

IEEE Guide for Temporary Protective Grounding Systems Used in Substations

IEEE Power & Energy Society

Sponsored by the
Substations Committee



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IEEE Guide for Temporary Protective Grounding Systems Used in Substations

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of the

IEEE Power & Energy Society

Approved 31 October 2011

IEEE-SA Standards Board

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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, IEEE 1246, personnel safety, protective grounding, safety, temporary grounding, ultimate rating, withstand rating

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Introduction

This introduction is not part of IEEE Std 1246-2011, IEEE Guide for Temporary Protective Grounding Systems Used in Substations.

Practices for applying temporary protective grounds (TPGs) in substations vary from company to company. These practices have come from a number of documents such as ASTM F855,^a IEC 61230, and IEEE Std 1048™-1990 [B15],^b 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 company 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 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, to successfully handle these high short-circuit currents. It also introduces a new method for determining the TPG impedance (length and cable size) for use in determining the current through the worker for an accidental energization.

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^a Information on references can be found in Clause 2.

^b The numbers in brackets correspond to those of the bibliography in Annex A.

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1. Overview

1.1 Scope

This guide covers the design, performance, use, testing, and installation of temporary protective grounding (TPG) 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. Normative 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~~

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

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

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

ASTM F2249, Standard Specification for In-Service Test Methods for Temporary Grounding Jumper Assemblies used on De-Energized Electric Power Lines and Equipment.

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

IEC 61230-~~1993~~, Live Working—Portable Equipment for Earthing or Earthing and Short-Circuiting. IEEE Std ~~1048-1990~~ 80™, IEEE Guide for ~~Protective Grounding of Power Lines~~ Safety in AC Substation Grounding.^{3,4}

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards [Dictionary: Glossary of Terms & Definitions](#)* should be consulted for terms not defined in this clause.⁵

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.

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.

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.

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.

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.

multipoint grounding: The application of temporary protective grounds (TPGs) on either side of the worksite plus TPGs at the worksite. See also: bracket grounding; worksite (single-point) grounding.

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 temporary protective ground (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.

¹ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, 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.

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⁵ The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.

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

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

source grounding: The location of temporary protective grounds (TPGs) so that a set of temporary protective grounds is between the worksite and all possible sources of current.

temporary protective ground (TPG) equipment: Devices to limit the voltage difference between any two accessible points at the worksite to [an appropriate](#) value for safety, and with sufficient current withstand rating. These ~~might~~ [typically](#) consist of cable assemblies, grounding switches, or temporarily installed bars.

ultimate rating (capacity): A calculated maximum symmetrical current that a temporary protective ground cable is capable of carrying for a specified time without fusing or melting. [When temporary protective ground \(TPG\) assemblies are exposed to currents that are close to the ultimate rating of the cable, they](#) ~~The TPGs are generally rated by this value. A TPG subjected to this current~~ might be damaged ~~and should not be reused.~~ [Some companies replace TPGs subjected to any known current from an accidental energization.](#)

~~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.~~

worksite (single-point) grounding: The application of temporary protective grounds only in the immediate vicinity of an electrically continuous worksite. The location of the temporary protective grounds (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 can be properly sized and assembled to protect personnel from injury during a steady state or abnormal power system operation. This is accomplished by creating a short circuit (using the TPGs) to deenergize the circuit as soon as possible while minimizing the exposure voltage at the worker.

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~~ short-circuit current are critical factors in sizing TPGs. The protective ground is sized to conduct the maximum available short-circuit current at the short-circuit location without failure for the duration of the short circuit.

4.3.1 Current magnitude including direct current (dc) offset

The current magnitude is one of the critical factors to be considered when sizing temporary protective grounding systems. The short-circuit current consists of a root-mean-square (rms) alternating current (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 dcoffset component is determined by the X/R ratio at the short-circuit location looking back into the power system and the time of short-circuit 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 symmetrical current-carrying capability for the six-cycle rating is reduced ~~about~~ approximately 28% when the X/R ratio is changed from $X/R = 40$ to $X/R = 0$ as shown in Table 2 and Table 5, respectively.

At or near large generating plants and transmission substations, a large X/R ratio is likely because the impedance of generators and transformers contains very little resistance. Whereas 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 substation, 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, whereas 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. Whereas 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 short circuit clears. IEC 61230-1993 requires temporary grounding (earthing) devices to withstand a peak asymmetrical current of 2.56 times the rms current value for 60 Hz systems above 1 kV.

