IEEE Standards

IEEE Std 1246™-2002
(Revision of IEEE Std 1246-1997)

1246™

IEEE Guide for Temporary Protective Grounding Systems Used in Substations

IEEE Power Engineering Society

Sponsored by the
Substations Committee

Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

14 April 2003

Print: SH95019
PDF: SS95019

Recognized as an
American National Standard (ANSI)

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of the
IEEE Power Engineering Society

Approved 12 September 2002

IEEE-SA Standards Board

Approved 21 January 2003

American National Standards Institute

Abstract: The design, performance, use, testing, and installation of temporary protective grounding systems, including the connection points, as used in permanent and mobile substations, are covered in this guide.
Keywords: grounding, personnel safety, protective grounding, safety, temporary grounding, ultimate rating, withstand rating

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The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Print: ISBN 0-7381-3361-2 SH95019
PDF: ISBN 0-7381-3362-0 SS95019

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Introduction

(This introduction is not a part of IEEE Std 1246-2002, IEEE Guide for Temporary Protective Grounding Systems Used in Substations.)

Practices for applying temporary protective grounds (TPGs) in substations vary from utility to utility. These practices have come from a number of documents such as ASTM F855-1997, IEC 61230-1993, and IEEE Std 1048™-1990,[a] as well as from field experience derived from line maintenance practices. This guide was developed to consolidate into one document all the necessary information for the utility to develop sound personnel safety grounding practices in substations. The guide provides information on the physical construction, application, and testing of TPGs as they are used in substations.

This revision includes several new definitions, which clarify and attempt to standardize the use and understanding of several commonly used terms for various temporary grounding practices. It also emphasizes the electromechanical forces present with high short-circuit currents and with high current offset (asymmetry). In recent tests, these forces were found to have significant impact on the ability of a complete TPG assembly, including attachment points, capable of successfully handling these high short-circuit currents.

Participants

This revised guide was developed by Working Group D4 of the Substations Committee, Distribution Substations Subcommittee. At the time of completion, the Working Group consisted of the following membership:

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[a]Information on references can be found in Clause 2.

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Contents

IEEE Guide for Temporary Protective Grounding Systems Used in Substations

1. Overview

1.1 Scope

This guide covers the design, performance, use, testing, and installation of temporary protective grounding systems, including the connection points, as used in permanent and mobile substations. This guide does not address series-capacitor compensated systems.

1.2 Purpose

This guide suggests good practices, technical information, and safety criteria to assist in the selection and application of temporary protective grounding systems, including the connection points, as used in permanent and mobile substations.

2. References

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

ASTM F855-1997, Standard Specifications for Temporary Protective Grounds to be Used on De-Energized Electrical Power Lines and Equipment.[1]

IEC 60227-1-1998, Polyvinyl Chloride Insulated Cables of Rated Voltages Up To and Including 450/750 V—Part 1: General Requirements.[2]

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[1]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

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

IEC 60227-2-1997, Polyvinyl Chloride Insulated Cables of Rated Voltages Up To and Including 450/750 V—Part 2: Test Methods.

IEC 60245-2-1998, Rubber Insulated Cables of Rated Voltages Up To and Including 450/750 V—Part 2: Test Methods.

IEC 61230-1993, Live Working—Portable Equipment for Earthing or Earthing and Short-Circuiting.

IEEE Std 1048-1990, IEEE Guide for Protective Grounding of Power Lines.[3,4]

3. Definitions

For the purposes of this guide, the following terms and definitions apply. IEEE 100™ [B4],[5] should be referenced for terms not defined in the clause.

3.1 bracket grounding: The location of temporary protective grounds (TPGs) on all sides of a worksite. The location of the TPGs can be immediately adjacent to or some distance from the worksite.

3.2 cluster ground assembly: A preassembled set of four cable or bar assemblies, with three phase connections and one ground connection, all terminating at a common (cluster) point.

3.3 continuity: A continuous, unbroken electrical circuit. For the purposes of temporary protective grounding, any device capable of transforming voltage or producing a significant voltage drop cannot be considered as maintaining continuity. Examples include transformers, fuses, reactors, resistors, circuit breakers, and line traps.

3.4 equipotential zone (equipotential grounding): A general term used to describe the application of temporary protective grounds to limit the potential across the worker's body. It is often associated with worksite or single-point grounding, but also includes other applications of temporary grounding.

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

3.6 phase-to-ground (parallel) grounding: The installation of temporary protective grounds from each phase to ground. The ground attachment point can be a common point for all three TPG ground connections or can be a different point for one or more TPG ground connections, but a low-resistance connection between any separated TPG ground connection points is required.

3.7 phase-to-phase (chain) grounding: The installation of temporary protective grounds from phase to phase to phase with an additional TPG connecting from one of the three phases to ground.

3.8 source grounding: The location of TPGs to ensure that a set of temporary protective grounds is between the worksite and all possible sources of current.

3.9 temporary protective ground equipment (TPG): Devices to limit the voltage difference between any two accessible points at the worksite to a safe value, and having sufficient current withstand rating. These might consist of cable assemblies, grounding switches, or temporarily installed bars.

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

[4]The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, inc.

[5]The numbers in brackets correspond to those of the bibliography in Annex B.

3.10 ultimate rating (capacity): A calculated maximum symmetrical current that a temporary protective ground is capable of carrying for a specified time without fusing or melting the cable. The TPGs are generally rated by this value. A TPG subjected to this current might be damaged and should not be reused.

3.11 withstand rating: The current a temporary protective ground should conduct for a specified time to allow the protective devices to clear the fault without being damaged sufficiently to prevent being operable. The TPG should be capable of passing a second test at this current rating after being cooled to ambient temperature.

3.12 worksite (single-point) grounding: The application of temporary protective grounds only in the immediate vicinity of an electrically continuous worksite. The location of the TPGs must be close enough to the worksite to prevent a hazardous difference in potential across a worker at the worksite.

4. Considerations for temporary protective grounding systems

4.1 General TPG

Temporary protective ground equipment is used when grounding a substation power bus and equipment to protect personnel from high voltages that can be induced or applied because of equipment failure or operating error. The TPGs should be properly sized and assembled to protect personnel from injury during a steady-state or abnormal power system operation.

4.2 Permanent or mobile substation

These TPG assemblies are applicable for both mobile and permanent substations.

4.3 Current magnitude and duration

The current magnitude and duration of the fault are critical factors in sizing TPGs. The protective ground shall be capable of carrying the maximum available fault current at the fault location without failure for the duration of the fault.

4.3.1 Current magnitude including dc offset

The current magnitude is one of the critical factors to be considered when sizing temporary protective grounding systems. The fault current consists of a rms ac component and a dc offset current component. The rms ac component is determined by the subtransient impedances of the rotating machinery, the impedance of transformers, and the impedance of lines. The dc offset component is determined by the X/R ratio at the fault location looking back into the power system and the time of fault initiation on the voltage waveform.

Analytical studies indicate that when full dc offsets occur in the locations with high X/R ratios (such as close to a generating plant or a large transmission substation), the short duration (6 to 60 cycles) fusing current ratings of grounding cables calculated using Onderdonk's equation as considered in ASTM F855-1997 might not be conservative. The additional heating from the dc current component reduces the cable current-carrying capability. The cable current-carrying capability for the six-cycle rating is reduced about 28% when the X/R ratio is changed from 0–40 as shown in Table 2a) and Table 2d), respectively.

At or near large generating plants and transmission substations, a large X/R ratio is likely since the impedance of generators and transformers contains very little resistance. While in extreme cases the X/R ratio can be as high as 50, under most circumstances the X/R ratio does not exceed 40 within the substations. Several miles away from the substations, the X/R ratio is dominated by the impedance of the line. The overall X/R ratio in such cases can be determined from the line's X/R ratio. The typical range of X/R ratios for lines is from 2 to 20 depending on the conductor configuration. A single small conductor line will have a low X/R ratio while a bundled large conductor line will have a higher X/R ratio.

In addition to the effects on fusing current, the X/R ratio and dc offset can produce extremely high current peaks in the first few cycles relative to the rms current. While the current peaks are proportional to the X/R ratio, the rate of decay is inversely proportional to the X/R ratio. The slowly decaying high current peaks, corresponding to higher X/R ratios, create the most severe electromechanical forces, which can destroy the TPG assembly long before it fails thermally. In such a case, the worker would be without protection for a longer duration before the fault clears. IEC 61230-1993 requires temporary earthing devices to withstand a peak asymmetrical current of 2.5 times the rms current value.

4.3.2 Fault duration including primary and backup relaying

The fault duration is another critical factor to be considered when sizing protective grounds. The fault duration is the time required to clear the fault by primary or backup relaying. The fault clearing time is the sum of relay and breaker operation times. Primary relaying is the first line of defense to clear a fault at high speed. Even though utilizing the primary relay fault clearing time minimizes the grounding cable size, the reliability of primary relay operation should be evaluated if this is considered for sizing the protective ground.

Backup relaying is provided for possible failure in the primary relaying system or for possible failure of the circuit breaker or other protective device. Remote backup and local backup are two forms of backup protection in common use on power systems. In remote backup relaying, faults are cleared from the system, one substation away from where the fault has occurred. In local backup relaying, faults are cleared locally in the same substation where the fault has occurred. Local backup protection will clear the fault from the system in less time than that provided by remote backup protection. Utilizing the backup relay fault clearing time provides a conservatively sized protection ground. Since more than one relay operates to clear a fault on the system, the time it takes for a specific number of relay contact operations to clear a fault can be chosen as the backup clearing time. For example, local breaker failure can add from 8 to 12 cycles to the primary clearing time. Second zone or remote backup relaying can add from 12 to 24 cycles to the primary clearing times listed in Table 1 for 4–765 kV systems. Each utility should evaluate the primary and backup relay fault clearing times on their power system and determine which fault clearing time to use for sizing the protective ground.

