



# IEEE Guide for Temporary Protective Grounding Systems Used in Substations

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Developed by the  
Substations Committee

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# IEEE Guide for Temporary Protective Grounding Systems Used in Substations

Developed by the

**Substations Committee**  
of the  
**IEEE Power and Energy Society**

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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 1246-2025, 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, IEC 61230, and IEEE Std 1048™, as well as from field experience derived from line maintenance practices.<sup>6</sup> 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 a 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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<sup>6</sup> Information on references can be found in [Clause 2](#).

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# 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 (TPG) systems, including the connection points, as used in permanent and mobile substations.

### 1.2 Purpose

This guide provides technical information and suggests good practices 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.

### 1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).<sup>7,8</sup>

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

<sup>7</sup> The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

<sup>8</sup> The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

## 2. Normative references

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, Standard Specifications for Temporary Protective Grounds to be used on De-Energized Electric Power Lines and Equipment.<sup>9</sup>

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

IEC 61230, Live Working—Portable Equipment for earthing or earthing and short-circuiting.<sup>10</sup>

IEEE Std 80™, IEEE Guide for Safety in AC Substation Grounding.<sup>11,12</sup>

IEEE Std 1048™, IEEE Guide for Protective Grounding of Power Lines.

## 3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.<sup>13</sup>

**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 cables or bar assemblies, with multiple clamps to connect to a phase or ground, 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 change cannot be considered as maintaining continuity. Examples include transformers, fuses, reactors, resistors, circuit breakers, and line traps.

**equipotential zone (for protective grounding) (EPZ):** The state of maintaining a near identical electrical potential between two or more items.

**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 all sides of the worksite, plus TPGs at the worksite.

**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) 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.

<sup>9</sup>ASTM publications are available from the American Society for Testing and Materials, <http://www.astm.org/>.

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**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 identified sources of current.

**temporary protective ground equipment (TPG):** Devices to limit the voltage difference between any two accessible points at the worksite to an appropriate value for safety, and having sufficient current withstand rating. These 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 might be damaged.

**worksite (single-point) grounding:** The application of temporary protective grounds only in the immediate vicinity of an electrically continuous worksite. In order to be effective, the location of the temporary protective grounds (TPGs) must be close enough to the worksite and connected in a manner to minimize the potentials in the vicinity of the worker.

## 4. Considerations for temporary protective grounding systems

### 4.1 General TPG

TPG equipment is used when grounding a substation power bus and equipment to protect personnel from high voltages and/or currents that can be induced or applied because of equipment failure or operating error. A properly sized and assembled TPG can protect personnel from injury during a steady-state or abnormal power system operation. This is accomplished by creating a short-circuit (using the TPGs) resulting in the protective devices operating to de-energize the circuit as soon as possible, while also minimizing the exposure voltage at the worker. For grounding practices when working on transmission and distribution lines outside the substation see IEEE Std 1048.

### 4.2 Permanent or mobile substations

TPG assemblies are applicable for both mobile and permanent substations.

### 4.3 Current magnitude and duration

The current magnitude and duration of the short-circuit current are critical factors in sizing TPGs. A properly sized and assembled TPG can protect personnel from injury during a steady-state or abnormal power system operation.

#### 4.3.1 Current magnitude including dc offset

The current magnitude is one of the critical factors to be considered when sizing TPG systems. The short-circuit current consists of an rms ac component and a dc offset 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 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 (15 to 60 cycles) fusing current ratings of grounding cables calculated using Onderdonk's equation as considered in ASTM F855 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 15-cycle rating is reduced approximately 20% when the  $X/R$  ratio is changed from  $X/R = 0$  to  $X/R = 40$  as shown in Table 5 and Table 2, 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 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 are 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. The current peaks increase with higher  $X/R$  ratios and the rate of decay reduces with higher  $X/R$  ratios. 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.

#### 4.3.2 Short-circuit duration including primary and backup relaying

The short-circuit duration is another critical factor to be considered 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 short-circuit current at high speed.

Backup protection is provided for possible failure in the primary protection system, the circuit breaker, or other protective devices. Remote backup and local backup are two forms of backup protection commonly used in 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. 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 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. Table 1 gives example ranges of clearing times for different protection schemes.<sup>14</sup> 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. Each company also evaluates any activities, such as relay or breaker maintenance, that may take place while the TPG are installed to help ensure the proper operation of protection scheme and that appropriate short-circuit clearing time is maintained.

