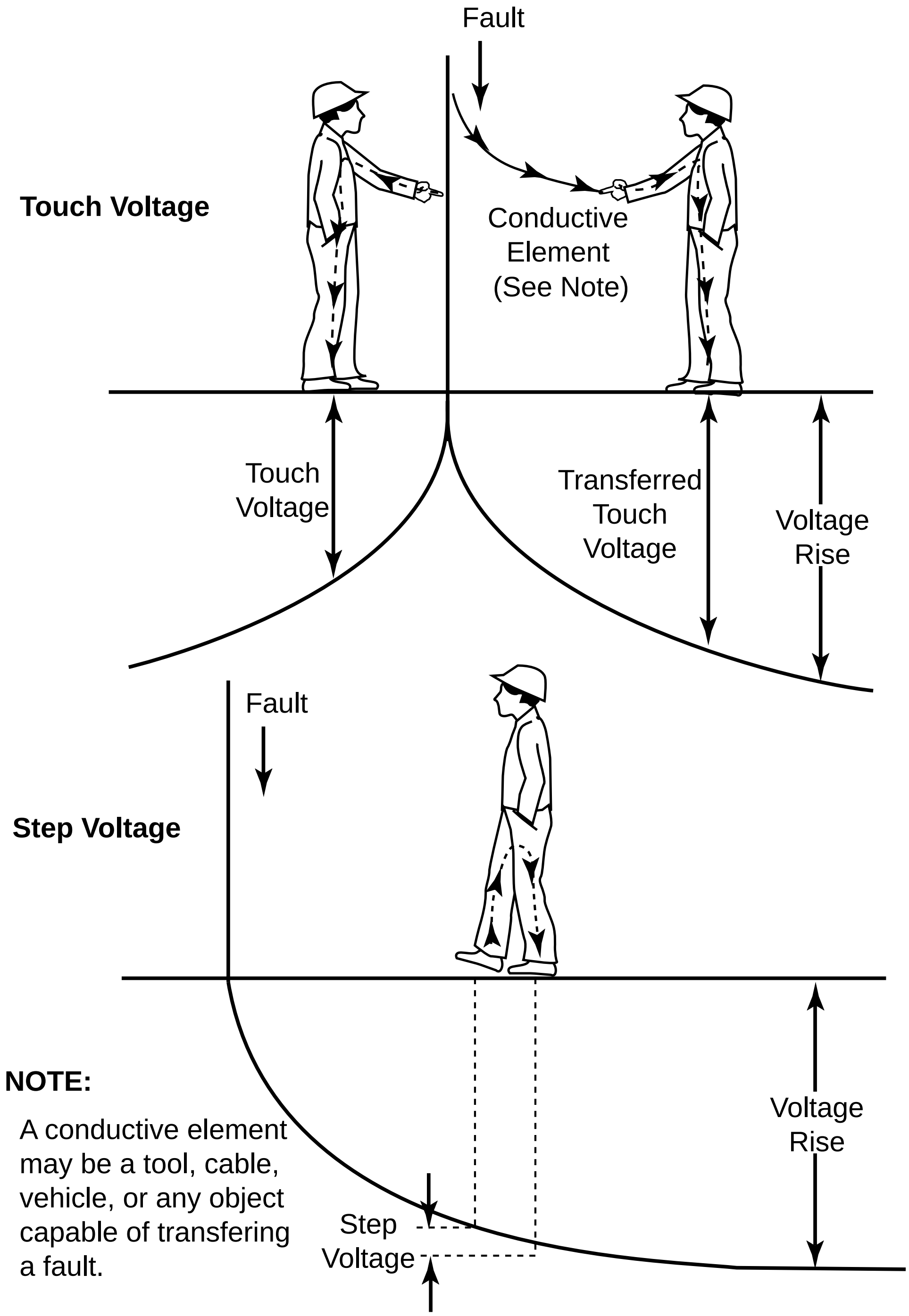


Figure 3
Step and Touch Voltages

connect the other end of the protective grounding cable to the normally energized circuit or equipment. Reverse the sequence when removing the protective grounding cables.

g) Remember that if a transmission line or piece of equipment is not properly grounded, it is not dead.

h) Minimize exposure to possible step, touch, and transferred touch voltages.

5. Protective grounding principles

Proper protective grounding results in a low risk working environment. Low resistance protective ground cables will limit the voltage drop at the worksite to acceptable levels. Therefore, it is imperative that the protective ground cables be designed and assembled to handle the maximum acceptable levels of anticipated fault current. Transmission line and substation bus fault currents must be calculated from the electrical parameters of the power system to identify the size and number of protective ground cables required.

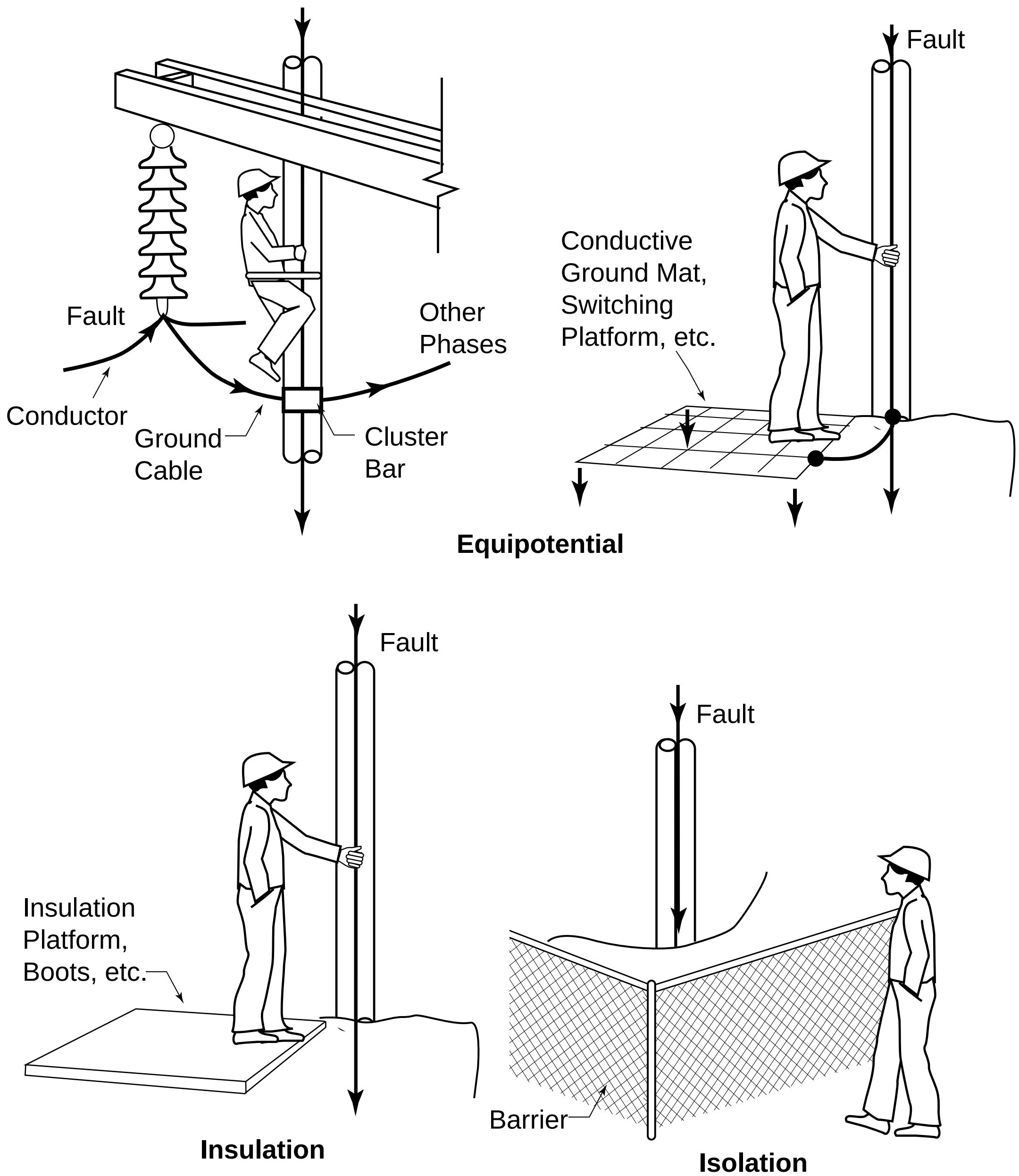


Figure 4
Methods of Personal Protection From Faults and Induced Current

Each field office shall develop a listing of the maximum anticipated fault currents annually for each of its transmission lines and substation buses, as well as the proper size and number (if parallel grounds are to be used) of protective grounding cables to be used in each facility. Circuits carrying significant induced currents should include the maximum anticipated continuous current [11]. This listing must be reviewed and updated annually to ensure proper sizing of protective grounding cables. A copy of this data shall also be submitted annually to the respective crews, CSO Technical Support (A3940), and CSO Safety (A3700).

6. Grounding cables and hardware

Protective ground cables and accessories shall be in accordance with American Society for Testing and Materials (ASTM) Standard F 855, Standard Specifications for Temporary Grounding Systems to be used on De-energized Electric Power Lines and Equipment [2]. **Aluminum cables shall not be used for protective grounds.** Grounding cables shall be electrically tested every two years, after sustaining a fault, or after modification. An electrical acceptance test shall be preformed on new grounding cables prior to use. Testing shall be in accordance with the Power System Safety Manual and the Protective Grounding Engineering Guidelines.

Protective grounding cables consist of appropriate lengths of suitable copper grounding cable, with electrically and mechanically compatible copper ferrules and clamps at each end. In addition, appropriate hotsticks are required for installing and removing the normally energized clamp end. Hotsticks are required for attaching ground end clamps if the grounded system and the worker are at different potentials. Cluster bars provide a low resistance means of connecting the ground end clamps.

6.1 Grounding cables. Most of the grounding cables in use today are actually manufactured for another purpose—principally as welding cable. These extra flexible copper cables with jackets are manufactured according to appropriate ASTM standards for cables and jackets and can be expected to perform satisfactorily as grounding cables.

6.1.1 Stranding. Stranding for several classes of flexible cable in the sizes normally used for grounding cables are given in American Society for Testing and Materials (ASTM) Standard F 855, Standard Specifications for Temporary Grounding Systems to be used on De-energized Electric Power Lines and Equipment [2] and the Protective Grounding Engineering Guidelines [11].

6.1.2 Jackets. Welding cables are nominally insulated at 600 volts. When used as grounding cable, the insulation or jacket serves primarily for mechanical protection of the conductor. The flexible elastomer or thermoplastic jackets are manufactured, applied, and tested according to ASTM standards. Black, red, and yellow jackets are usually neoprene rubber compounds, while clear jackets are ultraviolet inhibited polyvinyl chloride. All jackets should have the American Wire Gage size stamped or printed repeatedly along the length of the cable. The clear jacket allows easy visual inspection of the conductor for strand breakage but becomes stiff and hard to handle at low temperatures. The clear jacket will split or shatter at very low temperatures.

6.1.3 Ferrules. Ferrules shall be threaded stud copper base compression type. Ferrules should have the filler compound vent hole at the bottom of the cable so that workers can visually check that the cable is fully inserted into the ferrule (see figure 5). The ferrule manufacturers recommended compound should be used with crimped ferrules. The ferrules should be crimped with the ferrule manufacturer's recommended die. The press shall have enough pressure to completely close the die. The area covering the inserted cable jacket should not be compressed. Heat shrink should be installed over a portion of the ferrule to minimize strand breakage caused by bending. In all cases, the manufacturer's recommendations should be followed. Caution should be used if springs are installed as induction can cause heating and can reduce the cable rating.

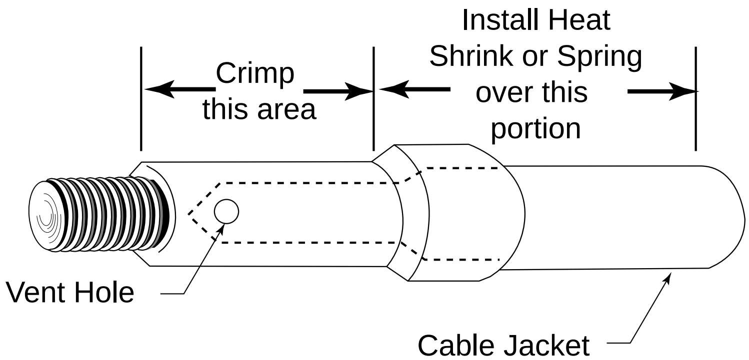


Figure 5
Compression Ferrule

6.1.4 Handling of grounding cable. Care should be used in handling and lifting grounding cables as continuous flexing eventually breaks the conductor strands beneath the jacket. Sharp bends in the cable should be avoided.

6.1.5 Size of grounding cable. The size of the grounding cable must be selected for the maximum anticipated (calculated) fault current at the worksite. The minimum size that should be used for grounding cables is 1/0 American Wire Gage flexible copper. In several of Western's larger substations, the maximum anticipated fault current may be high enough to require larger diameter cables. If larger diameter cables are not available, parallel cables (with the appropriate derating factor) may be used.

NOTE: If the anticipated continuous current at the jobsite exceeds the continuous current rating for the grounding cable, a section of aluminum conductor or bus (including clamps) rated for the anticipated continuous current shall be used. Grounding cables shall be capable of handling the available

able

Table 1
Maximum Fault Current Capability and Continuous Current Rating for Grounding Cables

Cable Size (AWG)	Continuous Current (rms)	Fault Time (hertz)	Fault Current Capability (rms)
1/0	250	15	21,000
		30	15,000
2/0	300	15	27,000
		30	20,000
3/0	350	15	36,000
		30	25,000
4/0	400	15	43,000
		30	30,000

continuous current. In areas where induced voltages may be a hazard, calculations shall be made to determine the magnitude and time characteristics of continuous current for grounding cables to be left in place for more than one day. The use of multiple grounding cables shall be in accordance with paragraph 7.4.6.