Table 1—Typical fault clearing times for various system voltages

kV	Primary clearing time (cycles)	kV	Primary clearing time (cycles)
765	2–8	115	3–8
500	2–8	69	4–40
345	2–8	46/34	4–60
230	3–8	25/12/4	5–120
138	3–8		

4.3.3 Circuit breaker reclosure considerations

Tests (EPRI EL-5258 [B1]) have indicated that the cooling of TPGs between reclosures is insignificant. If the reclosing scheme is not disabled, the additional fault duration after reclosure(s) should be included in the total time used to size the TPG.

4.4 Special areas of concern

4.4.1 General

Any device capable of transforming voltage or producing a voltage drop should not be considered as maintaining continuity for the purpose of personnel safety. Such devices include transformers, fuses, reactors, resistors, circuit breakers, and line traps. Switches or other devices with movable contact surfaces, though locked in a closed position, can introduce a significant impedance between TPGs located on one side of the device and a worker on the opposite side. Such devices, when between the worksite and the TPGs, should be operated a few times to clean the contacts and reduce the contact resistance.

Subclauses 4.4.2 through 4.4.6 might be useful when planning installation of TPGs on major equipment in substations.

4.4.2 Main power transformers

The following should be considered when applying TPGs:

a) The turns ratio of many transformers makes them capable of transforming low voltages to high voltages, even when they are not connected to the normal power source. These normally low voltages can come from continuity checking instruments, insulation checking apparatus, and electric arc welders.
b) Shorting of current transformer (CT) secondary leads, and opening of disconnect switches or removal of fuses located in voltage transformer (VT) secondary leads.
c) During oil handling, the oil storage tank, the hose, the filtering, and pumping equipment should be bonded together with the transformer tank being filled. Not only can the hose pick up an induced current, but also the oil flowing in the hose can build up a static charge, unless prevented.

4.4.3 Circuit breakers and circuit switches

The TPG assemblies should be applied on both sides of the device when maintaining circuit breakers, circuit switches, or other devices that can have a circuit disconnection not visible to the worker. Consideration should be given to:

a) Shorting of circuit breaker bushing CT secondary leads.
b) Applying a TPG assembly between the breaker and its free standing CTs in order to prevent creation of an electrical loop that can cause circulating current and spurious operation of protective devices.

4.4.4 Instrument and substation service transformers

Voltage and substation service transformers, because of their very high turns ratio, are extremely hazardous if they are hooked up to electrical equipment in such a way as to allow the applied voltages to be backfed. Backfeeding could cause a severe electric shock to personnel who come in contact with any of the connected circuits anywhere in the substation yard. The secondary leads of voltage-transforming devices should have the secondary disconnect switches open and/or the fuses removed.

4.4.5 Capacitor banks

Substation capacitor banks retain stored charge even if the power source has been disconnected. After allowing for self-discharge (typically 5 min), the de-energized capacitor bank should be fully discharged by the application of a grounded short circuit across its terminal. Where two or more capacitor units are connected in series, each parallel group that is within reach should be shorted and grounded, and each individual unit of a series string that is within reach should be shorted to ensure full discharge.

4.4.6 Power cables and terminations

Capacitive energy stored in a power cable should be dissipated by an approved method before grounding. Before cutting a power cable for splicing, TPGs should be applied at terminations at each end of the power cable.

4.5 TPG cable assemblies

The TPG cable assemblies typically consist of a combination of cable and ground clamps configured for connecting the phase conductors or equipment to a substation grounding system. Refer to Table 2 for selecting the appropriate TPG cable assemblies based on the fault clearing time and available fault current for thermal considerations. For electromechanical considerations, TPG components and assemblies should be tested for a peak asymmetrical current of 2.5 times the rms current, or an appropriate safety factor should be used to size the TPG cable assembly.

A TPG cable assembly consists of:

a) *Ground end*. The ground end consists of a clamp (typically T-handle type) to be connected to a grounded structure or to a ground grid riser, a cable termination, and possibly heat-shrinkable tubing to seal exposed cable strands.
b) *Flexible conductor with a suitable jacket*.
c) *Source end*. The source end consists of a clamp (typically with an "eye" for handling and tightening) to be connected with the insulating stick to a de-energized conductor, bus, or an attachment stud, a cable termination, and (possibly) heat-shrinkable tubing to seal exposed cable strands.

Figure 1a), Figure 1b), and Figure 1c) show various TPG cable assemblies.

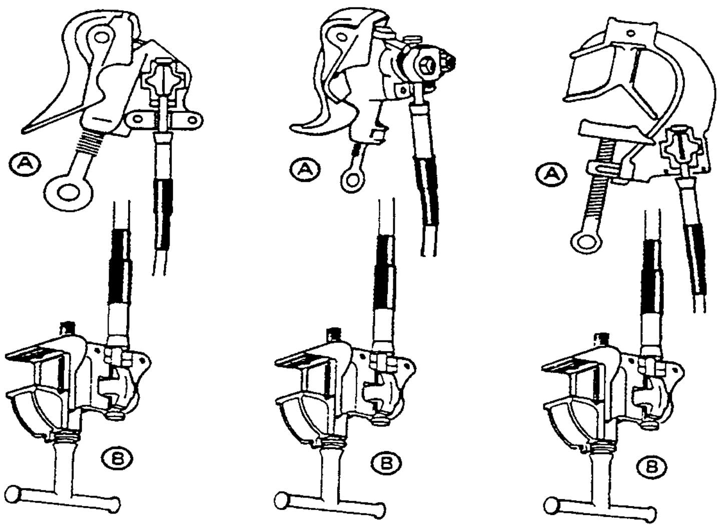


Figure 1a)—Typical TPG assemblies

NOTES
A—Bus (conductor) end.
B—Ground end.

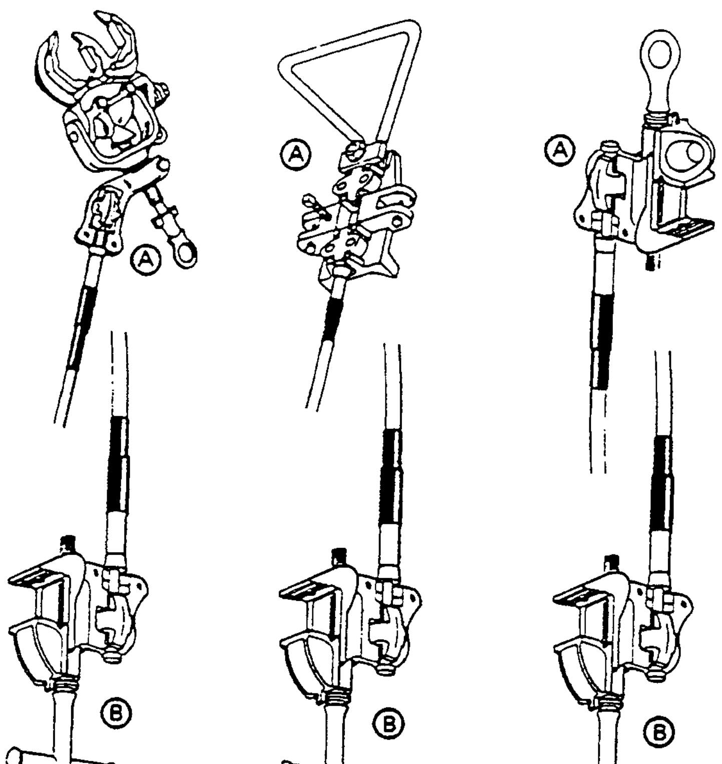


Figure 1b)—Typical TPG assemblies

NOTES
A—Bus (conductor) end.
B—Ground end.

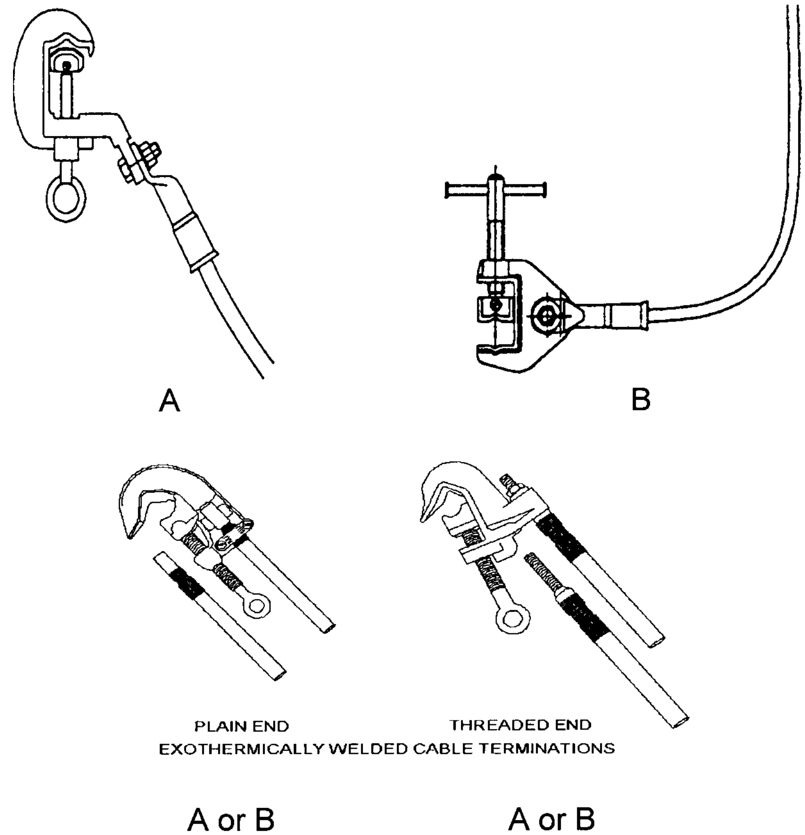


Figure 1c)—Typical TPG assemblies

NOTES
A—Bus (conductor) end.
B—Ground end.