4.3.2 Short-circuit duration including primary and backup relaying

The short-circuit duration is another critical factor to consider when sizing protective grounds. The short-circuit duration is the time required to clear the short circuit by primary or backup relaying. The short-circuit clearing time is the sum of relay and breaker operation times. Primary relaying is the first line of defense to clear a short circuit at high speed. ~~Even though~~ Utilizing the primary relay short-circuit clearing time minimizes the grounding cable size, ~~the reliability of~~; however, before relying on the primary relay operation ~~should be evaluated if this is considered for sizing the protective ground.~~ to size the protective grounds, consider the reliability of the relays. Many circuits are protected by slower clearing fuses that can take many cycles or even seconds to interrupt the current.

Backup protection is provided for possible failure in the primary protection 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 protection, short circuits are cleared from the system, one substation away from where the short circuit has occurred. In local backup protection, short circuits are cleared locally in the same substation where the short circuit has occurred. Local backup protection will clear the short circuit from the system in less time than that provided by remote backup protection. Utilizing the backup protection, short-circuit clearing time provides a conservatively sized protective ground. If more than one relay operates to clear a short circuit on the system, the total time required for ~~a specific number of relay contact operations to clear a fault can be chosen as~~ the last relay to operate determines the backup clearing time. For example, local breaker failure can add from 8 to 12 cycles to the primary clearing time. Zone 2 or remote backup relaying can add from 12 to 24 cycles to the primary clearing time. Backup protection from fuses can add seconds to the primary clearing time. s listed in Table 1 ~~for 4-765-kV systems~~ gives example ranges of clearing times for different protection schemes. Each company evaluates the primary and backup relay short-circuit clearing times on their power system and determines the short-circuit clearing time to use for sizing the protective ground.

Table 1.—Typical fault clearing times for various ~~system voltages~~ substation bus protection schemes

~~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~~		

<u>Bus protection scheme type</u>	<u>Typical clearing time (cycles)</u>
<u>Busses with differential protection</u>	<u>2–8</u>
<u>Busses without differential protection</u>	<u>12–60</u>
<u>Busses cleared remotely</u>	<u>20–90</u>
<u>Busses with fused primary protection</u>	<u>60–300</u>

4.3.3 Circuit breaker reclosure considerations

Tests (EPRI EL-5258-[1987](#) [B4]) have indicated that the cooling of TPGs between reclosures is insignificant. If the reclosing scheme is not disabled, [then](#) the additional short-circuit duration after reclosure(s) can 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 is not [to](#) be considered as maintaining continuity for the purpose of personnel safety. Such devices include transformers, fuses, reactors, resistors, circuit breakers, [disconnect switches](#), 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 are used when planning installation of TPGs on major equipment in substations.

4.4.2 Main power transformers

The following can be considered when applying TPGs:

- a) The turn 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, hose, filtering equipment, and pumping equipment can be bonded together with the transformer tank being filled [to minimize electric potentials on the equipment](#). 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.
- [d\) Ground all terminals \(windings\).](#)

4.4.3 Circuit breakers and circuit switchers

The TPG assemblies are applied on both sides of the device when maintaining circuit breakers, circuit switchers, or other devices that can have a circuit disconnection not visible to the worker. Consider the following:

- 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 transformer

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~~ Opening secondary disconnect switches and removing fuses minimizes the hazards from secondary backfeed.

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 deenergized capacitor bank can be fully discharged by the application of a grounded short circuit across its terminal. ~~In a Where two or more capacitor units are connected in series, each bank comprised of two or more~~ parallel groups of series strings of units, each series group that is within reach ~~should be shorted and grounded~~ can have a TPG connected across the entire string, and each individual unit of a series string that is within reach can be shorted by temporarily touching a wire across the unit terminals to provide full discharge. Similarly, in a capacitor bank composed of two or more series groups of parallel units, each parallel group that is within reach can have a TPG installed across the parallel group, and each unit that is within reach can be shorted by temporarily touching a wire across the unit terminals or from a single terminal to ground to provide 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 the power cable, apply TPGs ~~should be applied at terminations~~ at each end of the power cable [to dissipate capacitive energy](#).

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. [TPG cable assemblies are appropriately sized and configured to survive the available short-circuit current exposure.](#) Refer to Table [1 and Table 2 in ASTM F855 \(2009 or later\)](#) for selecting the appropriate TPG cable assemblies based on the short-circuit clearing time, available short-circuit current, [and X/R ratio](#) for thermal ~~considerations~~, and ~~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 the following:

- a) Ground end. The ground end consists of a clamp (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. T-handled clamps [can have difficulty achieving the required torque for certain types of clamps \(especially flat-faced clamps\).](#)
- 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 deenergized conductor, a bus, an attachment stud, a cable termination, and (possibly) heat-shrinkable tubing to seal exposed cable strands.