Cable sizes shall be in accordance with the maximum anticipated worksite fault current and/or the continuous (induced) current for the specific facility and Table 1 [2].

Protective grounds must be designed, assembled, and installed in a manner that satisfies the following basic criteria:

a) Protective grounding cables shall be capable of conducting the maximum anticipated fault current that could occur at the worksite if the electrically isolated line or equipment becomes momentarily energized from any source. A grounding cable which will conduct the maximum anticipated fault current must also conduct the steady state current(s) induced by electromagnetic coupled voltage on adjacent energized parallel lines, as discussed in the Protective Grounding Engineering Guidelines [11].

b) The grounding cable must be rated to carry the maximum anticipated continuous current for the time that the grounding cable is in place.

c) As discussed in the Protective Grounding Engineering Guidelines [11], the voltage drop across a protective grounding cable, when carrying maximum anticipated fault current, must be low enough to prevent hazardous current flow through the worker's body. The values of voltage drop must not exceed 100 volts for 15 Hz (250-millisecond) substation clearing or 75 volts for 30 Hz transmission line (500 millisecond) clearing.

d) The protective grounding cable must be terminated with clamps of adequate capacity and strength to withstand all electrical and mechanical forces present under maximum fault conditions.

e) The grounding cable must:

1) Be easy and timely to apply.

2) Satisfy the requirements of field conditions.

3) Adapt to a wide range of conductor, structural steel, and ground wire/rod sizes.

f) Cable length should be as short as practical for the specific task being performed. This is necessary to comply with the concerns noted in subparagraph 6.1.6.

g) The following personal protective grounding considerations apply to personnel working on grounded lines that cross fused lines (NOTE: These conditions may also apply to some distribution voltage reclosers):

The maximum anticipated fault current values given for protective ground cables, ferrules, and clamps are for 15 and 30 Hz clearing times. Continuous current carrying capacities for copper cables are from 250 amps for 1/0 cable to 400 amps for 4/0 cable. Under continuous current conditions greater than the specified values, calculations indicate that the cable jacket will begin to melt in approximately 1 minute and the copper will begin to fuse in approximately 3 minutes.

Personnel working on grounded lines that cross fused lines should be aware of this hazard. If personnel become aware of cable heating, they should move clear of situations that would place them in parallel with a deteriorated personal protective ground cable, warn their coworkers, and remain clear until the hazard has been removed. In this situation, the protective grounds are primarily for protection from induced voltage buildup at the worksite and not intended as backup protection for accidental energization.

6.1.6 Grounding cable length. Excessive cable lengths should be avoided by selecting grounding cables of the approximate required length. Slack in the installed cables should be minimal to reduce possible injury to workers due to the whipping action from fault currents. Resistance in the cable increases with cable length, and excessive length will exceed the tolerable voltage drop. Longer than necessary cables also tend to twist or coil, which reduces the current carrying capacity of the cable. Excess cable should never be wrapped around a metal structure or coiled. A wrapped or coiled cable creates a transformer effect which will reduce the current carrying capacity of the cable and, if the fault or induced current is high enough, destroy the cable.

6.2 Grounding cable couplers. Cable lengths should not be extended by hooking cable clamps together or attaching them to an intermediate conductor except as permitted by paragraph 6.4. Commercial cable couplers that are rated for maximum anticipated fault current are available. Cable couplers are convenient for keeping substation and vehicle grounding cables reasonably short.

6.3 Grounding clamps. Grounding clamps are normally made of copper or aluminum alloys; sized to meet or exceed the current carrying capacity of the cable; and designed to provide a strong mechanical connection to the conductor, metal structure, or ground wire/rod.

6.3.1 Grounding clamp types. Grounding clamps are manufactured in, but not limited to, four types according to their function and methods of installation. They are:

a) Type I clamps, installed to electrically isolate normally energized conductors, are equipped with eyes for installation with removable hotsticks.

b) Type III clamps, for installation on permanently grounded conductors or metal structures, have T-handles, eyes, and/or square or hexagon head screws.

c) Ball-and-socket type clamps. These clamps shall only be used on a ball of size and shape designed for the specific socket type clamp.

d) Other types of special clamps are designed for specific applications, such as cluster grounds and underground equipment grounding.

6.3.2 Clamp jaws. Bus clamps should be furnished with smooth jaws for installation on copper, aluminum, or silver plated bus work without marring the surface. Conductor or metal structure clamps should be furnished with serrations or cross hatching designed to abrade or bite through corrosion products on the surfaces of the conductor or the metal structure being clamped. Several styles of conductor and ground end clamps have jaws that can be replaced when the serrations have worn. Self cleaning jaws are recommended for conductor end clamps used on aluminum or aluminum conductor steel reinforced conductors. Several styles of ground end clamps are designed with a cup point setscrew which should be tightened with a wrench (after the serrated jaws have been securely tightened) to break through paint, rust, galvanized coating, or corrosion on the surface that is to be clamped.

NOTE: Only clamps designed for use with threaded stud copper base compression ferrules shall be used. The threaded stud fitting should be checked for tightness periodically. To ensure a lasting snug fit, aluminum alloy ferrules shall not be used. More information concerning clamp size, design, testing, and materials is available in ASTM publication F-855 [2].
A typical grounding cable for transmission line work consists of a 2/0 American Wire Gage copper

cable with an insulating jacket and is equipped with an all angle self cleaning aluminum conductor clamp at the conductor end and a flat faced clamp with a setscrew at the ground end.

6.4 Grounding cluster bars. When applying personal protective ground cables to wood pole structures, workers may use a grounding cluster bar to connect each conductor grounding cable to a pole ground wire. Cluster bars must have an attached bonding lead. If there is no pole ground wire, the cluster bar for each pole is connected to a common driven ground rod with a grounding cable (or cables). In substation grounding, a copper bar is sometimes used to connect the three phase cables and a fourth cable to a riser from the station ground mat. When installing personal grounds on wood structures from a bucket, the ground cables may be connected between the overhead ground wire and the phases without the use of cluster bars provided that a visual electrical bond exists between the overhead ground wire and the structure ground and that there is an electrical bond between the poles or overhead ground wires. Grounding cluster bars should be used on all poles of wood structures (see paragraph 11.3.2 for details).

6.5 Temporary ground rods. Temporary ground rods shall be either:

(1) A minimum 16 mm (5/8 in) diameter bronze, copper, or copper weld rod at least 1.8 m (6 ft) long, driven to a depth of at least 1.5 m (5 ft); or

(2) A 1.8 m (6 ft), screw type ground rod, consisting of a minimum 16 mm (5/8 in) diameter copper weld shaft with a bronze auger bit and bronze T-handle, screwed to a depth of at least 1.5 m (5 ft) (preferred). The T-handle must be tightly connected to the rod. As screw type ground rods disturb the entire earth contact area, they may not be as efficient as driven ground rods.

If a temporary rod cannot be driven or screwed to a depth of 1.5 m (5 ft), additional rod(s) should be driven or screwed so that a total of at least 1.5 m (5 ft) of rod is buried. The effectiveness of a temporary ground rods and multiple ground rods is covered in the *Protective Grounding Engineering Guidelines* [11]. These rods shall be bonded together with grounding cables prior to installing phase grounds. The rods should be placed 1.5 m (5 ft) to 3 m (10 ft) apart; however, a 3 m (10 ft) approach distance from all ground rods should be maintained. Overhead ground wires may be used to bond the conductors provided that these wires are electrically bonded to the structure ground, either permanently or by personal protective grounds.

Groundmen should stay clear (at least 3 m (10 ft) where feasible) of items such as down guys, ground rods, maintenance vehicles, and structure legs or ground wires while they are bonded to protective grounds which are in place. When it is absolutely necessary to work on or near these features, workers should use bonded conductive or insulated platforms or approved insulated footwear to minimize the hazards from step and touch voltages.

7. Application of protective grounds

This section includes the following procedures for placement and removal of protective grounds. Circuits in close proximity to heavily energized circuits (usually 500 kV) may cause the personal protective ground cable to draw an unacceptable arc during application. The test method and procedure outlined in the *Protective Grounding Engineering Guidelines* [11] should be used for these circuits.

7.1 Clearance procedure. Before work begins on a line, circuit, or piece of equipment that is to be electrically isolated and grounded, a clearance must be obtained in accordance with Western's Power System Switching Procedure, Chapter 1 of the *Power System Operations Manual* [10]. The clearance is a documented statement that the line or equipment to be worked on has been disconnected from all power sources and has been electrically isolated (PSSM: de-energized). The circuit may be energized from static or induced sources and will not be considered as dead until it has been grounded.

7.2 Voltage detection methods. After obtaining a clearance, the workman shall verify that the line, circuit, or piece of equipment has been removed from service by testing. Voltage detection is the process of sensing voltage on a line to determine whether or not line voltage is present and is used only for conformation of electrical isolation. The test is not a test for induced voltage. It should be noted that induced voltages may cause the tests to falsely indicate an energized circuit. There are several types of voltage detectors commercially available.

7.2.1 Hotstick method. Buzzing a circuit by using a hotstick is one of the simplest methods for detecting voltage. This process involves touching the metal cap at the end of a hotstick to the normally energized circuit. If the voltage is high enough to produce a buzzing sound, the circuit is considered energized. If the buzz is not heard, the circuit is considered to be electrically isolated (PSSM: de-energized). Noise may prevent a buzz from being heard, in such cases, a worker may need to use another method to determine if the line is energized.

7.2.2 Noisy tester method. The noisy tester operates using the same concept as the hotstick method. A noisy tester is an instrument attached to the end of a liveline tool, which is used to produce a buzzing sound to indicate an energized line. The noisy tester resembles a two pronged metal fork with a ball attached to the end of one prong and a point on the other. By touching the ball to the circuit, the tool produces corona on the pointed end. If corona can be heard, other methods should be used to determine the electrical status of the circuit.

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

Voltage detection is used to provide an indication of voltage levels and to ensure that the line has been electrically isolated (PSSM: de-energized). Voltage detection should be used only as a secondary confirmation of electrical isolation and only after a clearance is in effect.

Each voltage detector has its advantages and disadvantages. The user should choose which detector will be most appropriate for each circumstance.

7.2.3.1 Neon indicator. The neon indicator is attached to the end of a liveline tool and positioned in the electric field produced by the circuit. It will produce a clear visual indication of an energized circuit. Neon indicators should be tested prior to and after each use.

The neon voltage indicator provides a good visual indication; however, the detector is limited in its application(s) and may light up because of induced voltage from a nearby line.

7.2.3.2 Hot horn or noisy tester. The noisy tester voltage detector (NTVD), not to be confused with the noisy tester buzzing device, sounds an alarm to alert personnel that voltage is present. The tester is often used to check areas above or underground, areas around switchgear, substations, and overhead lines. Many NTVDs will give a signal despite the type of voltage on the circuit. Other types of NTVDs are equipped with two pitches to differentiate between circuit and electromagnetically induced voltages. This detector is battery operated, with 4.5 or 9 volts, depending upon the voltage detector, and is attached to the end of a liveline tool. NTVD operation may vary according to the specific manufacturer; however, typically all that is involved is turning on the device and placing the detector in the field of the conductor. Table 2 (from manufacturers data) lists the distances from the circuit that will ensure safe and accurate results.

Distance From Conductor		Kilovolts On Conductor
25 mm	(1 in)	4
102 mm	(4 in)	13
305 mm	(1 ft)	26
457 mm	(1 ft 6 in)	33
0.9 m	(3 ft)	110
1.8 m	(6 ft)	230

Table 2
Operating Characteristics for the
Noisy Test Voltage Detector

Note: The NTVD should not be touched to circuits containing 33 kilovolts or more.

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.

The advantages to using an NTVD are:

a) The user can receive an approximation of the voltage without making contact with the circuit.

b) The NTVD is one of the simplest devices to use.

c) The NTVD is less expensive than the MRVD.

d) The NTVD is lighter than the MRVD.

The disadvantages are that the device is limited to a maximum of about 250 kilovolts and that it does not give any specific indication of estimated voltage.

7.2.3.3 Multiple range voltage detector. The multiple range voltage detector (MRVD) is essentially a multiple range field intensity meter equipped with an internally connected steel contact hook mounted on a liveline tool. To operate the MRVD, a selector switch is activated which enables the user to vary kilovolt ranges. The worker can then use the MRVD to approximate phase-to-phase voltages by hanging the steel contact hook on the circuit. The MRVD uses field intensity to estimate phase-to-phase voltage, whereas the voltmeter uses the actual voltage and difference in potential to determine the voltage reading. Therefore; the MRVD is an inaccurate instrument, and all readings should be regarded as estimates. If the interpretation of the meter reading is questioned, the worker should assume that the line is energized and use other methods to determine the electrical status of the circuit. 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.

There are many advantages to using an MRVD:

a) The MRVD provides a more reliable indication between energized circuits and circuits that have been electrically isolated from all sources of primary system energy than other voltage detectors.

b) The MRVD also provides the user with a specific approximation of the voltage on line.

c) On certain MRVDs, the operating voltages may be as high as 550 kilovolts.

The disadvantages of the MRVD:

a) To operate the MRVD, the MRVD must come in contact with the circuit.

b) The MRVD is heavier and more expensive than other voltage detectors.

c) If the MRVD is close to a ground or to another energized circuit, the reading will register higher than the actual voltage on the measured circuit. The opposite is true if the MRVD is near a circuit operating at the same voltage.

7.3 Cleaning circuit and ground end connections. The surface of the structure ground wire, ground rod, or metal structure member to which the ground end clamp is to be applied is usually corroded, contaminated, or insulated by paint. Aluminum pipe bus or conductor to which the conductor clamp is to be applied will have a high resistance oxide film. These surfaces must either be cleaned by wire brushing before the grounding clamps are installed, or self cleaning clamps must be used to ensure the lowest possible voltage drop at the worksite.

7.3.1 Wire brushing. Unless a self cleaning clamp is used, the clamp jaws shall be wire brushed immediately before attachment, and the conducting surface itself shall be cleaned before the clamp is attached to it. The conductor must be cleaned with a wire brush attached to a hotstick since the conductor is considered energized until it is properly grounded. The cleaning effect of wire brushing is nearly gone within 20 minutes requiring the clamp to be applied immediately after brushing.