4.6 TPG cable

4.6.1 Conductor material

Annealed copper conductors are used for temporary protective ground cables. The strands can be plain or tinned. The diameters of the strands are generally specified by the manufacturer or by the appropriate standard. Compliance with the cable material requirements should be checked by inspection and testing.

The electrical resistance of the conductors at 20 °C can be checked by the test given in IEC 60227-2-1997 and IEC 60245-2-1998.

4.6.2 Sizing of protective ground cables

The withstand rating of the cable should be considered when sizing the TPG cable assembly. Typically, the withstand rating is 70 to 80% of the ultimate capacity. The dc offset current should be considered when selecting a cable rated to its ultimate capacity for short durations. Some utilities use the ultimate capacity and replace the assembly after exposure to a fault. Table 2a), Table 2b), Table 2c), and Table 2d) list the ultimate current-carrying capability for a worst case dc offset for X/R ratios of 40, 20, 10, and 0, respectively. If the X/R ratio is unknown, Table 2a) should be used.

Table 2a)—Ultimate current-carrying capabilities of copper grounding cables (currents are rms values, for frequency of 60 Hz; $X/R = 40$; current in kA)

Cable size (AWG)	Nominal cross section (mm^2)	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	22	16	12	10	9	5
#1	42.41	28	21	16	13	11	7
1/0	53.48	36	26	20	17	14	8
2/0	67.42	45	33	25	21	18	11
3/0	85.03	57	42	32	27	23	14
4/0	107.20	72	53	40	34	30	17
250 kcmil	126.65	85	62	47	40	35	21
350 kcmil	177.36	119	87	67	56	49	29

Table 2b)—Ultimate current-carrying capabilities of copper grounding cables (currents are rms values, for frequency of 60 Hz; $X/R = 20$; current in kA)

Cable size (AWG)	Nominal cross section (mm^2)	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	25	18	13	11	9	5
#1	42.41	32	22	16	13	12	7
1/0	53.48	40	28	21	17	15	9
2/0	67.42	51	36	26	22	19	11
3/0	85.03	64	45	33	27	24	14
4/0	107.20	81	57	42	35	30	18
250 kcmil	126.65	95	67	50	41	36	21
350 kcmil	177.36	134	94	70	58	50	29

Table 2c)—Ultimate current-carrying capabilities of copper grounding cables (currents are rms values, for frequency of 60 Hz; $X/R = 10$; current in kA)

Cable size (AWG)	Nominal cross section (mm^2)	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	27	19	13	11	9	5
#1	42.41	35	23	17	14	12	7
1/0	53.48	44	30	21	17	15	9
2/0	67.42	56	38	27	22	19	11
3/0	85.03	70	48	34	28	24	14
4/0	107.20	89	60	43	36	31	18
250 kcmil	126.65	105	71	51	42	36	21
350 kcmil	177.36	147	99	72	59	51	30

Table 2d)—Ultimate current-carrying capabilities of copper grounding cables (currents are rms values, for frequency of 60 Hz; $X/R = 0$; current in kA)

Cable size (AWG)	Nominal cross section (mm²)	6 cycles (100 ms)	15 cycles (250 ms)	30 cycles (500 ms)	45 cycles (750 ms)	60 cycles (1 s)	180 cycles (3 s)
#2	33.63	31	19	14	11	9	5
#1	42.41	39	24	17	14	12	7
1/0	53.48	49	31	22	18	15	9
2/0	67.42	62	39	28	22	19	11
3/0	85.03	79	50	35	28	25	14
4/0	107.20	99	63	44	36	31	18
250 kcmil	126.65	117	74	52	43	37	21
350 kcmil	177.36	165	104	73	60	52	30

NOTES

1—The current values in Table 2a), Table 2b), Table 2c), and Table 2d) were calculated from the computer program RTGC, Reichman et al. [B6]. This computer program can be used directly to determine the grounding cable size requirements for known X/R ratio and fault clearing time.
2—Angle of current initiation = 90° (maximum dc offset). Initial conductor temperature = 40 °C; final conductor temperature = 1083 °C.
3—These current values reflect thermal limits only and do not reflect the severe electromechanical forces present during the first few cycles of a fully offset wave, which can mechanically damage the TPG cable assembly or cause complete failure.
4—For derating of multiple cables, refer to 4.8.3.
5—Metric values are soft conversions. Soft conversion is a direct area calculation in metric units from the AWG size.

4.6.3 Jacket

The following types of jacketing materials are generally used in cable designs, primarily for the protection of the conductor:

a) A jacket based on a compound of vulcanized ethylene propylene rubber (EPR) or ethylene propylene diene monomer (EPDM).
b) A general-purpose jacket based on a compound of thermoplastic polyvinylchloride (PVC), copolymers, or silicone rubber compounds.
c) A cold-resistant jacket based on a compound of thermoplastic PVC or one of its copolymers or silicone rubber compounds.

A separating tape, made of suitable material, might be placed between the conductor and the jacket. Consideration should be given to the fire-retardant characteristics of the jacket material. Because some jacketing materials produce toxic fumes if overheated, their use should be limited to outdoor applications. An indoor application could be permissible with forced-air ventilation.

The jacket should have adequate mechanical strength and elasticity within the temperature limits to which it can be exposed in normal use. Compliance can be checked by carrying out the tests specified for each type of jacketing material in the following references:

1) IEC 60502-1994 [B2] for EPR or similar compound. Additionally, cables covered by this type of compound should be subjected to a bending or elongation test at 50 °C.
2) IEC 60227-1-1998 for a general-purpose compound.

The applicable test methods and the results to be obtained for each type of jacketing material are also specified in these standards.

The jacket should be closely applied to the conductor or the separator if any. It should be possible to remove the jacket without damaging the strands. This should be checked by visual inspection.

The jackets are available in several colors. Typical colors include orange, yellow, black, and green. There is no preferred color for the jacket. The PVC (thermoplastic) jackets are usually made transparent. Some users prefer transparent jackets because it allows for visual inspection of the conductor. PVC (thermoplastic) jackets can, over time, become opaque and brittle.

4.6.4 Cable stranding configuration

Cable stranding is specified in ASTM F855-1997. TPG cables are typically furnished in three types. The type depends on both the cable and protective jacket. The major characteristics of these ground cables are as follows:

a) Type I
   1) *Conductor*—Stranded soft drawn copper conductor with 665 strands or more of #30 or #34 AWG.
   2) *Jacket*—Elastomer jacket, as rated by manufacturer, flexible for installation and serviceable for continuous use within the temperature range −40 °C to +90 °C.

b) Type II
   1) *Conductor*—Stranded soft drawn copper conductor with 133 strands or more for #2, or 259 strands or more for 1/0 AWG, and greater.
   2) *Jacket*—Elastomer jacket, as rated by manufacturer, flexible for installation and serviceable for continuous use within the temperature range −25 °C to +90 °C.

c) Type III
   1) *Conductor*—Stranded soft drawn copper conductor with 665 strands or more of #30 AWG.
   2) *Jacket*—Thermoplastic jacket, as rated by manufacturer, flexible for installation and serviceable for continuous use within the temperature range −10 °C to +60 °C.

Use of the above cables should be restricted to open areas or spaces with adequate ventilation so that any fumes produced by overheating can be dispersed.