[Multiple manufacturers make specific](#) TPG assemblies and [components. For more details, refer to the manufacturer’s literature and 4.7.1.](#)

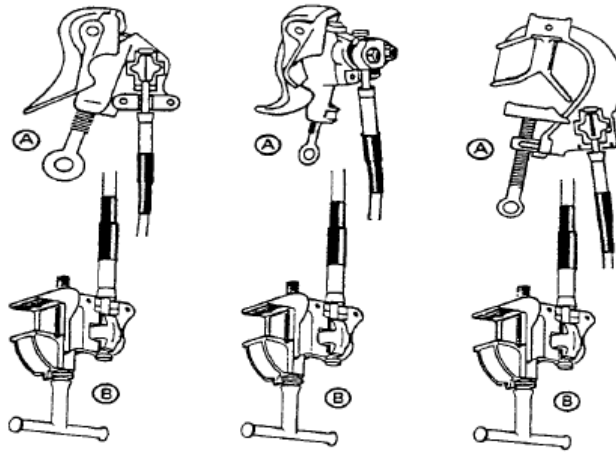


Figure 1a)—Typical TPG assemblies

NOTES

A—Bus (conductor) end.
B—Ground end.

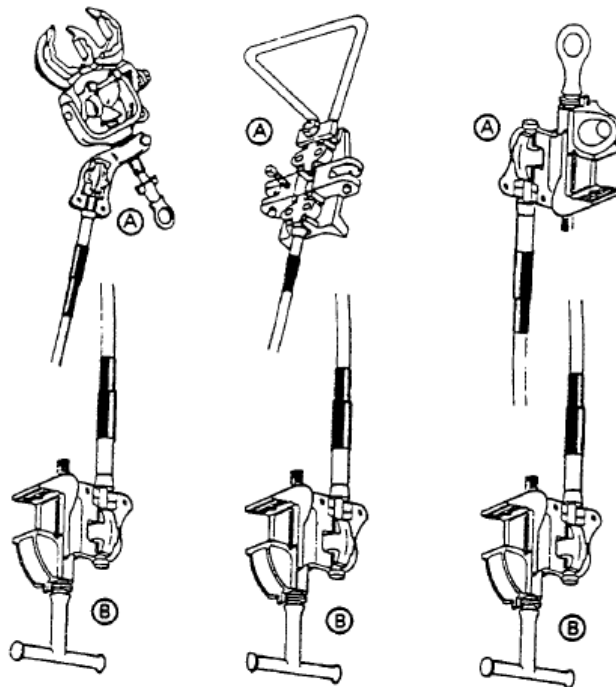


Figure 1b)—Typical TPG assemblies

NOTES

A—Bus (conductor) end.
B—Ground end.

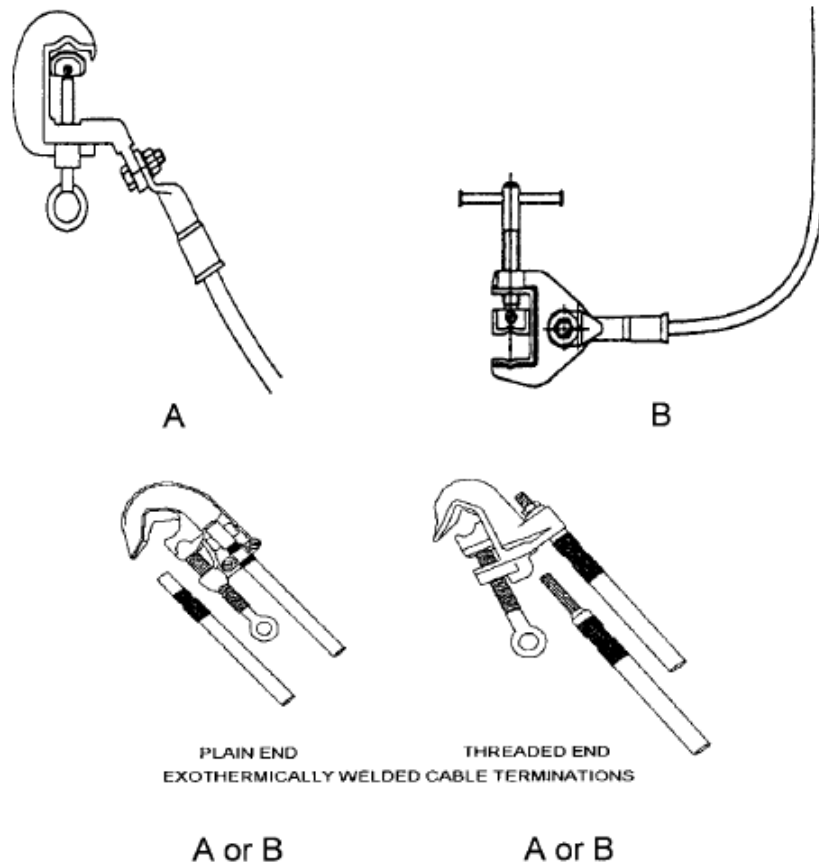


Figure 1c)—Typical TPG assemblies

NOTES

A—Bus (conductor) end.
B—Ground end.