7.3.2 Self cleaning clamps. The self-cleaning circuit end clamp is installed lightly on the conductor or bus, rotated a few degrees in each direction to clean the conductor, and then securely tightened. Setscrews on flat faced clamps connected to structure members provide an extra margin of corrosion penetration. After the clamp has been lightly tightened, rotated, and then securely tightened on the structure member, the cup pointed setscrew is tightened with a wrench to ensure penetration of any remaining surface contamination.

7.4 Grounding cable installation. Prior to installation, each grounding cable assembly shall be visually inspected for mechanical damage. Suspect cables shall be destroyed. Grounds should be placed as near the worksite as practical. If installing a grounding cable is impractical or if it would create an unsafe condition, the ground cable should not be installed and the circuit worked as if it were energized at system voltage. Hotsticks shall be used to physically check ground clamps for tightness. When ground resistance is suspect, such as in rocky soil or buried pole-to-pole wood pole structure ground wire ties are deteriorated, the overhead ground wire may be used to provide a better ground than butt wrapped poles, steel structure foundations, or ground rods. Seventy to ninety percent of fault current flows to the overhead ground wire (see *Protective Grounding Engineering Guidelines* [11]), which makes the overhead ground wire a good choice (it also eliminates the need for cluster bars). Buried wood structure pole-to-pole ground wire ties shall not be relied upon for maintenance grounding activities.

7.4.1 Ground end clamps. The ground end clamp of each grounding cable shall always be the first connection made and the last to be removed. Ground end clamps shall be attached by hotstick if the grounded system and the worker are at different potentials. Most Western line and substation personnel use circuit end clamps with eye screws for installation by means of “grip all” or “shotgun” hotsticks. Hotsticks used for grounding should be given the same care, inspection, and testing as those used for live work.

7.4.2 Circuit end clamps. The circuit end clamps of grounding cables shall always be connected and disconnected by using hotsticks of a length and rating for the system voltage of the circuit or equipment. Workers must stay clear of the grounding cable while applying the grounding cable to the circuit or equipment. The practice of holding the cable near the base of the hotstick to lighten the load on the head of the stick is strictly prohibited. A coworker should assist in applying heavy grounds by holding the ground cable with another hotstick, or by using a "shepherd hook" with a pulley and nonconductive rope to hoist the grounding cable into position. After the ground end connection has been secured, the circuit end clamp should be connected in turn to the nearest circuit and proceeding outward and upward until all necessary phases have been grounded.

7.4.3 Three phase grounding. Protective grounding cables shall be installed so that all phases of lines, buses, equipment, and apparatus are visibly and effectively bonded together in a multi phase "short" and connected to ground at the worksite. Conductive objects within reach of any worker should be bonded to this grounding system. Equipment may be temporarily unbonded from the system to perform necessary maintenance functions such as power factor tests. Care must be taken on double circuit structures to ensure that live work procedures and approach distances are enforced for the energized circuit.

7.4.4 Single phase grounding. Single phase grounding is not allowed in substations. Single phase grounding or two phase grounding is normally used only in adverse weather conditions or in instances where three phase grounding creates a greater hazard (such as climbing a double circuit structure to ground the upper phases when only the lower phase is to be worked). The ungrounded phase(s) shall be treated as if energized at system voltage and the appropriate live work minimum approach distances shall apply. **NOTE:** Ungrounded phases exposed to induced currents will be at less than system operating voltage; however, using a lower minimum approach distance than required by system operating voltage is prohibited.

The probability of a fault occurring during the work process is small compared to unavoidable physical and weather hazards; however, workers must be aware that combining grounded and live work procedures requires additional awareness. If a supervisor determines that single phase grounding is the safest for all concerned, he should discuss the procedure with his crew and the entire crew should be in agreement with the work procedure.

7.4.5 Multiple crews working the same circuit. Multiple crews may work on radial lines provided that each crew uses its own worksite grounding and its own clearance. Each crew shall be responsible for clearance and grounding work procedure.

Multiple crews should not work on a line paralleling energized line(s) unless it has been determined that the magnitude of the circulating ground currents is at an acceptable level. Calculation of circulating ground currents shall be in accordance with the *Protective Grounding Engineering Guidelines* [11].

7.4.6 Parallel grounds. When the fault current capability at a specific location exceeds the capacity of the standard grounding set, a larger ground cable or two or more sets of grounds of the same size and approximate length shall be used. The cables shall be placed as close together as possible to minimize coupling. The division of current between parallel grounds depends upon the total resistance of each grounding cable, including the connection resistance. If the fault current to be carried by the cables would be near their combined capacity, it would be possible for the cable with the lower resistance to be overloaded. This could cause it to fail, which would allow the total fault current to appear on the other cable, causing it to fail also. Since it is not normally practical to ensure that parallel cables are identical, a derating multiplier of 0.9 shall be used for each cable. For example, two 2/0 copper cables in parallel can carry 2 x (20,000 x 0.9) = 36,000 amperes for 30 cycles (500 milliseconds). Multiple cables should be bound or twisted together. The cables shall be tied or twisted together to maximize the current carrying capacity of the cable set or the reduction factor shall be 0.8 to compensate for the mechanical and induced forces on unbound or non-twisted cables [4].

7.4.7 Bundled phase conductor. When subconductor hardware is separated or when subconductor bonding is suspect, the subconductors (on the phase being worked) shall be bonded by a cable of the same size as the protective grounds in use. Insulated phase spacers could cause the worker to experience unbalanced subconductor currents; therefore, the subconductors should be bonded during insulated spacer work.

7.4.8 Insulated overhead ground wires. When work is performed in the vicinity of insulated overhead ground wires, the specified working clearance for a 15-kilovolt circuit 0.66 m (2 ft 2 in) must be maintained, or protective grounds shall be applied. A typical insulated overhead ground wire connection is shown in figure 8.

	Distance to Worker			
Voltage in Kilovolts	Phase-to-Ground		Phase-to-Phase	
Phase-to-Phase	(m)	(ft-in)	(m)	(ft-in)
0 to 0.050	Not Specified Avoid Contact		Not Specified Avoid Contact	
0.051 to 0.300				
0.301 to 0.750	0.31	1-0	0.31	1-0
0.751 to 15.0	0.65	2-2	0.67	2-3
15.1 to 36.0	0.77	2-7	0.86	2-10
36.1 to 46.0	0.84	2-9	0.96	3-2
46.1 to72.5	1.00	3-3	1.20	3-11
72.6 to 121	0.95	3-2	1.29	4-3
138 to 145	1.09	3-7	1.50	4-11
161 to 169	1.22	4-0	1.71	5-8
230 to 242	1.59	5-3	2.27	7-6
345 to 362	2.59	8-6	3.80	12-6
500 to 550	3.42	11-3	5.50	18-1
765 to 800	4.53	14-11	7.91	26-0

Table 3
Minimum Approach Distances
for Electrical Workers (1)

The altitude correction factors of table 4 shall be applied to these distances in accordance with the 1997 Edition of the *National Electrical Safety Code* (1).

7.4.9 Removal of protective grounds. Protective grounding cables shall be removed in reverse order from installation, with the conductor or equipment end removed by hotstick first and the grounded end last.

8. Approach distance to energized circuits

Electrical workers may approach energized circuits up to the minimum approach distances of table 3 and table 4. Non-electrical workers shall comply with the minimum approach distances specified by table 5. Workers, before coming within the minimum approach distance of circuits or equipment to be grounded, shall obtain a clearance, electrically isolate the circuit or equipment, remove all power sources from the circuit or equipment, and test for voltage. Protective ground cables may then be applied while maintaining the minimum approach distance from adjacent energized circuits. Acceptable methods for installing protective ground cables while maintaining the minimum approach distances are shown in figure 6. All circuits and equipment shall be treated as energized until tested and properly grounded.

Altitude Correction Factor		
Altitude		Correction Factor
(m)	(ft)	
900	3,000	1.00
1,200	4,000	1.02
1,500	5,000	1.05
1,800	6,000	1.08
2,100	7,000	1.11
2,400	8,000	1.14
2,700	9,000	1.17
3,000	10,000	1.20
3,600	12,000	1.25
4,200	14,000	1.30
4,800	16,000	1.35
5,400	18,000	1.39
6,000	20,000	1.44

Table 4
Altitude Correction Factors (1)

Voltage in Kilovolts Phase-to-Phase	Electrical Distance Phase-to-Ground (m)	(ft-in)
0.751 to 90.0	3.05	10-0
91 to 121	3.26	10-8
138 to 145	3.46	11-4
161 to 169	3.56	11-8
230 to 242	3.97	13-0
345 to 362	4.68	15-4
500 to 550	5.80	19-0
765 to 800	7.32	24-0

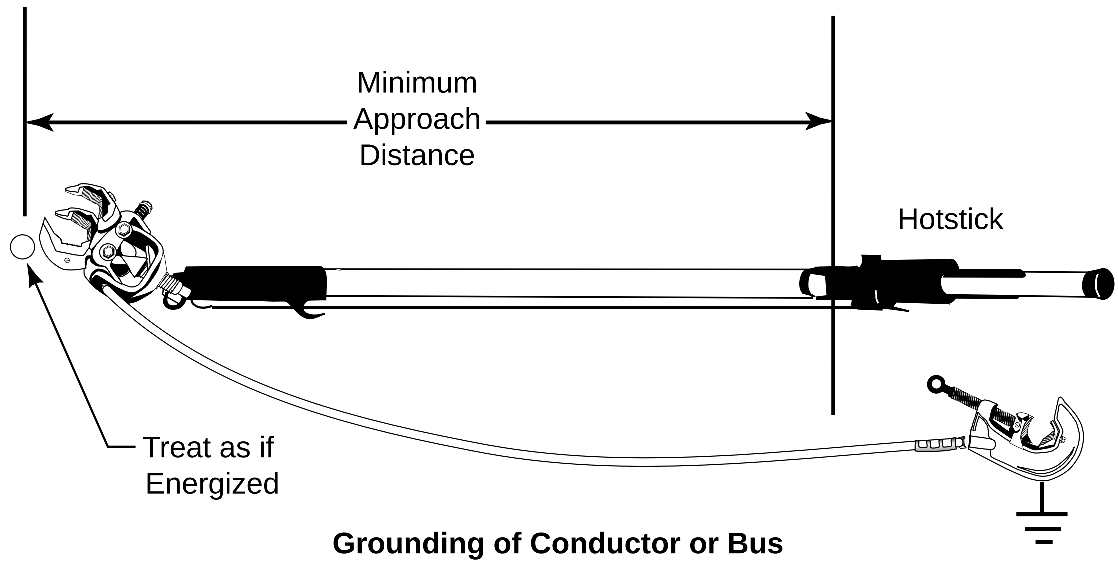
Table 5
Minimum Approach Distances
for Non Electrical Workers

9. Equipment and vehicle grounding

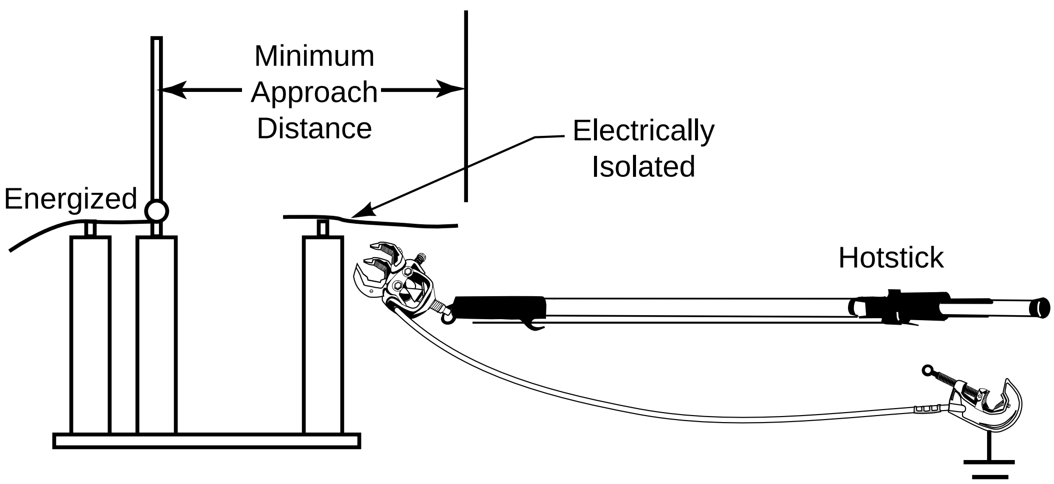
Vehicles involved in maintenance activities shall be grounded as the first step in establishing a grounding system. Ground cables on reels or looped on the vehicle shall be completely unwound to eliminate destructive forces resulting from induction. A hotstick shall be used to install and remove vehicle grounds on a grounded system bonded to a conductor, bus or piece of equipment. Whenever possible, vehicles should be grounded to a structure or piece of equipment rather than to a ground rod. See *Protective Grounding Engineering Guidelines* [11] for system grounding analysis. Vehicles situated such that a worker can contact them simultaneously shall be bonded to a common ground. Metal liners in buckets should be removed or bonded to the grounded system. Noninsulated aerial devices should be bonded to the conductor to eliminate multiple current paths and potential differences during fault conditions. Vehicles with conductive winch lines in contact with a grounding system should be equipped with an insulated platform or conductive mat for the winch operator to stand on. No one shall approach to within 3 m (10 ft) of a grounded vehicle while it is in contact with a conductor, bus, or other grounded equipment.

9.1 Vehicle grounding on transmission lines. Aerial devices, whether with an insulated or uninsulated boom, and other maintenance vehicles that may contact a grounded system shall be grounded to that grounding system. When grounding to the structure is not practical, such as during in-span work, the vehicle shall be grounded to a ground rod installed near the midpoint and as close to the vehicle as practical. If grounding of the vehicle(s) is not possible, the operator shall remain on the vehicle, on an insulated platform, or on a conductive mat that is bonded to the vehicle.