4.7 Clamps

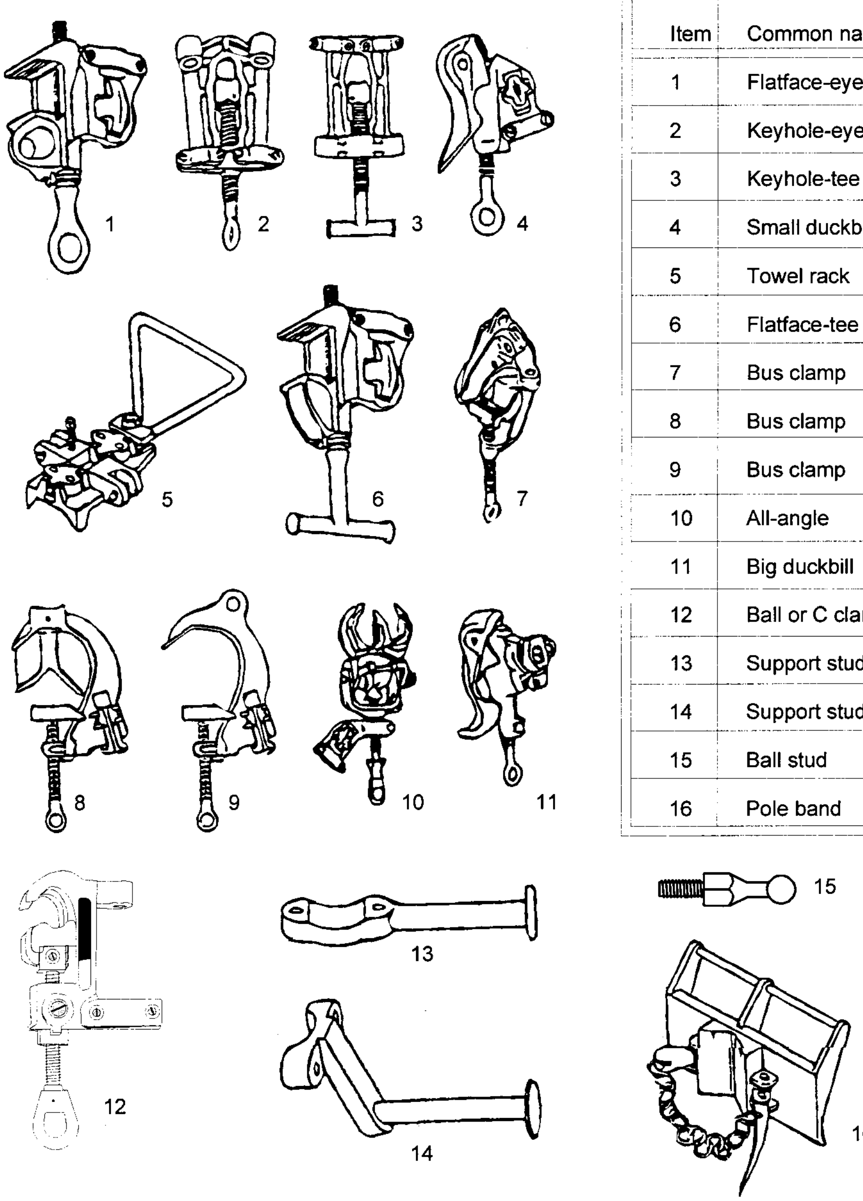
Clamps should be rated for maximum fault current and duration to which they can be subjected. The clamp and conductor assembly should be capable of carrying the fault current for the specific time without damage or separation from the phase conductor or ground point.

Clamps for grounding applications are characterized by their time versus current ratings, their overall general shape, and clamping configuration. The clamp configuration should accept the main and tap conductor sizes and have the appropriate jaw configuration.

If inadequately rated, electromechanical forces due to a fault can break the connection of the clamp from the phase conductor, or even break the clamp. At lower current, the high resistance of clamped connections can cause overheating. In either case, the clamped connection can loosen and fail.

4.7.1 Clamp types

A large variety of clamps are available in the industry, each suitable for either a specific or multiple applications. Clamps are designed to fit various shapes of bus-work, stranded or solid conductors, and steel tower structures. See Figure 2 for typical ground clamps.



Item	Common name
1	Flatface-eye
2	Keyhole-eye
3	Keyhole-tee
4	Small duckbill
5	Towel rack
6	Flatface-tee
7	Bus clamp
8	Bus clamp
9	Bus clamp
10	All-angle
11	Big duckbill
12	Ball or C clamp
13	Support stud
14	Support stud
15	Ball stud
16	Pole band

Figure 2—Typical ground clamp, stirrup, and support stud used in the utility industry

A clamp can have either smooth or serrated jaws. The smooth jaw clamp is designed to minimize conductor damage and should be used on cleaned conductors to ensure a clean connection. The serrated jaw clamps are designed to break through the buildup of corrosion or oxide film on the conductor. If a clamp with serrated jaws is used improperly, the conductor surface could be damaged.

4.7.2 Clamp material

Clamps are typically made from aluminum or copper alloy. Copper cables should not be fitted directly into aluminum alloy clamps because of corrosion and resulting loss of both electrical contact and mechanical strength. To minimize corrosion, cable terminations can be tinned or a suitable corrosion inhibitor used. Even with these precautions, care should be taken not to expose the TPG cable assembly to a corrosive atmosphere or excessive moisture.

4.7.3 Mechanical considerations

For high fault currents, the clamps and the terminations are subjected to very high electromechanical forces during fault conditions, especially when long cables are left unsecured. Under such conditions, large electromagnetic forces can accelerate the cables to high velocities and the clamps are called on to absorb much of this kinetic energy. Also, if a TPG were to fail mechanically, the failure would most likely be within the first three cycles and the worker would be without any protection for the remainder of the fault duration.

To prevent violent cable whipping, the cables should be restrained, using a rope. The restraint should not create a rigid binding point, but it should absorb shock and prevent the violent cable movement produced by the electromagnetic forces. Cables should not be twisted or wrapped around the structure because this creates a transformer effect and causes cable overheating and possible failure. In addition, when there is a large dc offset with full asymmetry, the peak current can be up to twice the value of the symmetrical peak current. The magnetic forces can be up to four times as high in such cases. It should be noted that clamps rated in accordance with ASTM F855-1997 are tested for maximum peak current of only 20% over the symmetrical peak current (1.7 times the rms current). IEC 61230-1993, on the other hand, requires testing at 77% peak over the symmetrical peak current (2.5 times the rms current).

The mechanical adequacy of a given design and construction of a clamp, for a given fault current, depends on the combination of cable type and length, and the type of cable-to-clamp attachment with which it is to be used. For a given fault current magnitude and duration, a certain clamp can be entirely adequate mechanically for one application, but inadequate for another. Only full-scale fault current tests on the most adverse application of a clamp would allow one to determine its mechanical ruggedness and acceptability for the specific application.

Most substation applications involve three-phase TPGs, and there can be high electromechanical forces produced between the individual TPGs when subjected to high fault currents. A TPG assembly that would otherwise pass a single-phase test might not survive a three-phase test. Examples would include the chain grounding configuration (with two or three TPGs installed in close proximity on one of the conductors) and parallel grounding (with all three TPG ground ends attached to a common point). Thus, the TPGs used in substation applications should be tested and applied with due consideration of these interphase forces.

4.7.4 Cable-to-clamp termination

The most critical component of the TPG cable assembly for withstanding the extreme electromechanical forces is probably the cable termination, and how it is attached to the clamp. The cable can be terminated at the clamp in several ways. Typical cable terminations are compression or exothermic type, but wedge and bolted cable connections can be used. For compression ferrules, the manufacturer's specifications should be followed closely, including compression die type, size, pressure, and compression pattern (i.e., overlap versus nonoverlap, how many compressions, etc.). Cable terminations are available in threaded and nonthreaded form. Terminations using solder should not be used. Terminations should provide a low-resistance connection at the cable-to-clamp interface. Due to the high mechanical forces, one of the most important requirements of the cable-to-clamp termination is the provision for strain relief for the cable.

Heat-shrinkable tubing should be used for all connections where possible to minimize corrosion between the cable strands.

4.8 Multiple assemblies

Multiple assemblies terminated at the same point provide multiple paths for the fault current. This reduces the size requirement for any individual path (cable). However, unless the current paths have equal impedance, it should not be assumed that the fault current will divide equally.

Extreme electromechanical forces present under high fault current conditions can break the clamp or cable termination, leaving a worker without protection. Unlike thermal energy, electromechanical forces on individual TPGs do not reduce in the same proportion as the current. More likely, the electromechanical forces on multiple assemblies would be the same as that developed by the total fault current. This is because the various loops consisting of phase conductors, TPGs, and current-return circuits primarily determine the electromechanical forces on a TPG regardless of its multiplicity.

Even if properly sized for fault current (including any derating factors for multiple assemblies), the manner in which the TPGs are physically located and arranged on the phase conductor can have significant impact on the ability of the multiple assemblies to handle successfully the high fault current. It might be possible to reduce electromechanical forces on multiple assemblies by providing a small separation (2 m to 3 m) between the individual TPGs. In such a case, a proper derating factor of individual TPGs must be considered. The best arrangement, however, will be one that minimizes cable movement, or allows cable movement only in a direction that the strain relief is intended to allow.

More than two parallel TPGs should be avoided because of the uncertainty of equal fault current distribution and electromechanical forces. It might be possible to reduce the number of the TPG assemblies by increasing conductor size, reducing the required protection time, reconfiguring the system to reduce the available fault current, or a combination of these. If more than two TPGs are required, custom-designed assemblies with special installation techniques should be considered.

4.8.1 Path impedance

When it is necessary to use multiple temporary grounds in parallel per phase, it is very important to assure equal impedance of each TPG. To be sure that balanced current flows through each TPG, the following items should be made equal:

a) Size and type of stirrups
b) Size and type of clamp
c) Length and ampacity of each conductor
d) Similar connection of each conductor in the clamp
e) Cleanliness of conductors, stirrups, and mating surfaces of clamps
f) Torque applied to each clamp
g) Size and location of ground riser to which the TPGs are attached, if applicable

The cleanliness of each connection and the torque applied to the clamps are of major importance. Dirty surfaces or insufficient torque can result in overheating and failure.

Inductive reactance is often more important than resistance in terms of the total impedance of the grounding cable. However, differences in resistance where the cable is connected to the clamp and where the clamp is connected to the phase conductor can be very significant in determining current sharing.

Because some unbalance is inevitable, 600 V insulated cables should be used to prevent potential differences in the cables from creating a problem, such as cable-to-cable arcing.

4.8.2 Positioning

If two TPGs in parallel are used, the clamps should be connected as close together as possible. Butting the clamps together will reduce the possibility of the clamps slipping off due to the large attractive force between them during the fault. It is an industry practice to connect the TPGs as close to each other as possible on the phase conductor, which further improves equal current distribution. They should also be installed with reasonable speed to limit the exposure of a single cable to a fault.