**Table 1—Typical fault clearing times for various substation bus protection schemes**

| Bus protection scheme type                                           | Typical clearing time (cycles) |
|----------------------------------------------------------------------|--------------------------------|
| Buses with differential protection                                   | 2–8                            |
| Buses without differential protection                                | 12–60                          |
| Buses cleared remotely                                               | 20–90                          |
| Buses with fused primary protection                                  | 60–300                         |
| NOTE—These values are typical and do not apply to all power systems. |                                |

<sup>14</sup> Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard

Utilizing the primary relay clearing time reduces the grounding cable size; however, before relying on the primary relay operation 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.

### 4.3.3 Circuit Breaker Re-closer Considerations

Tests (EPRI EL-5258 [B7]) have indicated that the cooling of TPGs between re-closures is insignificant.<sup>15</sup> If the re-closing scheme is not disabled, the additional short-circuit duration after re-closure(s) should be included in the total time used to size the TPG.

## 4.4 Special areas of concern

### 4.4.1 General

For TPGs to provide proper protection, continuity must be maintained between the point of connection and the work location. Any device capable of transforming voltage or producing a voltage drop or increase should not 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.

Subclauses 4.4.2 through 4.4.7 are used when planning installation of TPGs on major equipment in substations.

### 4.4.2 Main power transformers

Considerations when applying TPGs are as follows:

- 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. Isolation and grounding are common practices to address these hazards.
- b) During oil handling, the oil storage tank, the hose, the filtering, and pumping equipment can be bonded together with the transformer tank being filled to reduce electric potentials on the equipment. Not only can the hose pick up an induced current, but the oil flowing in the hose can build up a static charge, unless measures are in place to limit the voltage gradient in the oil.

### 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. Consider the shorting of circuit breaker bushing CT secondary leads.

### 4.4.4 Instrument and station service transformers

Instrument transformers (CT, VT, and CCVTs) and station 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. 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 de-energized capacitor bank can be fully discharged by the application of a grounded short-circuit across its terminal. In a capacitor bank composed of two or more parallel groups of series strings of units, each series group can have a TPG connected across the entire string, and each individual

<sup>15</sup>The numbers in brackets correspond to those of the bibliography in Annex A.

unit of a series string can be shorted by temporarily touching a wire across the unit terminals to provide full discharge. Similarly, in a capacitor bank comprised of two or more series groups of parallel units, each parallel group can have a TPG installed across the parallel group, and each individual unit 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

Before cutting the power cable, apply TPGs at each end of the power cable to dissipate capacitive energy. To assist in grounding, TPG attachment points may be installed at both ends of the cable in a fashion where the TPGs can remain connected to the cable after the phase conductor is disconnected from the terminal.

#### 4.4.7 Remote ground electrodes

Connecting TPGs to a remote ground electrode can significantly increase the exposure voltage at the worksite. This can happen if TPGs are connected to ground rods or a remote substation instead of to the substation ground grid where the work is being performed. When this is done, the exposure voltage can increase to levels as high as the entire ground potential rise of that remote electrode. This is often done while bringing overhead conductors and un-insulated conductors into the substation. Remote earth potentials are also possible when using a crane outside the periphery of the ground grid to perform lifting operations within the substation. If this kind of activity is to be done, an equipotential zone or electrical isolation should be employed to avoid this difference in potential.

### 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 ASTM F855 for selecting the appropriate TPG cable assemblies based on the short-circuit clearing time, available short-circuit current, and  $X/R$  ratio for thermal and electromechanical considerations.

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.
- 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.

There are multiple manufacturers that make specific TPG assemblies and components. For more details, refer to the manufacturer’s literature, 4.6, and 4.7.

### 4.6 TPG cable

#### 4.6.1 Conductor material

Fine stranded copper conductors (as described in 4.6.4) are used for TPG cables. (See 4.6.4.) The diameters of the strands are generally specified by the manufacturer or by the appropriate standard. Inspection and testing helps ensure compliance with the cable material requirements. Check the electrical resistance of the conductors by the test given in IEC 60227-2 [B11] and IEC 63294 [B15].

#### 4.6.2 Sizing protective ground cables

The rating of the cable is a key component of sizing the TPG cable assembly. For cables rated for low current asymmetry, ASTM F855 defines both withstand and ultimate capacity ratings for grades 1 through 7; the current values for the withstand ratings are about 70% to 80% of the ultimate capacity ratings. ASTM F855 defines only ultimate capacity ratings for grades 1H to 7H. 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 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. Table 2, Table 3, Table 4, and 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. Sizing TPG cable assemblies based on cable ampacity alone, rather than the tested rating of the whole assembly, may result in unexpected failures.