When grounding vehicles with permanently mounted reel-type grounding cables, it is permissible to bond the ground cable to the structure ground or to a ground rod. If there is a potential for hazardous induced voltages to be present on the vehicle, a hotstick should be used to attach the grounding cable.



Grounding of Conductor or Bus



Grounding of Switches

Figure 6
Application of Grounding Cables

9.2 Stringing and splicing equipment grounding. Vehicles and equipment used in stringing and splicing operations shall be grounded in accordance with the appropriate subparagraphs of paragraph 13.

9.3 Equipment and vehicle grounding in substations.

9.3.1 Non-oil handling vehicle grounding. Workers shall ground parked vehicles that are involved in substation maintenance activities to the station ground mat, using a grounding cable(s) of adequate size, if the vehicle is subject to coming within the minimum approach distances specified in table 3 for electrical workers and tables 5 and 6 for nonelectrical workers.

9.3.2 Equipment grounding during oil handling. During oil handling operations on oil filled equipment (e.g., transformers, regulators, and circuit breakers), the following precautions should be observed:

a) Apparatus tanks, shielded hoses, pumping or filtering equipment, drums, tank cars, trucks, and portable storage tanks shall be solidly bonded to the substation ground mat. Workers shall connect the vehicle ground end first and disconnect it last to prevent possible arcs near the vehicle.

b) Exposed conductors (e.g., transformer or circuit breaker bushings, or coil ends of a transformer with the bushing physically removed) shall be connected to the same grounding system.

Note: When returning to work on a partially completed oil filtering job after shutdown for any reason, all switching, bonding, and grounding should be checked before resuming the operation.

10. Protective grounding on overhead ground wires

10.1 General. Figure 7 illustrates typical mechanical hardware to structure connections. Average level span weights shown in the figure do not allow for a good electrical connection. Fault currents through this hardware can be very hazardous; therefore, the connection should be bonded to prevent injury during fault conditions.

10.2 Non insulated overhead ground wires. Noninsulated overhead ground wires shall be electrically bonded to the structure grounding system prior to making contact with the overhead ground wire with the following exceptions:

a) When momentary contact is made (i.e., hanging hand lines).

b) When personal protective grounds are not in place (i.e., climbing inspections).

The overhead ground wire shall always be bonded to the structure ground by a personal protective ground cable when any part of the overhead ground wire connecting hardware is to be disconnected.

10.3 Insulated overhead ground wires. Insulated overhead ground wires shall be treated in accordance with paragraph 7.4.9.

11. Protective grounding on transmission line structures

11.1 Capacitors and reactors. Heavily loaded parallel circuits will transfer induced current onto the line being worked. Depending on magnitude of induced current and the work location on the line, the induced charge on capacitors and reactors may create situations where it is difficult or impossible to install protective grounds. In these situations, capacitors and reactors, on the transmission line being worked, should be removed from the circuit prior to installing the grounding cables.

11.2 Grounding on metal transmission structures.

11.2.1 Lattice steel structures. The preferred method for installing grounds on higher voltage single circuit lattice steel transmission line structures, where the conductors are a greater distance from the structure than those on lower voltage structures, is to install them from the bridge above the conductors (see in figure 8).

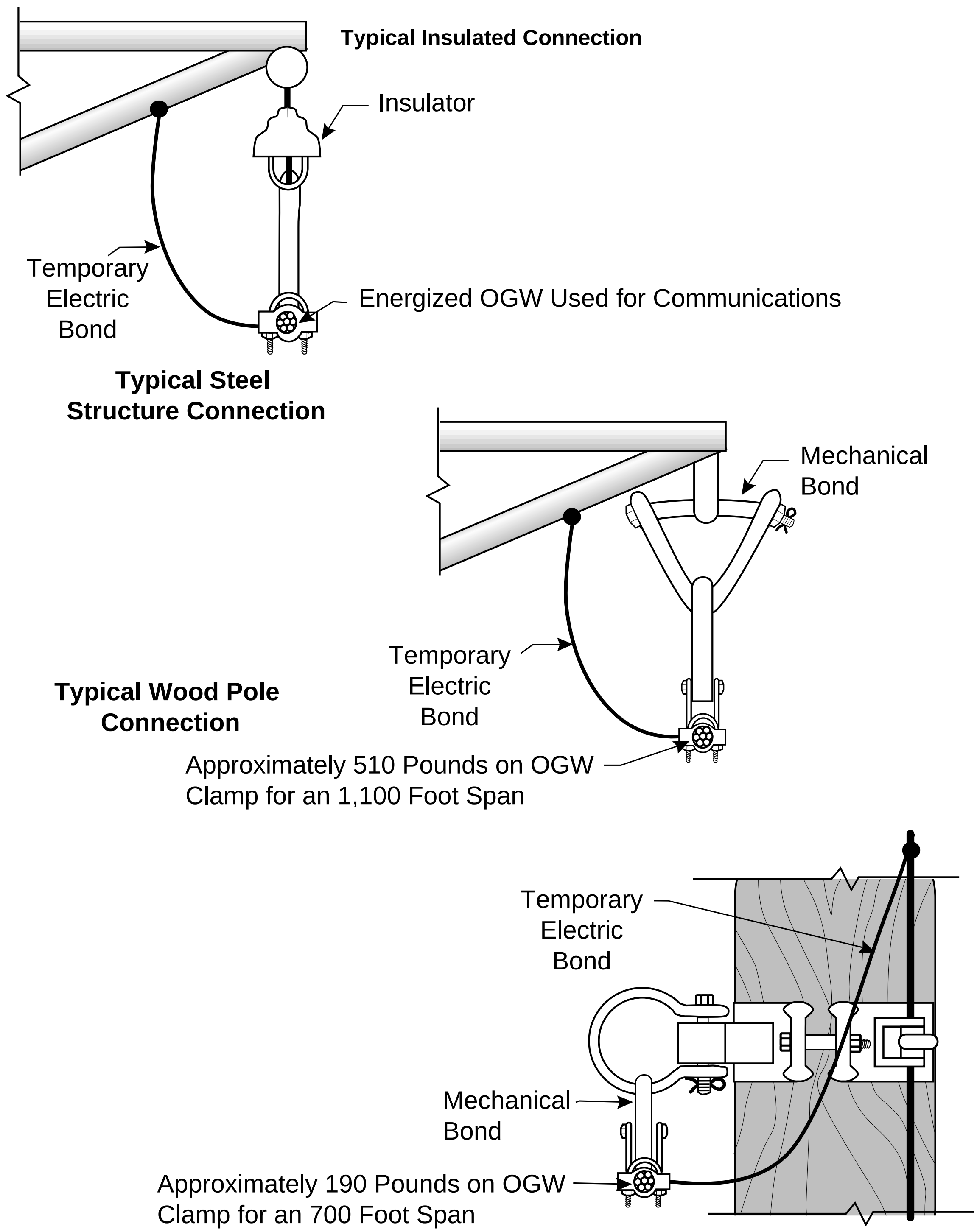


Figure 7
Overhead Ground Wire Attachments

On lower voltage lattice steel transmission lines, grounding the phases from positions on the structure near the level of the conductors (see figure 9) may be more practical and easier. However, this is not the preferred method. The inductive loop formed by the grounding cable and the structure should be kept to a minimum.

On 230 kilovolt and 345 kilovolt double circuit lattice steel transmission structures, workers should ground the phase conductors to the structure arms (see figure 10). Personal protective grounds should be attached from the bottom phase up and removed from the top phase down.

Grounding on deadend or angle lattice steel structures is normally installed on the conductor (see figure 11). Protective grounds installed by an aerial device may be easier to attach to the structure at conductor level in each case. If the jumper is to be removed or disconnected on either end, the conductor (or conductor and jumper) on both sides of the tension insulator strings shall be grounded.

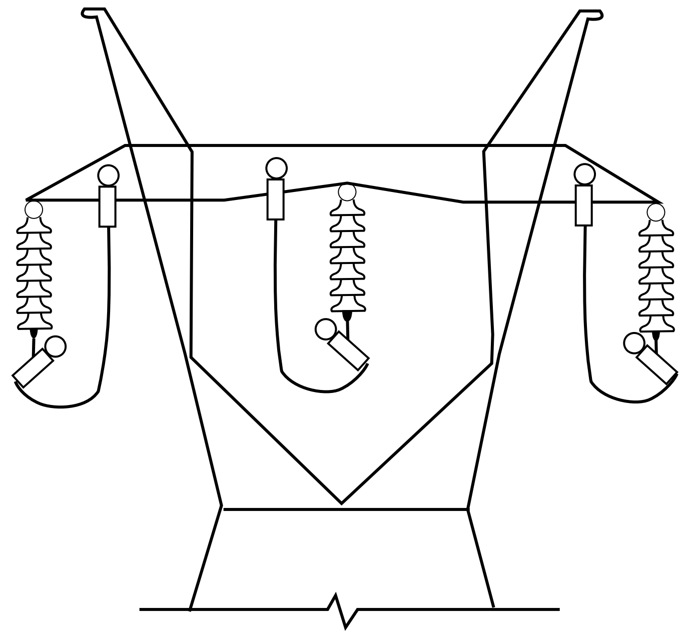


Figure 8
Grounding on Single Circuit

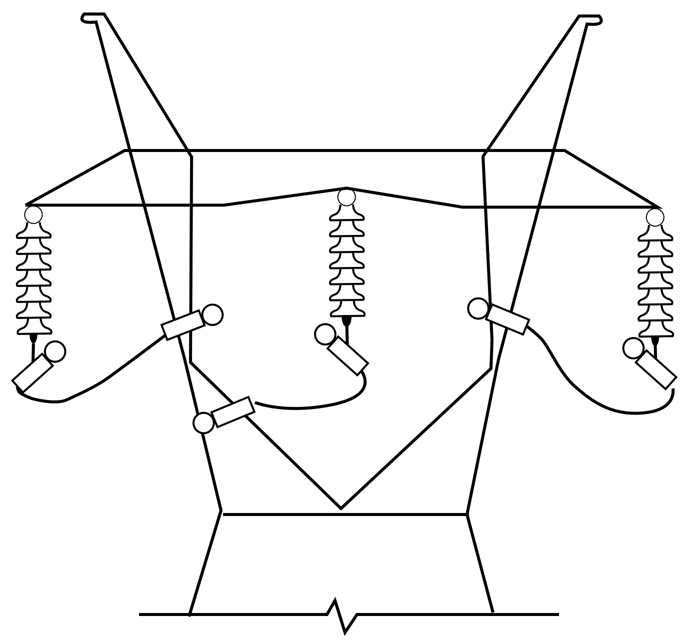


Figure 9
Grounding on Single Circuit
Steel Structures (alternate)

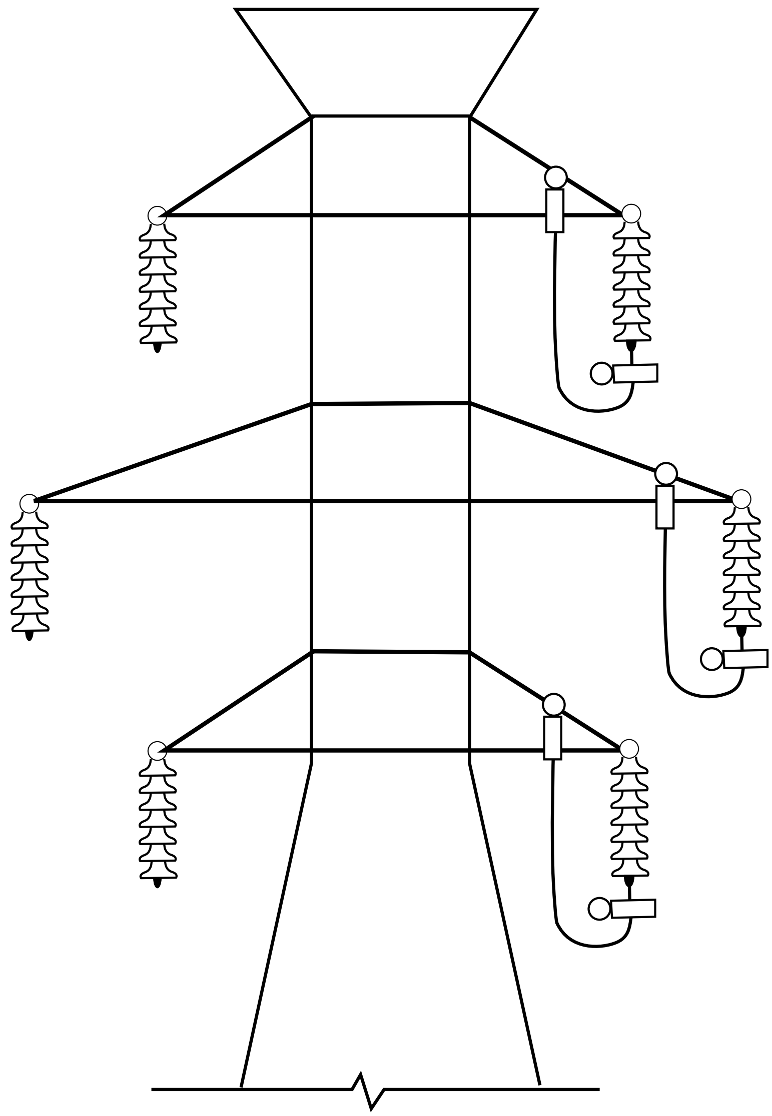
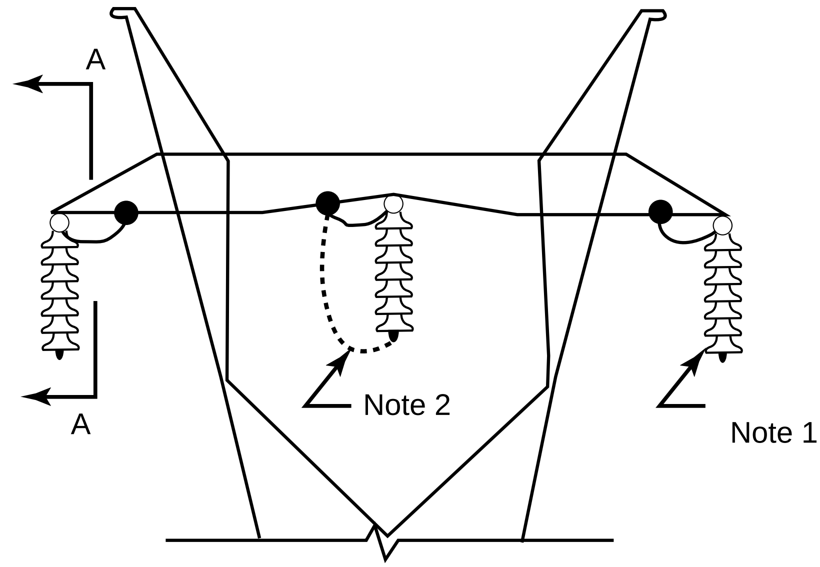


Figure 10
Grounding on Double Circuit
Steel Structures

11.2.2 Grounding on slip joint steel pole structures. Slip joint structure should either have bonding cables permanently attached to each slip joint or joint resistance should be measured on selected structures after installation and periodically as maintenance personnel deem necessary. Surfaces where protective grounds are to be attached shall be cleaned prior to cable attachment to ensure a proper electrical contact.