4.8.3 Derating of multiple TPGs

To account for unequal current division, the withstand rating (determined by following 4.6.2) of each TPG used in the multiple assembly set should be reduced by at least 10%.

4.9 Attachment points

Fixed-point protective grounding terminals attached to the bus conductors, equipment terminals, or structures have been gaining acceptance in the utility industry. These terminals provide an attachment point for protective grounds that lends itself to adaptability of standard clamps. This avoids forcing these clamps to conform to a wide range of conductor sizes and configurations. These fixed attachments (studs and stirrups) should be able to withstand, mechanically and electrically, the available fault current. Corona protection of the attachment points should be considered.

The ASTM F-855-1997 and IEC 61230-1993 standards do not include specific testing of attachment hardware similar to testing a TPG cable or bar assembly. To ensure thermal and electromechanical withstand capabilities for the available fault current, this hardware should be tested as suggested in 4.5 and 8.1.

4.9.1 Bus conductors

A substation can include a wide range of conductor sizes and shapes. If 125 mm or larger diameter tubular bus is used, special attachment points (stirrups) are usually provided for the installation of TPGs. Regardless of the type of attachment point, it has to be compatible with the thermal and electromechanical capabilities of the TPGs with which it will be used.

4.9.2 Stirrups

a) Stirrups of various sizes and shapes can be manufactured.
b) Stirrup material should be compatible with conductor material to which the stirrup is attached.

4.9.3 Studs

a) Studs can be bolted, welded, or compressed on to the conductor.
b) Studs should be manufactured from material compatible with the conductor to which they are attached.
c) Studs should be designed such that the clamps are prevented from sliding off during a fault.

4.10 Cable extensions

Dangerous voltage levels can develop across extremely small resistances during high current faults. The TPGs with center splices to extend their length should be avoided because they can increase the overall TPG resistance. This caution is not intended to prohibit the use of cluster devices on a worksite, but to point out matters to be considered.

5. Application

5.1 General

The TPGs should be installed, used, and serviced only by competent personnel using good work and safety practices. This clause is intended to provide the user with information and guidance in the proper selection and installation of TPGs.

5.1.1 Single phase

When maintenance is required on single-phase circuits, a single-phase TPG assembly should be used to connect each phase conductor to a grounding electrode.

5.1.2 Three phase

When maintenance is required on three-phase circuits, one of the following methods should be used:

a) Three single-phase TPGs connecting each phase (phase-to-ground grounding) to ground.
b) TPGs connecting phase-to-phase-to-phase—with one of the three phases connecting to ground (phase-to-phase or chain grounding).
c) One prefabricated three-phase TPG (cluster ground) connecting each phase to a common point, then connecting that common point to ground.

The type of three-phase configuration used will influence the fault current distribution among the individual TPGs and the worker, as illustrated in Figure 3 for both three-phase and single-phase

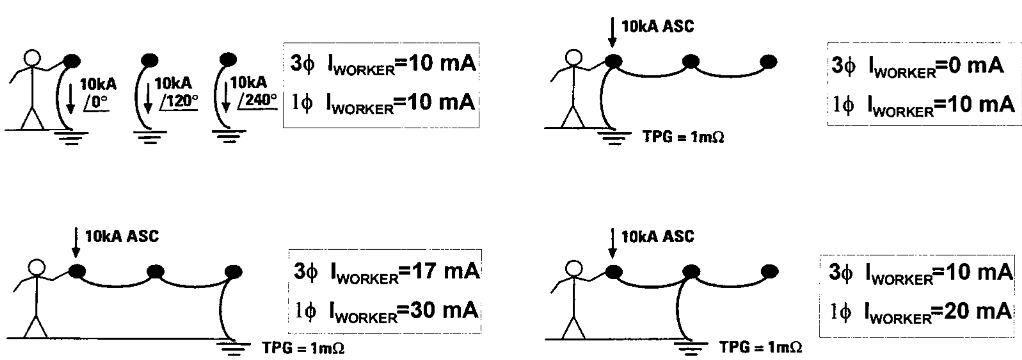


Figure 3—Variation of current flows for various TPG configurations

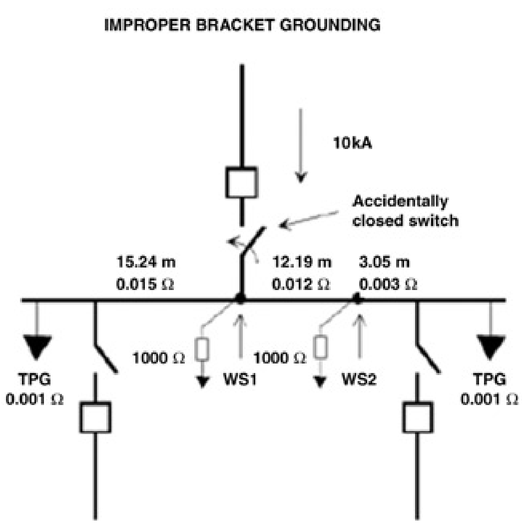
energizations. In the parallel configuration, a TPG is in parallel with the worker between the phase and ground, resulting in the minimum possible current through the worker. In the chain configuration, with one of the outer phases connected through a TPG to the ground while the worker is on the opposite outer phase, the current through the worker would be the maximum possible current. This is because of the additional TPG conductor length from the contacted phase to the grounded phase. Grounding the middle phase would reduce the current through the worker, as compared with grounding one of the outer phases. In contrast, if the worker simultaneously contacts two phases, chain grounding provides the minimum possible current through the worker. Cluster TPGs provide some of the advantages of both parallel and chain grounding.

5.2 Location of TPGs

5.2.1 Source (bracket) grounding

Source grounding uses TPGs placed between the worksite and any possible energy source. The energy sources include transformers, transmission lines, and generating units, and also include backfeed to the bus from networked distribution lines, energized secondaries of VTs, and bus crossings (possible energized bus dropping on to a de-energized bus, or vice versa). The TPGs connect the de-energized bus or equipment to the substation ground. The TPGs might be located an appreciable distance from the worksite in large substations.

A variation of source grounding, generally involving two sources—one source on each side of the worksite, is often referred to as bracket grounding. This term is more appropriate in transmission or distribution line grounding, where the worksite might be energized from either end of the line. In a substation, improper application of bracket grounding might result in energy sources connected to the de-energized bus between the worksite and the TPG location(s). While many applications of bracket grounding are electrically the same as source grounding (such as TPGs applied on either side of a circuit breaker), some applications might meet the visual requirements of a bracket (or working between grounds) but are electrically quite different. An example would be TPGs located at the ends of a straight bus, with one or more transmission line terminations between the TPG locations. Personnel working on the straight bus would be between grounds (bracketed by grounds), but the TPGs would not be between the worksite and all sources of energy. Figure 4a) and Figure 4b) use a simplified



Worker at	Body current
WS1	80 mA
WS2	20 mA

Figure 4a)—Example of improper source (bracket) grounding (1000 Ω body is assumed at each worksite)

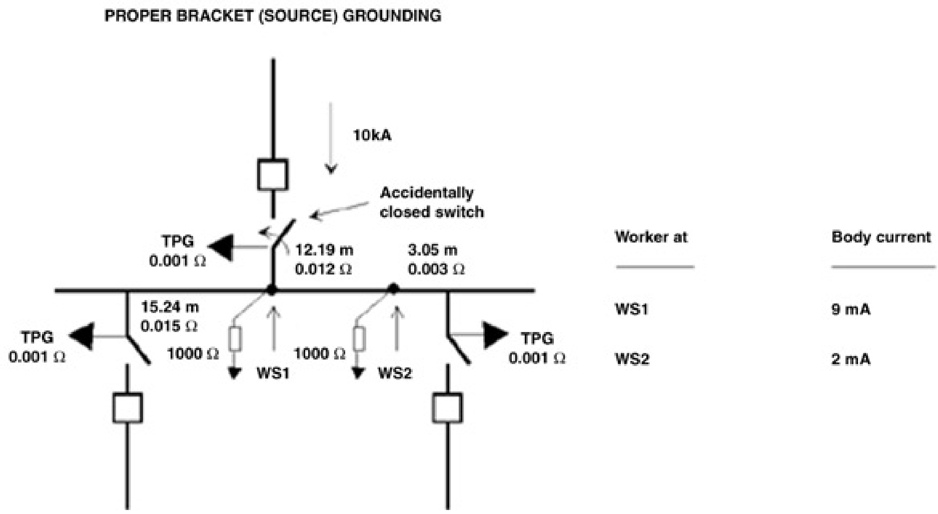


Figure 4b)—Example of proper source (bracket) grounding (1000 Ω body is assumed at each worksite)

circuit to illustrate the difference in body current for improper and proper bracket (source) grounding. A 1000 Ω body resistance is assumed for each worksite for these calculations. The distances represent the separation between the worksite and the TPG or between the worksite and the source (entry point) of current to the de-energized bus.