4.6 TPG cable

4.6.1 Conductor material

~~Annealed~~ Fine-stranded copper conductors are used for temporary protective ground cables. ~~The strands can be plain or tinned.~~(See 4.6.4.) The diameters of the strands are generally specified by the manufacturer or by the appropriate standard. Inspection and testing ensures compliance with the cable material requirements. Check the electrical resistance of the conductors at 20 °C by the test given in IEC 60227- 2 [B8] and IEC 60245-2-1997 [B9].

4.6.2 Sizing ~~of~~ protective ground cables

The ~~withstand~~ rating of the cable ~~should be considered when~~ is a key component of sizing the TPG cable assembly. ~~The dc offset~~ For cables rated for low 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~~ asymmetry, ASTM F855 defines grades 1 to 7 based on a ~~fault~~ withstand rating that is 70% to 80% of the ultimate capacity. ASTM F855 defines ratings for grades 1H to 7H for high current asymmetry applications based on a percentage of the cable's ultimate capacity. IEC 61230 only describes test procedures, with the test assembly being rated at the tested current value (i.e., it does not refer to either the ultimate or the withstand rating of the cable).

When selecting a cable for high current asymmetry, the dc offset current should be considered as it considerably reduces the capacity of cables for short durations. For added safety, some companies use the ultimate capacity and replace the assembly after exposure to an accidental energization. Table 2 through Table 5 list the ultimate equivalent symmetrical current-carrying capability of cables 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~~ Sizing TPG cable assemblies based on cable ampacity alone may result in unexpected failures. Refer to 4.5 for a discussion of proper TPG assembly sizing.

Table 2—Ultimate equivalent symmetrical 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 or kcmil)	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 3—Ultimate equivalent symmetrical 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 <u>or</u> <u>kcmil</u>)	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	126.65	95	67	50	41	36	21
350	177.36	134	94	70	58	50	29

Table 4—Ultimate equivalent symmetrical 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 or kcmil)	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	126.65	105	71	51	42	36	21
350	177.36	147	99	72	59	51	30

Table 5—Ultimate equivalent symmetrical 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 or kcmil)	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	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	126.65	117	74	52	43	37	21
350	177.36	165	104	73	60	52	30

NOTE 1—The current values in Table 2 through Table 5 were calculated from the computer program RTGC (Reichman et al. [B19]). This computer program can be used directly to determine the grounding cable size requirements for a known X/R ratio and short-circuit clearing time.

NOTE 2—Angle of current initiation = 90° (maximum dc offset). Initial conductor temperature = 40 °C; final conductor temperature = 1083 °C.

NOTE 3—These current values ~~reflect~~consider the cable thermal limits only and do not consider 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.

NOTE 4—For derating of multiple cables, refer to 4.8.3.

NOTE 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 might 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 with the following references verifies the [mechanical strength and elasticity](#) of each type of jacketing material:

↓ IEC 60502-1994 [B12] for EPR or a similar compound. Additionally, the cables covered by this type of compound are subject to a bending or elongation test at 50 °C.

↓ IEC 60227-1 [B8] 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 is normally applied closely ~~applied~~ to the conductor with a separator, if any. It should be possible to remove the jacket without damaging the strands. This may be checked by visual inspection.

The jackets are available in several colors. The typical colors [available](#) 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 a visual inspection of the conductor. PVC (thermoplastic) jackets can become opaque and brittle over time.

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 [the](#) 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 the manufacturer, flexible for installation and serviceable for continuous use within the temperature range $-40\text{ }^{\circ}\text{C}$ to $+90\text{ }^{\circ}\text{C}$.

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 the manufacturer, flexible for installation and serviceable for continuous use within the temperature range $-25\text{ }^{\circ}\text{C}$ to $+90\text{ }^{\circ}\text{C}$.

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 [the](#) manufacturer, flexible for installation and serviceable for continuous use within the temperature range $-10\text{ }^{\circ}\text{C}$ to $+60\text{ }^{\circ}\text{C}$.

The use of type III cables is sometimes restricted to open areas or spaces with adequate ventilation so that any fumes produced by overheating can be dispersed.

4.7 Clamps

Clamps are rated for [the](#) maximum available short-circuit current, [including asymmetry](#) and duration, to which they can be subjected [without exceeding service requirements](#). The clamp and conductor assembly should be capable of carrying the available short-circuit current for the specific time without damage or separation from the phase conductor or ground point.