11.2.3 Grounding on weathering steel pole structures. The highly resistive protective oxide on weathered steel should not be removed. Grounding is best accomplished by welding a copper bar, steel bar, or a stainless steel nut to which a threaded copper stud can be inserted at each grounding location. Weathering steel poles should be constructed with bonds between crossarms and poles and between slip joints to ensure electrical continuity. If bonding straps are not part of the structure, ground cables must be extended to a ground rod or to the overhead ground wire.



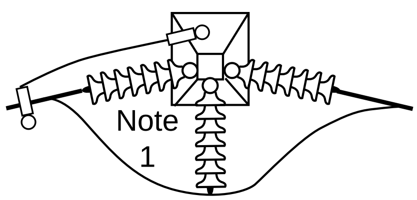


Figure 11a
Deadend Insulator Assembly Grounding

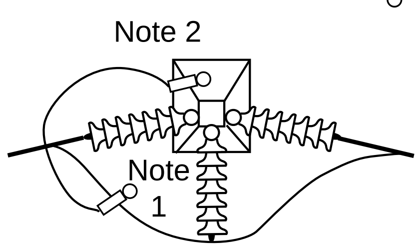


Figure 11b
Deadend Insulator Assembly Grounding

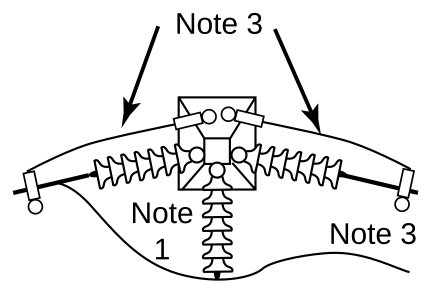


Figure 11c
Deadend Insulator Assembly Grounding with Jumper Disconnected

NOTES:

1: The jumpers may be supported by insulator strings.

2: This ground cable location is acceptable depending on the work being done.

3: If the jumper will be disconnected, the conductors (or conductor and jumper) on both sides of the deadends must be grounded.

Figure 11
Grounding on Steel Deadend Tangent and Angle Structures

11.2.4 Grounding on painted steel. Grounding is best accomplished by welding a copper bar, steel bar, or a stainless steel nut to which a threaded copper stud can be inserted at each grounding location. Grounds may be extended to a ground rod or to the overhead ground wire. Scraping the paint and refinishing will seldom provide an adequate electrical connection.

11.2.5 Grounding on light duty steel poles. Light duty poles are slip joint galvanized construction. These poles have a nonconductive wrap in the corrosion active zone which extends approximately 0.61 m (2 ft) above ground to 0.61 m (2 ft) below ground. Vehicles and equipment shall be grounded to the grounding lug which is provided above the protective wrap.

11.3 Grounding on wood pole structures. Western's staged fault tests indicate that there is no significant difference between three phase and single phase fault current distribution at the worksite on steel structures; however, the staged fault tests do indicate that there can be a significant fault current distribution difference on multiple pole wood structures. Eighty to ninety percent of a fault current exits the worksite through the overhead ground wires (where they exist). Although fault current is evenly distributed between each of the overhead ground wires on steel structures, the fault current distribution on

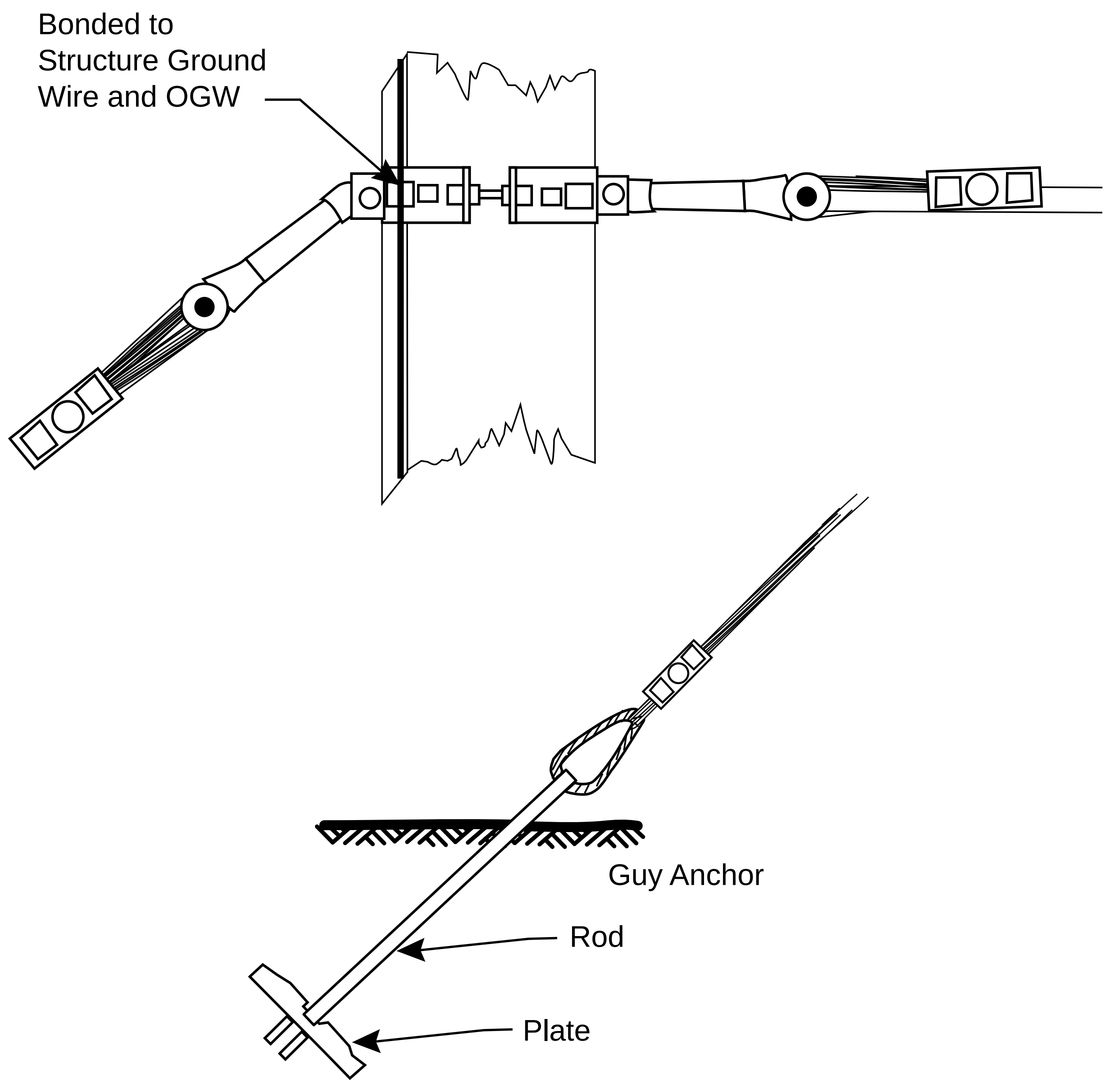


Figure 12
Woodpole Hardware Grounding Connections

wood structures is dependent on the electrical potential difference between the poles. Deterioration of butt wrap, under ground pole-to-pole ties, structure ground wires, and structure ground wire to hardware connections require that each structure be treated uniquely for the work practice being employed. Fault current distribution on wood pole structures is discussed in the Protective Grounding Engineering Guidelines [11].

11.3.1 Structure ground wires and hardware connections. Structure ground wire to hardware connections and hardware to overhead ground wire and guy wires are bolted connections that are not necessarily good electrical connections. Overhead ground wire connections should be inspected during the installation of grounding cables to ensure adequate worker protection (see figure 12). Guy wires may be used for personal protective ground wire attachment provided that the guy wire is tight, does not utilize isolating insulators, and/or are not connected by unbonded through bolts.

11.3.2 Installation of cluster bars. Cluster bars should be mounted below the worker's feet and as near to conductor level as possible. Cluster bars shall be bonded to the pole ground wire at the mounting location and may be connected to the overhead ground wires or to a temporary ground rod(s). Structure pole ground wires used in the grounding system shall be inspected before attaching the cluster bar ground lead to determine that these wires have not been deteriorated, cut, damaged, or removed. Personal protective grounding cables shall be connected between the grounding cluster bars and the phase conductors to provide a solid ground. Structures without pole ground wires or those whose structure ground wires are damaged, or their condition is questionable, shall have the grounding cluster bars connected to temporary ground rods.

The center phase conductor shall be connected to the grounding system of each pole as shown in figures 13 through 17. Under ground pole-to-pole ties shall not be relied upon for completion of the grounding system.

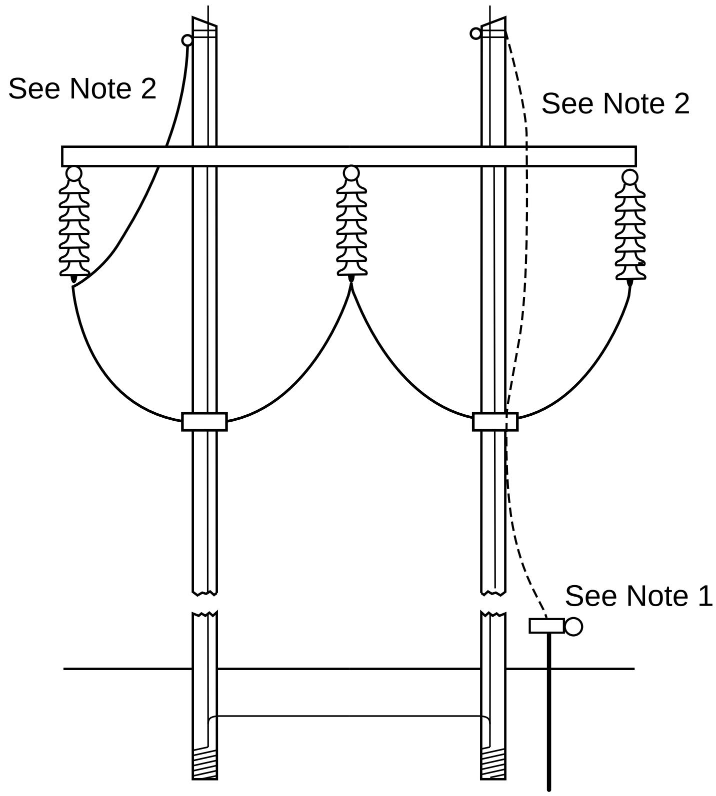
Cluster bars are not required on both poles in situations such as pole change out. The pole grounds must be bonded at the base by a protective ground to keep each pole at the same potential until the pole being removed is completely isolated from the rest of the structure. The ground may then be removed with a hotstick. Protective grounds on the new pole shall be installed in reverse order.

11.3.3 Approved wood pole structure personal protective grounding practices.

11.3.3.1 Three phase grounding. Preferred three phase grounding applications on wood pole structures are shown in figures 13 through 17.

11.3.3.2 Single phase grounding. Western's fault tests on wood H-frames with a deteriorated pole-to-pole tie indicate that the touch voltage, near the grounded pole, increases by approximately 50 percent with single phase grounding. For this reason, single phase grounding on wood H-frames should only be used when three phase grounding is not practical and should only be allowed if the two pole grounds are bonded together with a grounding cable as shown in figure 18.

11.4 Grounding on concrete and composite structures. Concrete and composite structures usually have a structure ground wire attached to the surface much the same as wood poles. Metal crossarms should be bonded to the structure ground wire during installation. If a structure ground wire is not available, ground cables must be extended to a ground rod or to the overhead ground wire.

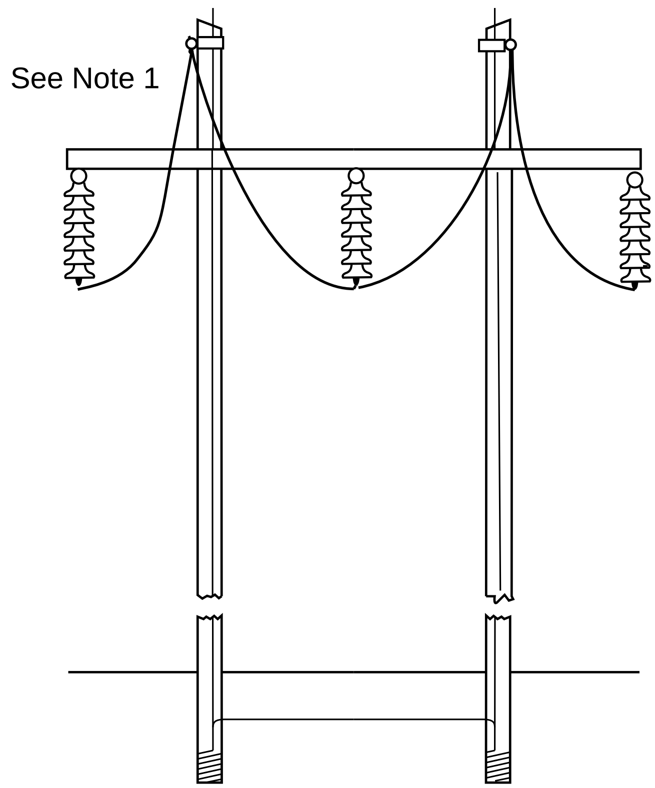


NOTES:

1: Workers should add a ground rod and cable to an ungrounded structure or to structure grounds that are suspect. The ground rod cable shall be attacted to the cluster bar first with subsequent cables continuing from the cluster bar.