5.2.2 Worksite (single-point) grounding

In worksite grounding, the TPGs are placed as close as possible to the worksite. They are used to connect the de-energized bus or equipment to the substation ground or local ground. They are designed to carry the maximum fault current, both symmetrical and asymmetrical, that can occur at the worksite, in the event of accidental re-energization. A perceived disadvantage is that the worker is not working between two visible grounds on a circuit that can be energized from either of two directions, resulting in a sense of a lack of safe work location. Typically, the current through the worker will be greater if energization occurs from the side opposite the TPG location. To be considered a worksite ground, the TPGs must be located very close to the actual worksite (worker exposure). A good rule of thumb is to place the TPGs within a distance reachable from the worksite using a live-line tool. Mechanical whipping of TPGs placed too close to the worker might be a safety concern. The TPGs in this situation should be restrained. An advantage of this method is that fewer connections are made by the worker.

5.2.3 Multipoint grounds

Multipoint grounding is a combination of both worksite and bracket or source grounds. An advantage of multipoint grounding follows from the principle of current division between ALL paths. Multipoint grounding significantly reduces the current through the worker, as compared with either worksite or bracket grounding. Due to redundancy of TPGs, the worker would be better protected even if one of the bracket TPGs were to fail mechanically or thermally.

5.3 Ratings and selections

The size of a TPG should be based on the application and available fault current, using the sizing criteria of 4.6.2. When TPGs are located at two or more locations, it should be noted that the TPGs will not share the available fault current equally. If TPGs are placed as close as 8 m on either side of the worksite, they do not share equal current division—the majority of the current flows in the TPG closest to the source of energy. At 16 m, the split between two sets of TPGs is on the order of 75% to 25%, while at 128 m the split is close to 95% to 5%. Thus, all TPGs should be sized as though they are the only TPG installed, or a derating factor should be considered (refer to 4.8 for multiple sets of TPGs at the same location).

5.4 Methods

5.4.1 TPG cable or bar assemblies

The TPG cable or bar assemblies connect the phase conductors or equipment to a substation grounding system or a local ground.

5.4.2 Grounding switches

Grounding switches are permanently installed switches, kept in the open position until required. Grounding switches are used for connecting the bus (de-energized, i.e., for maintenance) to the substation grounding system. They are often used to connect the phase conductors to a ground electrode when the phase conductors are too large in diameter or too high to accommodate a TPG effectively.

The advantages of grounding switches are their operational convenience when frequent grounding is required, and the capability of including mechanical interlocks to prevent inadvertently opening the switch or even to restrict access to an area. Ground switches should be designed to withstand the maximum asymmetrical current anticipated at the substation. Grounding switches have another advantage in that they facilitate multipoint grounds in the substation. A disadvantage is that ground switches require maintenance and might not easily operate when called upon, due to long periods between operations. If grounding switches are used, TPGs can be used to ensure worker protection at the worksite. For example, ground switches might be located at the ends of a long section of bus, with TPGs located at one or more worksites between the ground switches.

5.4.3 Ground and test devices

A ground and test device is a device used in metal-clad switchgear for accessing the primary bus (either "main" bus or "outgoing" bus) and ground bus within an individual cell or cubicle. It provides visible, protective grounding in the work area.

As a grounding device, it makes available the accessed primary bus and ground bus for interconnecting by an equipment operator. This interconnecting can be done either manually, using standard TPGs, or through an integral "grounding" switch.

As a testing device, it makes the primary bus and ground bus accessible for voltage and phase relation checks. These devices are installed in place of the standard circuit breakers.

6. Installation and removal

6.1 General procedures

The exact procedures for applying TPGs can differ, depending on the type, rating, and configuration of the equipment being isolated and grounded, and specific policies of the organization. The possible arc flash hazard involved with installing and removing TPGs should be considered and appropriate personnel protective equipment can be used to minimize burn hazards. (For further relevant information on arc-flash hazards, refer to IEEE Std 1584™-2002 [B5]). The TPG is applied between the de-energized bus, line, or equipment and the ground electrode. The ground electrode consists of the substation grounding system, which can include system neutrals, ground mats, ground rods, overhead ground wires, and structures. The ground electrode should be capable of carrying the maximum available fault current at the point of application. The general procedures listed below should be followed:

a) Check grounding assembly to assure that it is in good operating condition.
b) Isolate the section of bus, line, or equipment.
c) Install barrier, if required (rope off area).
d) Test for voltage on the de-energized bus, line, or equipment.
e) Clean areas on bus and ground electrodes following approved safety procedures.
f) Install assembly on ground electrode.
g) Install assembly on de-energized bus, line, or equipment.
h) Remove assembly from de-energized bus, line, or equipment.
i) Remove assembly from ground electrode.

6.2 Tools

Live-line tools are protective operating devices made from suitable insulating materials. Ground clamps, cleaning tools, and measuring instruments can be attached to live-line tools for working on energized or statically charged conductors. Live-line tools are available in various shapes, sizes, and lengths.

6.2.1 Clamp stick

Clamp sticks are a class of the live-line tool used when more complex operations are required. These live-line tools have mechanical linkages to improve maneuverability and control of ground clamps, tools, measurement equipment, and other devices.

To increase the worker's lifting capabilities, a hook lift stick (shepherd's hook) with block and rope assembly reduces the effort required to raise and install large capacity clamps on an overhead bus.

6.2.2 Bucket and platform truck

Bucket and platform trucks are used to reach otherwise inaccessible equipment or bus conductors requiring grounding. Live-line tools can be used in conjunction with bucket and platform trucks for grounding applications. Before work begins, the truck frame should be properly grounded to the substation grounding system. (See 6.5.3.)

6.2.3 Platforms

Platforms are used to elevate the worker to the work area for better access. Platforms can be either insulated or noninsulated. Live-line tools can also be used in conjunction with platforms for grounding applications. Frames for platforms should be properly grounded before work begins.

6.3 Testing for voltage

Before any grounding connections are made, the bus or equipment should be tested to verify it is de-energized. The following devices and methods can be used to detect the presence of voltage on the bus, equipment, and ground electrode.

6.3.1 Proximity voltage detectors

These devices detect the presence of voltages by being placed in the electrostatic field near the bus, using the appropriate live-line tool.

6.3.2 Multirange voltage detectors

These devices are electric field measurement detectors, which are attached to live-line tools and have probes that need to be placed directly on the bus to be tested.

6.3.3 Fussing (buzzing or teasing)

Fussing, also known as *buzzing* or *teasing*, is a method using a conductive tool on the end of a clamp stick and dragging the conductive device along the bus. A buzzing could indicate an energized bus. Since this technique is very subjective, it is NOT suggested.

6.4 Placing and removing of TPGs

The temporary protective grounding assembly should be placed at such locations, and arranged in such a manner, as to prevent the employee from being exposed to hazardous differences in electrical potential and movement of the assembly under fault conditions.

6.4.1 Cleaning of bus and electrodes

Prior to making any grounding connection, all contact connection surfaces should be appropriately cleaned to remove any buildup of dirt, oil, grease, or oxides. Protective coatings, such as paint, should be removed from steel surfaces prior to making connections.

Contact surfaces can be cleaned using V-shaped wire brushes, standard wire brushes, sanders, or other similar tools. These cleaning tools can be obtained as an attachment to live-line tools. Grounding clamps can also be obtained with serrated jaws to penetrate the corrosion on a tubular bus. Clamps with piercing bolts can be used to penetrate galvanized surfaces, if desired. Piercing bolts are sometimes found to be ineffective under high fault current conditions. Clamps with serrated jaws can deform conductor surfaces, causing corona at higher voltages.

6.4.2 Order of connection of TPGs

When a ground is to be attached to a bus, incoming line, or equipment, the ground-end connection should be attached first, and then the other end should be attached by means of a live-line tool.

6.4.3 Order of removing TPGs

When a temporary protective ground is to be removed, the TPG assembly should be removed from the bus, line, or equipment using a live-line tool before the ground-end connection is removed.

6.5 Equipment grounding

6.5.1 General

Work in substations does not permit universal applications of grounding. Each job should be evaluated with regard to the live equipment installed at the substation, other work, and switching in the vicinity, and the type of work being done requiring grounding protection. Additional rigging and physical barriers might be necessary to prevent contact with live equipment.

Induction current can be a serious problem in a substation. A single ground will drain off static charges. Applying two grounds to a long object can provide a loop for electromagnetic current and add to the problems. Some equipment can also build up a charge due to capacitive coupling with nearby live conductors, even if the equipment is isolated. Refer to Annex A for more information.

Temporary grounds are used to extend the permanent grounded work zone to include bus, lines, cables, and equipment, which are normally energized.

6.5.2 Electrical bonding for static and capacitive coupled voltage

While working on a circuit that is grounded, a person is protected by proper bonding techniques. *Bonding* is the electrical connection between metallic parts or conductors and its purpose is to ensure every metallic part in the work area is solidly connected together to minimize any potential differences.

Bonding is done by interconnecting all metallic segments of electrical equipment that a person can touch as well as the vehicles, scaffolds, etc., that are part of a common ground grid.

6.5.3 Transport and work equipment

Vehicles utilizing any type of aerial equipment in the vicinity of energized conductors or apparatus should be grounded. The vehicle ground should be connected to the grounding system first and the vehicle last. In cases where vehicles are carrying combustible materials, the order of attachment should be reversed to minimize possible sparking at the vehicle.

Grounding the vehicle provides for quick clearing of the circuit if the vehicle becomes energized, thus reducing the time or exposure of persons in the work area to the electrical hazard.

External to the substation, protection to personnel is provided by ensuring that people on the ground do not contact the vehicle or equipment when it is being used in the vicinity of energized conductors or apparatus. If, however, the vehicle is within the substation grid and the grid is properly designed, touching the vehicle should be no worse than touching any other grounded structure or equipment during a fault, though the probability of an inadvertent energization of the vehicle would be higher.