2: Personal ground cables connected to overhead ground wires may be attached either to the cluster bar or to a grounded phase conductor. In either of these cases, the structure ground is connected to the cluster bar, and a solid electrical bond exists between the overhead ground wire and the rest of the system.

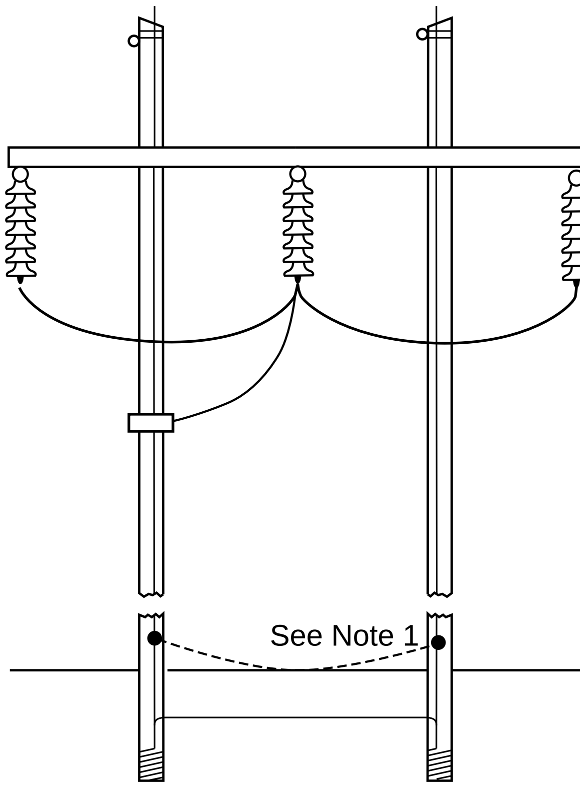
Figure 13
Grounding With Double Cluster Bars and Overhead Ground Wires



NOTE:

1: When hardware is to be disconnected or removed, a ground cable must be placed between the overhead ground wire and the structure ground to maintain grounding system continuity.

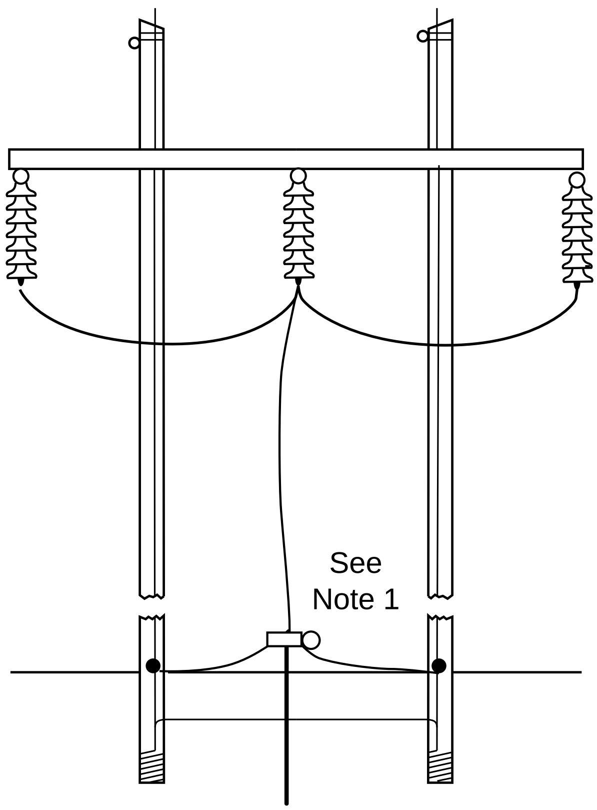
Figure 14
Grounding to the Overhead Ground Wires



NOTE:

1: If a single cluster bar is to be used, workers should stay 10 feet away from the ungrounded pole unless the poles are bonded together. When a pole is being replaced, the tie may be removed once the pole-ground has been electrically isolated from the grounding system.

Figure 15
Grounding With a Single Cluster Bar
(pole removal)



NOTE:

1. A temporary ground rod may be used in lieu of cluster bars PROVIDED that the pole grounds are attached to the ground rod prior to attaching to the conductors.

Figure 16
Grounding With a Temporary Ground Rod

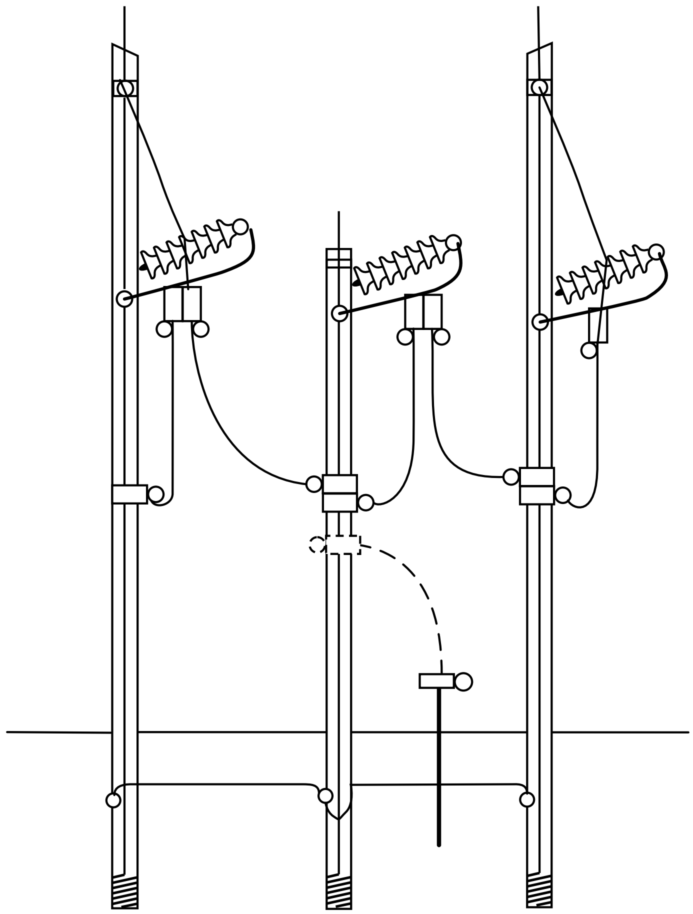
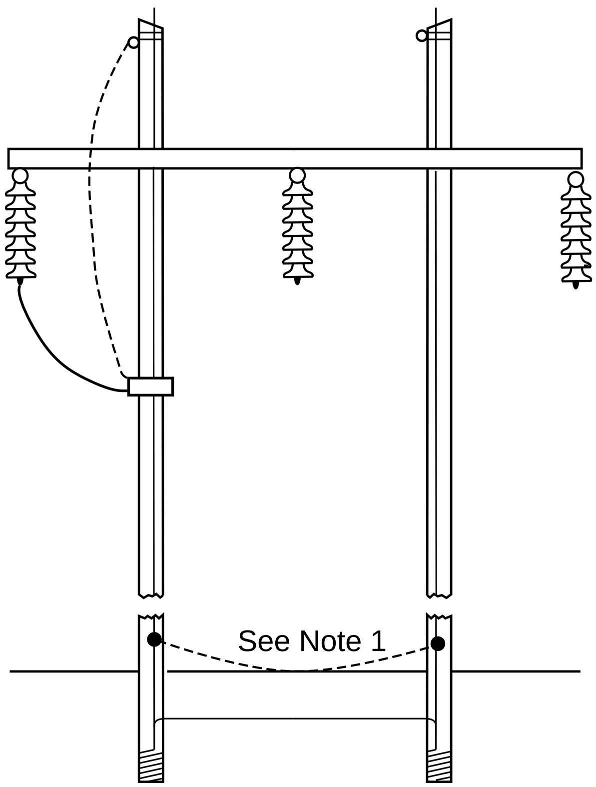


Figure 17
Grounding on Three Pole Structure



NOTE:

1. The underground pole-to-pole tie shall be considered to be non-existent. The structure ground wires on both poles shall be bonded together to ensure distribution of fault current to both overhead ground wires

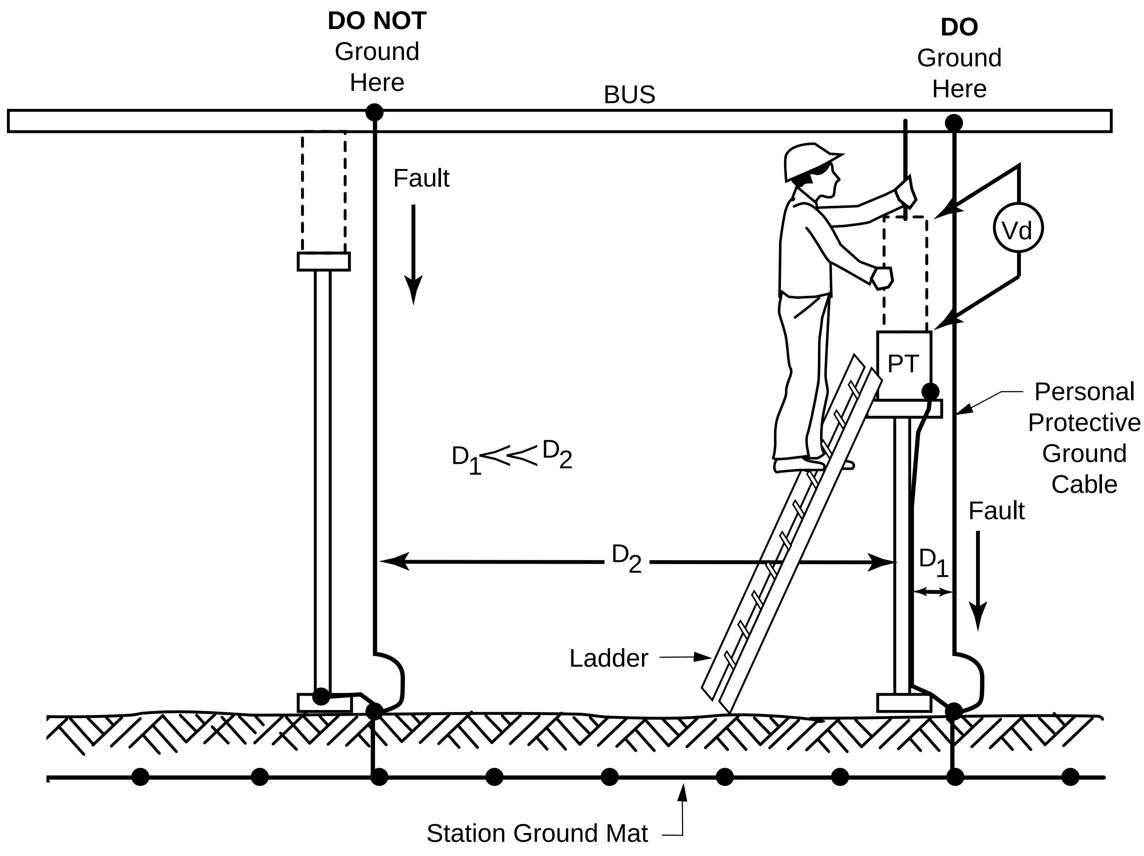
Figure 18
Single Phase Grounding on Wood Pole Structures

12. Protective grounding in substations and switchyards

12.1 Placement of protective grounds. Work on electrically isolated substation equipment and circuits should be performed with protective ground cables placed at the worksite as shown in figure 19. The grounding cables should be visible from the worksite. An analysis of Western's staged fault tests in substations is given in the *Protective Grounding Engineering Guidelines* [11].

12.2 Application of protective grounds

12.2.1 Permanent equipment grounding. On all electrical apparatus, the noncurrent carrying parts (such as transformer cases, circuit breaker tanks, oil storage tanks, rails, piping, screens, metal fences, switch platforms, and guards) shall be permanently grounded by a copper conductor to the station ground mat. These grounds shall be physically inspected periodically (i.e., during substation inspections) to ensure a good electrical and mechanical bond and shall not be removed while the equipment is in service. Equipment requiring multiple grounds shall have each ground visually inspected.



NOTE:

Distance D_1 should be kept as small as reasonable.

Figure 19
Substation Grounding

12.2.2 Power circuit breaker and transformer grounding. Personal protective grounds shall be in place on power circuit breakers and power transformers while workers are inside the equipment tanks or on top of equipment, and within the minimum approach distance (refer to table 3) of electrically isolated current carrying components, such as conductors and bushing terminals. Workers should bond grounding cables to a structure member or to common copper equipment or structure ground lead which, in turn, is bonded to the station ground mat, and then to each bushing lead of the respective equipment. Personal protective grounds shall be in place on instrument transformers, coupling capacitors, surge arresters, and similar station equipment while workers are within the minimum approach distance of the electrically isolated current carrying components. Protective grounds should be in place on transformers and oil circuit breakers before the oil is drained from the tanks or the tanks are opened. Bushing leads may be disconnected from bushing terminals as necessary to permit equipment testing (power factor test or oscillographic contact tests) that require the equipment terminals to be ungrounded, the bushing leads may be temporarily ungrounded (using a hotstick) to permit these tests. The ground shall be reestablished as soon as the test is completed. Work grounding instructions for the test equipment shall be in accordance with the manufacturer's recommendations.

12.2.3 Disconnect switch and bus grounding. Work on high voltage disconnect switches and bus conductors should be performed with protective grounding cables installed at the worksite (see figure 19). The grounding cables should be visible from the worksite. No switch shall be used to maintain continuity between the protective grounds and the worksite.

12.2.4 High voltage cable grounding. Work on high voltage cables shall be done with protective grounds installed on the potheads at each end of the cable. If the cable to be opened lies in a network of cables, or if there is any doubt as to whether or not the cable is electrically isolated (PSSM: de-energized), the cable shall be spiked (using an approved tool) prior to opening the cable. When a cable is to be opened or spliced, grounds shall be installed at the worksite if such grounding is feasible. Such grounds should remain in place until the conductor is joined, after which the grounds may be removed for taping or reinsulating the splice.

12.2.5 Grounding transformer and phase reactor personal protective grounds. Grounding transformers shall not be worked on unless electrically isolated and properly grounded. Phase reactors shall be electrically isolated from all energized sources and grounded.

12.2.6 Capacitor Bank Grounding. After fully charged capacitor banks (series and shunt) have been electrically isolated (PSSM: de-energized), wait at least 5 minutes to permit the capacitors to drain through the internal discharge resistor. Close the capacitor bank grounding switch, if available, and apply protective grounds. An additional 5 minutes shall be allowed after the ground switch is closed before issuing the clearance that permits protective grounds to be installed. Short the individual capacitors to be contacted from terminal-to-terminal and from terminal-to-case by approved means. If possible, allow several hours after a capacitor failure before shunting, grounding, and handling bulged units, to allow cooling and relieving of internal pressure. Capacitor banks shall remain electrically isolated for at least 5 minutes before being re-energized. The time required for these maneuvers shall be explicitly expressed in switching orders involving capacitor banks [9].

13. Grounding for nonroutine transmission line maintenance

13.1 General. The requirements of this paragraph shall apply to grounding of conductors, subconductors, conductive pulling lines, and overhead ground wires. Requirements not related to protective grounding must be adhered to (i.e., barriers, barricading, and crossing guard structures).

13.2 Grounding for splicing and installation of deadend terminations.

NOTE: Splicing requirements in this section shall also pertain to terminating deadends.

13.2.1 Overhead ground wires with fiber optic communications. If fiber optic leads must be spliced, workers must obtain proper instructions and special tools prior to beginning the work. Splicing instructions should be obtained from the fiber optics manufacturer.

13.2.2 Splicing at ground level. Prior to opening or splicing an electrically isolated conductor or overhead ground wire, three phase grounding shall be established at one of the structures from which it is to be worked, detached, or lowered. A single phase ground shall be established, for each conductor or overhead ground wire being spliced, at the other structure from which it is to be worked, detached, or lowered (see figures 20 and 21). Continuous grounding must be in place while lowering, splicing, and reinstalling the conductor or overhead ground wire.

A ground shall be located at each side and within 3 m (10 ft) of working areas where conductors, subconductors, or overhead ground wire are being spliced. The two ends to be spliced or repaired shall have a jumper or a section of conductor installed across the damaged or severed section (using a hotstick) to maintain continuity prior to cutting a damaged section or connecting a severed section (see figures 20 and 21). Splicing shall be carried out on either an insulated platform (figure 20) or on a conductive metallic grounding mat (figure 21).

13.2.2.1 Insulating platforms. When a splice is accomplished on the insulated platform, the press and worker's feet shall not extend over the platform or come in contact with the earth or grounded object.

13.2.2.2 Conductive mats. When a conductive mat is used, it is recommended that the mat be roped off and an insulated walkway provided for access to the mat. The conductor or overhead ground wire must be bonded to the mat grounding rod (each end may be bonded to the

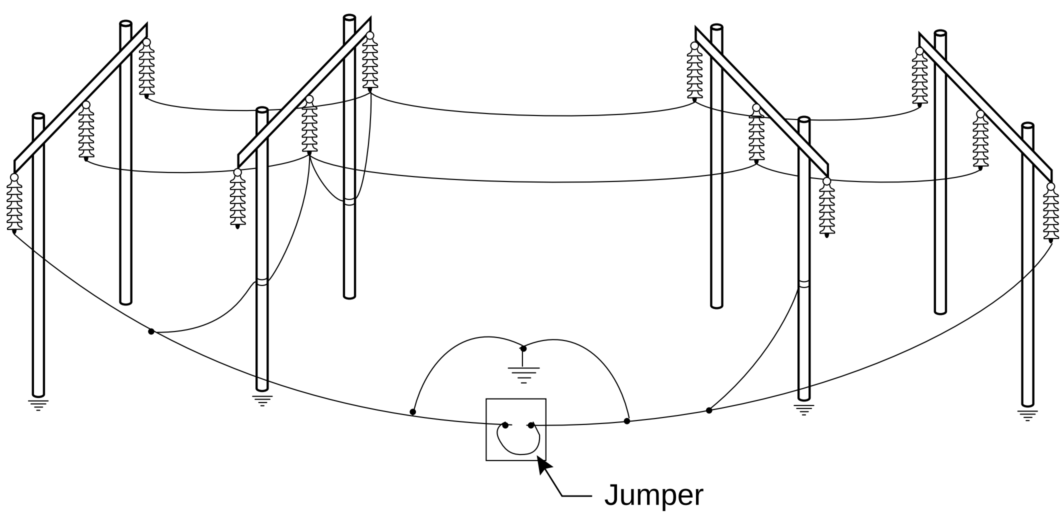


Figure 20
Splicing from an Insulated Platform

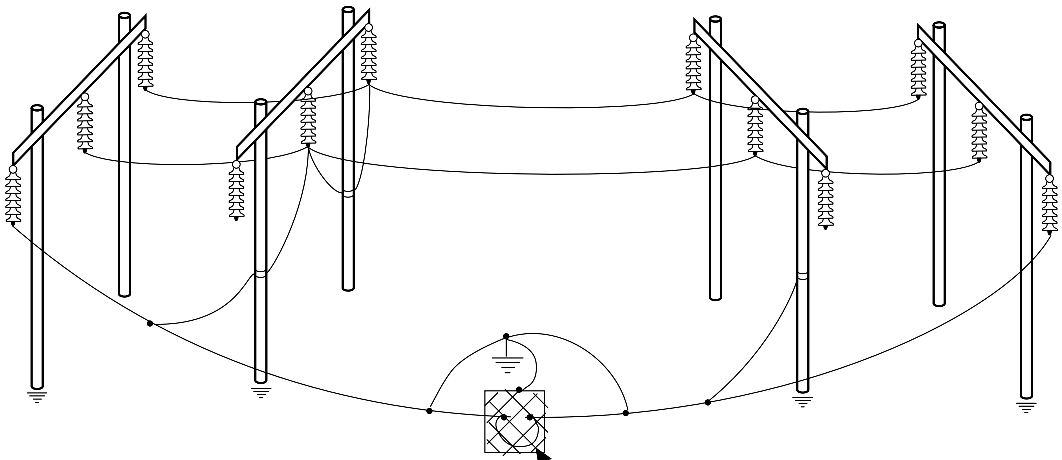


Figure 21
Splicing from a Conductive Mat

mat ground rod as shown in figure 21) using a hotstick. If a vehicle is involved in the splicing operation, it must be grounded and a ground cable from the common ground to the conductor or overhead ground wire must be installed with a hotstick. If the splice is to be completed from a vehicle, the vehicle and conductor or overhead ground wire shall be grounded as stated above and the workmen shall remain on the vehicle or stand on an insulated platform or metal conductive mat.

13.2.3 Splicing from aerial lift equipment. Prior to opening or splicing an electrically isolated conductor or overhead ground wire, three phase grounding shall be established at the worksite or at the structure nearest to the repair section. If the conductor or overhead ground wire is severed, a single phase ground shall be established at the opposite structure on the circuit to be repaired. Workers should install a jumper cable or a section of conductor (using a hotstick) to maintain the continuity of the conductor or overhead ground wire while accomplishing the splicing operation. The grounds shall be left in place until the splice is completed.

13.3 Reuniting severed conductors or overhead ground wires. In some situations, a cable cannot be used to jumper between the severed ends of a conductor or overhead ground wire (see figure 22). The protective three phase grounds on the adjacent structures on each side of the separation are adequate for protection from induced currents. To obtain protection from fault currents, insulated platforms should be used at the sock and pulley attachments and an insulated platform or conductive mat should be used by the winch operator at the winching vehicle. The ground man pulling the winch line should use an insulating rope or hotstick to avoid contact with the grounded system. An alternate approach is for the workman to stand on an insulated platform or wear insulated footwear and/or insulated gloves and to reduce contact time with the grounded system to a minimum.

13.4 Installing and removing conductors and overhead ground wires. The requirements of this paragraph shall apply to removing as well as installing conductors, subconductors, and overhead ground wires. When performing work from the structures, clipping crews and all others working on conductors, subconductors, and overhead ground wires shall be protected by individual grounds installed on the phase being worked. If, during the stringing operation, it is necessary to return to a structure to complete structure or hardware installation, all conductors, subconductors, and overhead ground wire

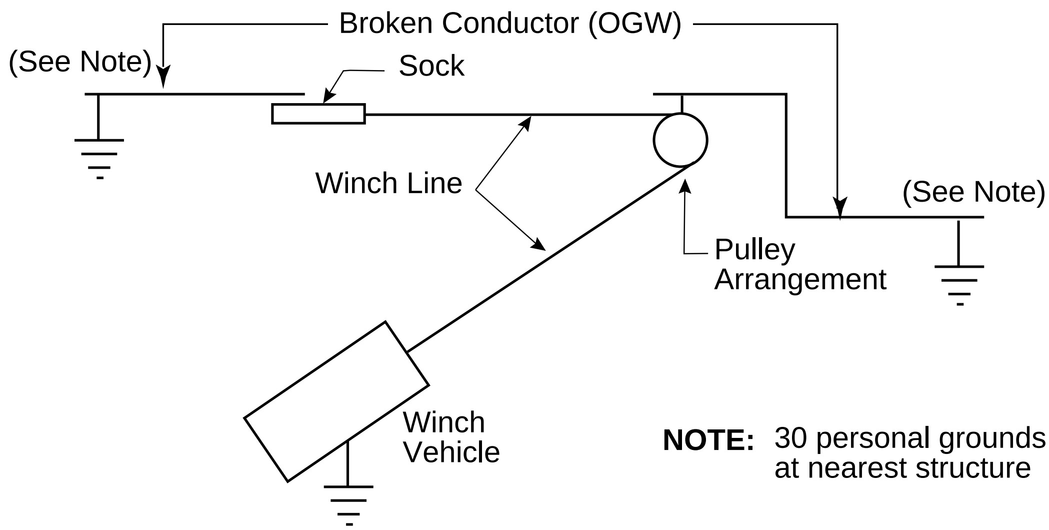


Figure 22
Broken Conductor (overhead ground wire) Splicing

shall be grounded to the structure or each ungrounded component shall be treated as energized. Grounds may be removed as soon as the work is completed, provided that the line is not left open circuited at the structure at which work is being completed.

13.4.1 New construction and temporary lines. Stringing equipment (i.e., reel stands, trailers, pullers, tensioners, etc.) shall be grounded and equipment shall be bonded to each other and each conductor, overhead ground wire, or conductive pulling line. A running ground shall be installed on each conductor, overhead ground wire, or conductive pulling line between the tensioning equipment and the first structure. During stringing operations, each bare conductor, subconductor and overhead ground wire, shall be grounded at the first structure adjacent to both the tensioning and pulling setup (figure 23 and 24). Where a hazard exists or grounding at the first structure is not practical, grounds may be applied at the next adjacent structure. A transmission clipping crew shall have a minimum of two structures clipped in between the crew and the conductor being sagged. When working on bare conductors, clipping crews shall work between grounds at all times. The grounds shall remain intact until the conductors are clipped in, except on deadend structures. Work on deadend structures shall require grounding on all conductors.

Each conductor temporarily terminated at deadends or catch-off points shall be grounded to the structure ground until the installation is completed. During clipping, the phase being clipped shall be grounded.

13.4.2 Crossing energized lines. The line being strung or removed shall be grounded on both sides of the crossing (crossover or cross under) or the line being strung or removed shall be considered and worked energized. When crossing a Western transmission line, obtain a clearance or hot line order on the line in accordance with Western's *Power System Switching Procedures* [10]. On other utility transmission or distribution lines, where practical, the automatic reclosing feature of the circuit interrupting device, on the line being crossed, shall be made inoperative. If the automatic reclosing feature of the other facilities transmission or distribution line can not be rendered inoperative, the line being pulled shall be considered to be energized. Traveling grounds shall be replaced with ground cables after clipping. The ground cables shall remain in place until the entire stringing

NOTE: If wire rope is used for a pulling line, then a running ground is required.