No person[6] standing on the ground should be in contact with a vehicle or an attached trailer while the boom aerial device is being moved in the vicinity of energized conductors or apparatus. When it is necessary to operate the controls at ground or vehicle level, the operator should be protected by one of the following methods:

a) Stand on a metal operator's platform installed for this specific purpose.
b) Stand on the deck of the vehicle.
c) Stand on a portable conductive mat electrically attached to the grounded vehicle.

[6]Persons, other than the operator, should not approach or contact the vehicle or operator while the controls are being operated.

6.5.4 Arc welders

The ground (work) lead of electric arc welders should be connected to the piece being welded at a point close to the weld location. The ground lead clamp should make a good electrical connection with the work. Both the ground lead and the electrode lead shall be properly insulated and should follow the same route to the work area.

Care should be exercised in placing the ground lead so as to avoid including a transformer or CT winding in the weld circuit because a hazardous voltage can be induced in another winding. The fact that some welding equipment operates on dc does not eliminate the hazard, because the voltage is induced when the electrode makes or breaks the circuit. Caution must also be exercised in attaching leads near capacitor banks so as to avoid forming a circuit that will charge the capacitors to a hazardous voltage.

7. Static, capacitive coupled, and electromagnetically coupled voltage protection

This clause serves as a guide to help alleviate the adverse effects of discharges between equipment or structures and personnel due to static, capacitive coupled, and electromagnetically coupled voltages in substations when a worker becomes isolated from the ground (i.e., working aloft, wearing insulated boots, etc.).

The purpose of protective equipment against static, capacitive coupled, and electromagnetically coupled voltages is to bring the worker and work surface to the same electrical potential and keep them at the same potential throughout the job.

This clause does not constitute a recommendation, but only suggests a method to alleviate the adverse effects of discharges due to static, capacitive coupled, and electromagnetically coupled voltages. Many utilities might not be affected by this phenomenon.

7.1 Protective garments

Protective garments can include conductive jackets, undershirts, shirts, trousers, boots, and gloves worn separately or in any combination as deemed necessary to mitigate the adverse affects of voltage discharges.

The fingers of conductive gloves can be cut off to improve dexterity of the worker.

7.2 Attachments

Attachments to a grounded steel structure or other grounded devices can be made with conductive straps using magnets or clamps for attaching to the grounded structure. The other end of the conductive strap is connected to the worker's conductive garments. A 2 m long conductive strap is suggested as an optimum manageable length.

8. Testing

8.1 New TPG component and assembly testing

The TPG assemblies or components should be tested in accordance with IEC 61230-1993, or with a peak asymmetrical current of 2.5 times the rms value if tested in accordance with ASTM F855-1997.

8.2 In-service inspection, maintenance, and testing of TPGs

8.2.1 Visual inspection

Make a close visual examination of the complete assembly.

a) Check for the presence of broken strands, especially near the cable termination.
b) Check for damaged or burned jacket material.
c) Check for damaged cable terminations.
d) Check the clamps for sharp edges, cracks, splits, or other defects.
e) Replace soldered ferrules with compression or exothermic connections. If any defects are found, either repair or replace the assembly (remove from service), as appropriate.

8.2.2 Operation check

Examine the individual components:

a) Verify that the clamps operate smoothly and are free of excessive looseness.
b) Clean the clamp jaws, eye-screws, and T-handle screws of dirt, oil, grease, and/or any corrosion.
c) Ensure that the interface connection between the cable termination and clamp is clean.
d) Verify that the cable termination is tight to the clamp body.

8.2.3 Periodic testing of TPGs

Experience has shown that TPGs can be damaged by rough usage or corrosion. Both visual and electrical tests should be performed.

8.2.3.1 Visual test

The ability of the welded or compression cable termination to sustain electromechanical force has been well demonstrated. The direct clamping of a conductor to the ground clamp might be satisfactory when new, but mechanical stresses on the conductor during its service life appear to degrade it substantially. A thorough visual inspection is essential in the review of a TPG quality. Evidence of broken strands or corrosion within the cable termination or the cable are signs of this degradation and require further investigation.

8.2.3.2 Electrical test

An electrical test provides a means of monitoring continuity and changes in the electrical properties of a TPG. The electrical test should be performed on a TPG when it is new and at intervals thereafter. Differences in the electrical properties of the TPG would be an indication of the changing condition of the TPG. The test can be performed with dc or ac. Equipment is commercially available to perform an electrical test on a TPG cable assembly.

8.2.3.2.1 Direct current test

A dc in the range 10–25 A is passed through the complete TPG cable assembly. The direct current resistance of the TPG cable assembly is the voltage across the assembly divided by the current. The dc test is not sensitive to placement or surroundings of the TPG cable assembly being tested and, therefore, tends to be more repeatable than the ac test.

8.2.3.2.2 Alternating current test

An ac is passed through the TPG cable assembly. Typically, the current magnitude is several hundred amperes. However, some procedures suggest using a current 10–20% of the ultimate current capability of the cable. The current is normally applied for less than 1 s. The TPG cable assembly impedance is calculated by dividing the measured voltage across the TPG by the test current. AC tests are sensitive to the physical arrangement of the TPG and to the proximity of magnetic materials.

8.2.3.3 Testing and maintenance intervals

Testing and maintenance intervals should depend on applicable codes, exposure, manner of use, individual company policy, and operating procedures.

Annex A

(informative)

Terminology

A.1 Voltages and currents at the worksite

A.1.1 System voltage

System voltage refers to the bus or phase voltage and is generally specified in kilovolts (kV), phase-to-phase.

A.1.2 Static voltage

Static voltage is voltage buildup on metallic objects (steel structures, bus conductors, etc.) due to wind friction, dry conduction, or dust, as illustrated in Figure A.1. Generally, static voltage buildup is less severe than the other worksite voltages that can exist.

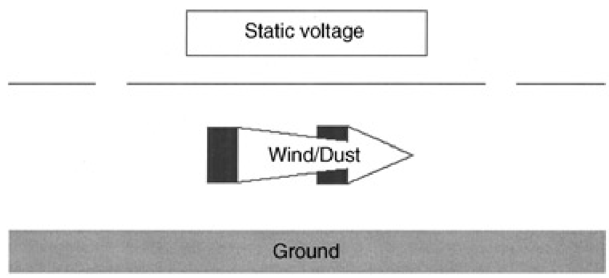


Figure A.1—Static voltage

A.1.3 Capacitive coupled voltage

Capacitive coupled voltages typically exist on an isolated object in an electric field from an energized circuit as shown in Figure A.2. The isolated object can be a de-energized bus, a metallic structure, or part of equipment, or a person on an insulated platform.

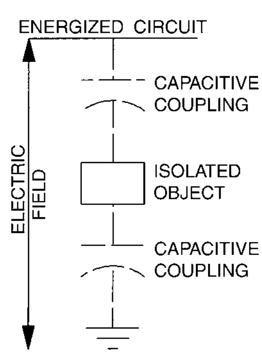


Figure A.2—Capacitive coupled voltage—equivalent circuit

Figure A.3 is more representative of the electrical circuit associated with capacitive coupled voltages. Figure A.3 represents one phase of an energized ac circuit with its ground return, and the section between the open switches represents one phase of an ac circuit that has been switched out of service.

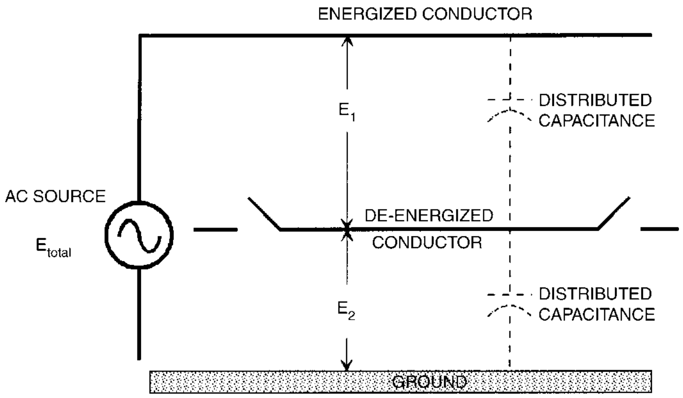


Figure A.3—Capacitive coupled voltage—circuit components

When an object comes into contact with the de-energized conductor, the circuit is as shown in Figure A.4.

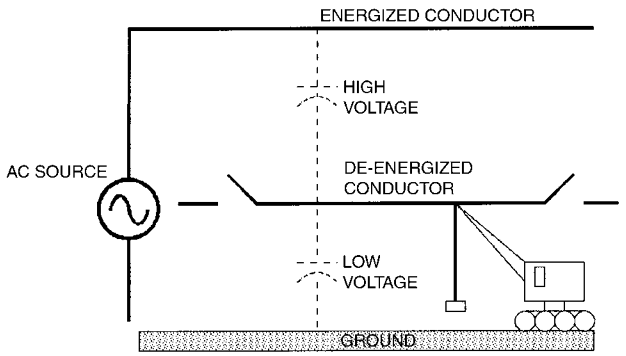


Figure A.4—Case of contact with de-energized conductor

When contact is first made with the conductor, the voltage is high. The capacitor will "discharge" into the object. As long as the stored energy is not very large and the final current is low, the final voltage will be very low. However, if there is a large amount of stored energy, such as a de-energized (switched out) transmission line or substation operating bus parallel to an energized transmission line or bus, the available discharge current can be high and extremely dangerous. A single ground placed on the de-energized conductor will effectively discharge the static and capacitive coupled voltages.