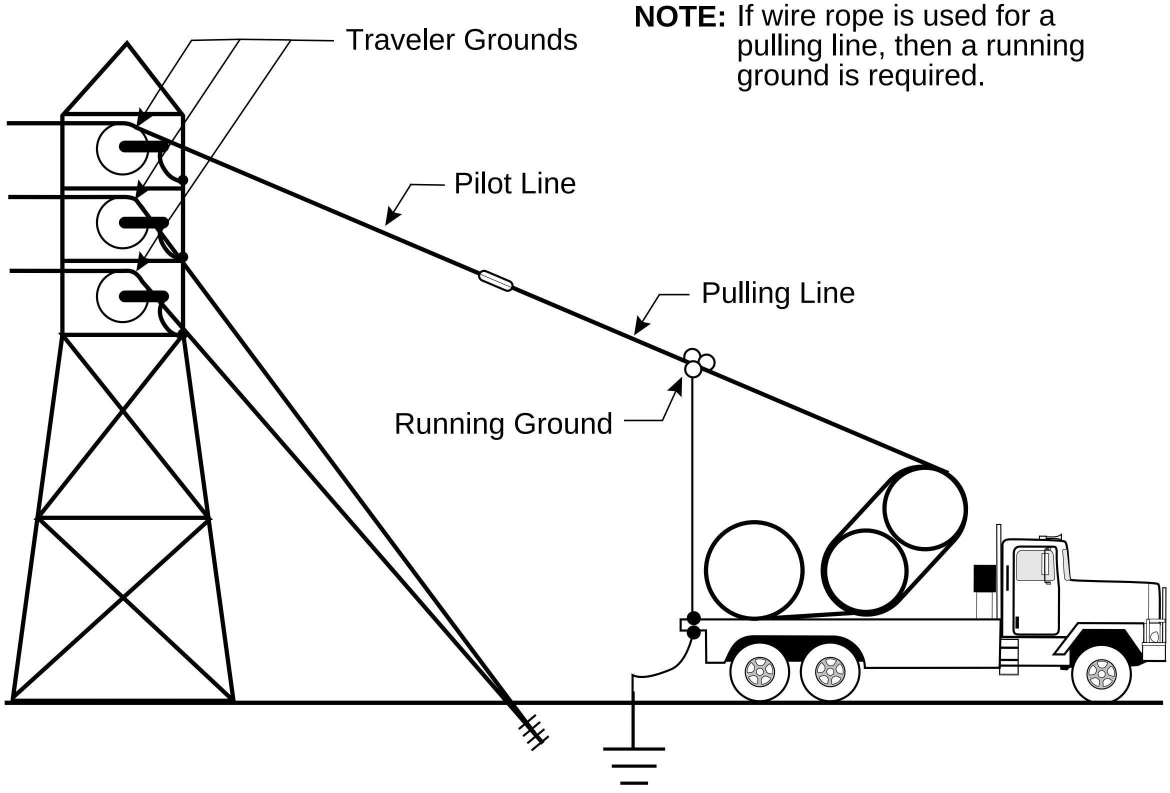


Figure 23
Stringing Pulling End Grounding

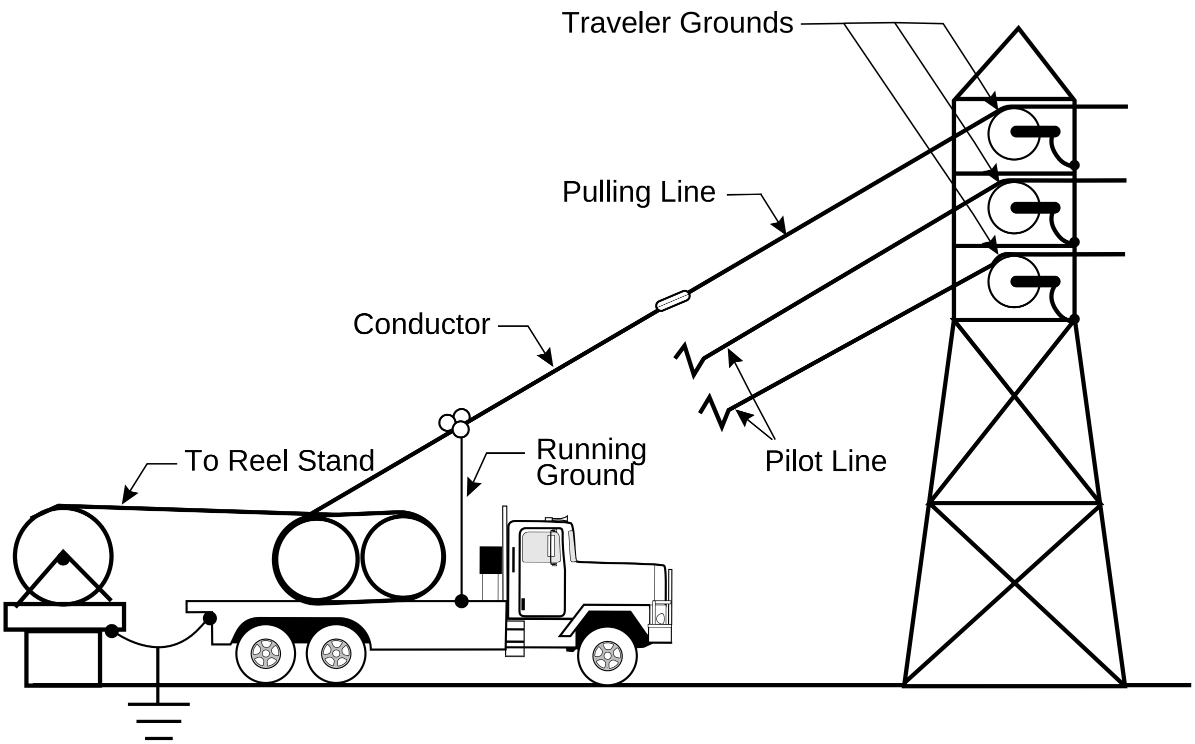
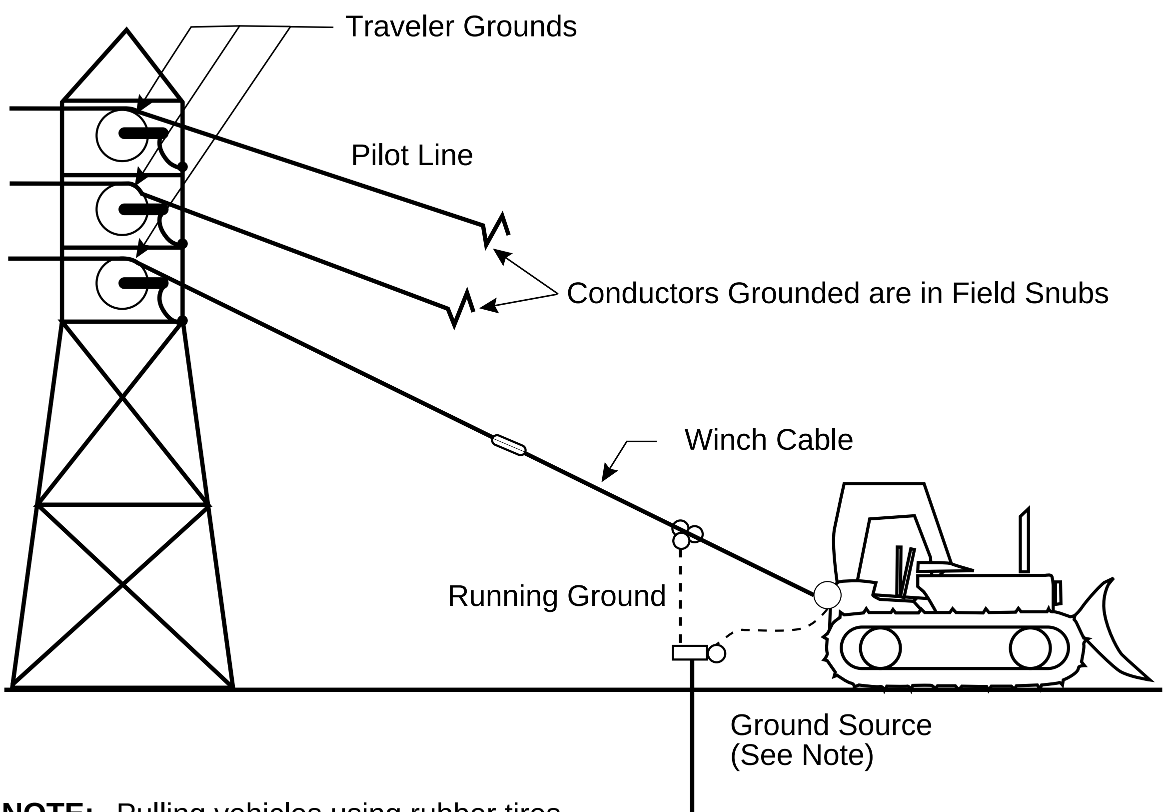


Figure 24
Stringing Tensioner End Grounding

operation is completed. Aerial devices shall be grounded and bonded to conductors, subconductors, overhead ground wires, and conductive pulling lines.

13.4.3 Paralleling energized lines. Prior to stringing parallel to an energized transmission line, an engineering determination shall be made to ascertain whether dangerous induced voltage buildups will occur, particularly during switching and ground fault conditions. When there is a possibility that such dangerous induced voltage may exist, the line shall be worked in accordance with the subparagraphs of 13.4 above and, unless the line is worked energized, shall comply with the following:

All pulling and tensioning equipment shall be electrically isolated (PSSM: de energized), insulated, or effectively grounded. Three phase grounds shall be placed on each conductor, subconductor, or conductive pulling line at increments of no more than four miles (so that no worker is more than 3.2 km (2 mi) from a ground). Conductors, subconductors, and overhead ground wires shall be grounded at all deadend or catch-off points. Except for moving type grounds, the grounds shall be placed and removed with a hotstick. The grounds shall be left in place until the entire stringing operation is completed. Such grounds shall be removed as the last part of the aerial cleanup. Aerial devices shall be grounded and bonded to conductors, subconductors, overhead ground wires, and conductive pulling lines.



NOTE: Pulling vehicles using rubber tires require that the vehicle and the running ground be grounded.

Figure 25
Sagging Utilizing a Pulling Vehicle

To protect workers and the public from stringing grounded systems, all vehicles and equipment at the pulling and tensioning sites, catch-off points, conductor tails, and slice areas shall be enclosed by a barricade with access to vehicles and equipment, conductors, subconductors, overhead ground wires, and conductive pulling lines accomplished by insulated platforms. If left unattended, the barricades shall be replaced with barriers and access points closed.

13.4.4 Storm damage. In situations such as storm damage, line relocation (shoo fly), or vandalism where worksite grounding is impractical, bracket grounding may be used. The structures at the extremes of the repair section shall have three phase grounding installed. Additional grounds should be used at the worksite when feasible. Metal tracked vehicles used for pulling need not be grounded See figure 25).

14. Transmission line terminal ground switches

14.1 General. Transmission line terminal ground switches can help to ensure that the protective devices (relays, circuit breakers, or fuses) operate within the given time/current relationship to isolate the source of accidental electrical energization. However, depending on system configuration and loading conditions, the closing of terminal ground switches can increase circulating induced current, causing hazardous levels of step and touch voltage. Transmission line terminal ground switches are mainly used to allow application of personal protective grounds where the transmission line is subjected to high induced voltages. Transmission line terminal ground switches shall not be used in lieu of personal protective ground cables. Transmission line terminal ground switch operation shall be used in accordance with Western's *Power System Operation Manual, Chapter 1, Power System Switching Procedure* [10]. Capacitors and reactors should be removed from the circuit in accordance with paragraph 10.1 of this chapter.

14.2 Low or no induced voltage. Transmission line terminal ground switches may be used at the discretion of the crew. Transmission line terminal ground switches do provide protection against accidental reclosures.

14.3 High or very high induced voltage. When the induced voltage is very high it becomes difficult or even impossible to install personal protective grounds due to excessive arcing. The method of work shall be chosen in accordance with the Job Hazard Analysis.

14.3.1 High induced voltage. If personal protective ground arcing is unacceptable while attempting conductor contact with the transmission line terminal ground switches open, the switches should be closed and application of the grounding cables should be completed. Transmission line terminal ground switches are then to be opened to reduce ground circulating current at the worksite.

14.3.2 Very high induced voltage. Very high induced voltage occurs on transmission lines in close proximity to transmission lines that are heavily loaded (usually 500 kV lines). In these cases, the work method is dependent on the transferred touch voltages at the worksite. The transferred touch voltage shall be measured in accordance in the test method given in *Protective Grounding Engineering Guidelines* [11]. This measurement need only be made and documented once unless significant system changes occur.

15. Acronyms

ASTM	American Society for Testing & Materials
AWG	American Wire Gauge
CSO	Corporate Services Office
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
MRVD	Multiple range voltage detector
NTVD	Noisy tester voltage detector
OSHA	Occupational Safety and Health Administration
PSSM	Power System Safety Manual
rmsroot	mean square

16. Related reading

A Study of Voltage Induction on Parallel Transmission Lines, A3940 Technical Support, Western Area Power Administration, May 1984.

ASTM F 855, *Standard Specifications for Temporary Grounding Systems to Be Used on Deenergized Electric Power Lines and Equipment.*

Electric Shock Hazard, Charles F. Dalziel, IEEE Spectrum, February 1972.

Electromagnetic Induced Voltage Measurements During Mead Staged Fault Tests, Western Area Power Administration, June 27, 1996.

Evaluation of Four Basic Transmission Line Grounding Methods During Staged Phase to Ground Bolted Faults at Mid Distance of Kayenta Shiprock 230 kV Line, Western Area Power Administration, August 9, 1995.

Evaluation of Two Basic Transmission Line Grounding Methods During Staged Phase to Ground Bolted Faults at Structure 1/5 of the Mead Perkins 525 kV Line, Western Area Power Administration, April 24, 1996.

Getting Down to Earth, James C. Biddle Instruments Manual 25Ta, April 1981.

IEEE Standard 80, *Guide for Safety in AC Substation Grounding.*

IEEE Paper 94 SM 606 4PWRD, *Methods For Protecting Employees and Others From Electrical Hazards Adjacent To Electric Utility Vehicles.*

IEEE Standard 1246, *Guide for Temporary Protective Grounding Systems Used in Substations.*

How Safe Are Your Protective Grounding Practices?, Western Area Power Administration, August 1984.

Lethal Electric Currents, Charles F. Dalziel and W.R. Lee, IEEE Spectrum, February 1969.

Safe Substation Grounding Part I, IEEE Transactions, Volume PAS 100, No. 9, September 1981.

Section 302 of Public Law 9591, The Department of Energy Organization Act, August 4, 1977.

Step and Touch Potential Measurements During Staged Phase to Ground Arcing Faults at Mead and Perkins Substation, Western Area Power Administration, April 24,1996.

Step and Touch Voltage Measurements During Staged Phase to Ground Arcing Faults at Kayenta Substation, Western Area Power Administration, August 9, 1995.

Technical Consideration in Protective Grounding and Jumpering, A.B. Chance Company, Bulletin 9 8001.

Transmission Line Reference Book 345 kV and Above (Red Book), Electric Power Research Institute.

Copies of these publications or parts thereof may be obtained from CSO Technical Support.