A.1.4 Electromagnetically coupled voltage

Electromagnetically induced voltage is similar to the action that occurs in a transformer. When the primary winding is energized, the resulting current flow induces a voltage in the secondary winding. The same phenomenon occurs when an energized conductor (primary winding) carrying current is adjacent to a de-energized (switched out) conductor (secondary winding). In this case, the transformer has an air core instead of an iron core. A voltage is thus developed at point B. This circuit is illustrated in Figure A.5. Both ends of the de-energized conductor should be grounded to minimize the potential difference across the worker in contact with the de-energized conductor, even though this provides a closed loop and allows current to flow in the de-energized conductor.

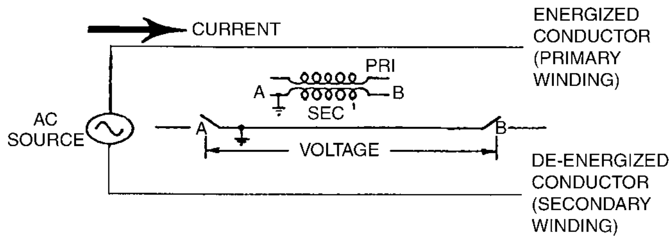


Figure A.5—Electromagnetically coupled voltage

A.1.5 Currents

Under normal circumstances only rated load current is present at an energized worksite. During de-energized maintenance operations, with TPGs in place, available fault currents shall be considered. This fault current will be substantially larger than the steady-state current. In addition, the current asymmetry and its duration should be considered.

The asymmetry is a function of the reactance divided by the resistance (X/R ratio) of the circuit. The result is a nonperiodic, exponentially decaying dc component combined with the ac symmetrical component, as illustrated in Figure A.6 (top graph). The peak current value can be increased to almost

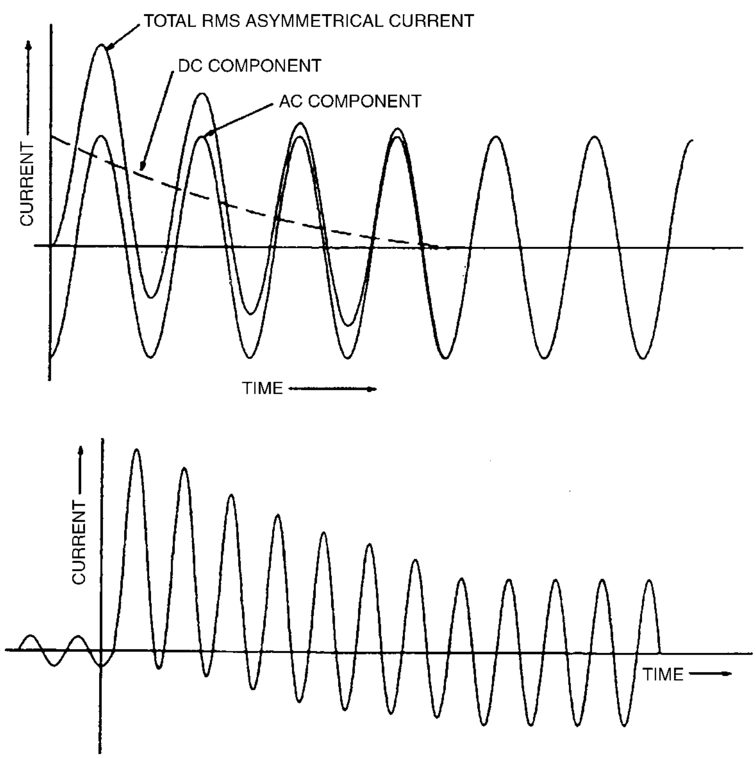


Figure A.6—Asymmetrical fault current components (example)

twice the symmetrical peak value. The asymmetry causes an increase in electromechanical forces, and in the heating of the protective equipment components. The bottom graph of Figure A.6 shows the typical current waveform from an oscillograph.

A.2 Safety criteria

A.2.1 Safe body currents

Humans are highly sensitive to electrical current, primarily because their body nervous system is electrically stimulated. The magnitude of current that a body can tolerate depends on frequency, duration, and physical condition of the body. It is the consensus of researchers, however, that generally for frequencies above 25 Hz and for a duration of a few seconds, the threshold of perception is 1 mA. A current of 9 to 25 mA makes it difficult for a person to release their grip from a power circuit, and at 30 mA muscular contractions can make breathing difficult. At higher currents, a person's heart can cease to function (ventricular fibrillation). See IEEE Std 80™-2000 [B3] for more information concerning body currents.

As previously stated, the magnitude of current a body can tolerate depends to a great extent on the duration of the shock. Researchers have concluded that 99.5% of all persons could withstand, without ventricular fibrillation, currents with a magnitude determined by Equation (1) or Equation (2):

$$I_B = \frac{0.116}{\sqrt{t_s}} \quad \text{for a 50 kg (110 lb) body} \tag{1}$$

or

$$I_B = \frac{0.157}{\sqrt{t_s}} \quad \text{for a 70 kg (155 lb) body} \tag{2}$$

where

I_B is the rms magnitude of body current (A),
t_s is the duration of current exposure (s).

Generally, Equation (1) is used for a more conservative approach. However, one may use Equation (2) provided that the average population weight can be expected to be at least 70 kg (155 lb).

Equation (1) and Equation (2) also indicate that much higher body currents can be allowed where fast operating protective devices can be relied on to limit fault durations.

A.2.2 Shock hazards

A.2.2.1 Touch voltage

The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing, while at the same time having a hand in contact with a grounded structure. (See Figure A.7.)

A.2.2.2 Step voltage

The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without contacting any grounded object. (See Figure A.7.)

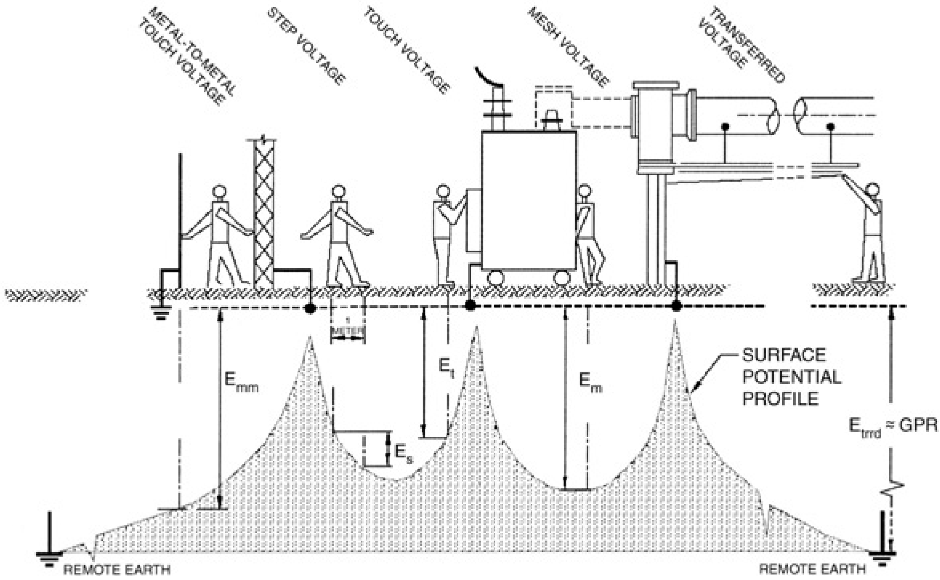


Figure A.7—Basic shock situations

A.2.2.3 Transferred voltage

A special case of touch voltage where a voltage is transferred into or out of the substation from or to a remote point external to the substation site. (See Figure A.7.)

A.2.2.4 Mesh voltage

The maximum touch voltage within a mesh of a ground grid.

A.2.2.5 Metal-to-metal touch voltage

The difference in potential between metallic objects or structures within the substation site that might be bridged by direct hand-to-hand or hand-to-feet contact.

Annex B

(informative)

Bibliography

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[B3] IEEE Std 80-2000, IEEE Guide for Safety in AC Substation Grounding.[8]

[B4] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

[B5] IEEE Std 1584-2002, IEEE Guide for Performing Arc-flash Hazard Calculations.

[B6] Reichman, J., Vainberg, M., and Kuffel, J., ''Short-circuit capacity of temporary grounding cables,'' *Transactions on Power Delivery*, vol. 4, no. 1, pp. 260–271, Jan. 1989.

For further reading

[B7] ASTM B172-2001, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members for Electrical Conductors.

[B8] ASTM B173-2001, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members for Electrical Conductors.

[B9] ICEA S-19-81/NEMA WC 3-1992, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.[9]

[B10] IEC 60068-2-42-1982, Environmental Testing—Part 2: Tests. Test Kc: Sulfur Dioxide Test for Contacts and Connections.

[B11] IEC 60479-1-1994, Effects of Current on Human Beings and Livestock—Part 1: General Aspects.

[B12] IEC 60479-2-1987, Effects of Current Passing Through the Human Body—Part 2: Special Aspects.

[7]IEC 60502-1994 has been withdrawn; however, copies can be obtained from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://www.global.ihs.com).

[8]IEEE standards or products referred to in Annex B are trademarks owned by the Institute of Electrical and Electronics Engineers, Inc.

[9]ICEA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://www.global.ihs.com/).

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[B15] IEEE Std C37.09™-1999, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

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