**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<br>(AWG or<br>kcmil) | Nominal cross<br>section (mm <sup>2</sup> ) | 15 cycles<br>(250 ms) | 30 cycles<br>(500 ms) | 45 cycles<br>(750 ms) | 60 cycles<br>(1 s) | 180 cycles<br>(3 s) |
|---------------------------------|---------------------------------------------|-----------------------|-----------------------|-----------------------|--------------------|---------------------|
| #2                              | 33.63                                       | 16                    | 12                    | 10                    | 9                  | 5                   |
| #1                              | 42.41                                       | 21                    | 16                    | 13                    | 11                 | 7                   |
| 1/0                             | 53.48                                       | 26                    | 20                    | 17                    | 14                 | 8                   |
| 2/0                             | 67.42                                       | 33                    | 25                    | 21                    | 18                 | 11                  |
| 3/0                             | 85.03                                       | 42                    | 32                    | 27                    | 23                 | 14                  |
| 4/0                             | 107.20                                      | 53                    | 40                    | 34                    | 30                 | 17                  |
| 250                             | 126.65                                      | 62                    | 47                    | 40                    | 35                 | 21                  |
| 350                             | 177.36                                      | 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<br>(AWG or<br>kcmil) | Nominal cross<br>section (mm <sup>2</sup> ) | 15 cycles<br>(250 ms) | 30 cycles<br>(500 ms) | 45 cycles<br>(750 ms) | 60 cycles<br>(1 s) | 180 cycles<br>(3 s) |
|---------------------------------|---------------------------------------------|-----------------------|-----------------------|-----------------------|--------------------|---------------------|
| #2                              | 33.63                                       | 18                    | 13                    | 11                    | 9                  | 5                   |
| #1                              | 42.41                                       | 22                    | 16                    | 13                    | 12                 | 7                   |
| 1/0                             | 53.48                                       | 28                    | 21                    | 17                    | 15                 | 9                   |
| 2/0                             | 67.42                                       | 36                    | 26                    | 22                    | 19                 | 11                  |
| 3/0                             | 85.03                                       | 45                    | 33                    | 27                    | 24                 | 14                  |
| 4/0                             | 107.20                                      | 57                    | 42                    | 35                    | 30                 | 18                  |
| 250                             | 126.65                                      | 67                    | 50                    | 41                    | 36                 | 21                  |
| 350                             | 177.36                                      | 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<br>(AWG or<br>kcmil) | Nominal cross<br>section (mm <sup>2</sup> ) | 15 cycles<br>(250 ms) | 30 cycles<br>(500 ms) | 45 cycles<br>(750 ms) | 60 cycles<br>(1 s) | 180 cycles<br>(3 s) |
|---------------------------------|---------------------------------------------|-----------------------|-----------------------|-----------------------|--------------------|---------------------|
| #2                              | 33.63                                       | 19                    | 13                    | 11                    | 9                  | 5                   |
| #1                              | 42.41                                       | 23                    | 17                    | 14                    | 12                 | 7                   |
| 1/0                             | 53.48                                       | 30                    | 21                    | 17                    | 15                 | 9                   |
| 2/0                             | 67.42                                       | 38                    | 27                    | 22                    | 19                 | 11                  |
| 3/0                             | 85.03                                       | 48                    | 34                    | 28                    | 24                 | 14                  |
| 4/0                             | 107.20                                      | 60                    | 43                    | 36                    | 31                 | 18                  |
| 250                             | 126.65                                      | 71                    | 51                    | 42                    | 36                 | 21                  |
| 350                             | 177.36                                      | 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<br>(AWG or<br>kcmil) | Nominal cross<br>section (mm <sup>2</sup> ) | 15 cycles<br>(250 ms) | 30 cycles<br>(500 ms) | 45 cycles<br>(750 ms) | 60 cycles<br>(1 s) | 180 cycles<br>(3 s) |
|---------------------------------|---------------------------------------------|-----------------------|-----------------------|-----------------------|--------------------|---------------------|
| #2                              | 33.63                                       | 19                    | 14                    | 11                    | 9                  | 5                   |
| #1                              | 42.41                                       | 24                    | 17                    | 14                    | 12                 | 7                   |
| 1/0                             | 53.48                                       | 31                    | 22                    | 18                    | 15                 | 9                   |
| 2/0                             | 67.42                                       | 39                    | 28                    | 22                    | 19                 | 11                  |
| 3/0                             | 85.03                                       | 50                    | 35                    | 28                    | 25                 | 14                  |
| 4/0                             | 107.20                                      | 63                    | 44                    | 36                    | 31                 | 18                  |
| 250                             | 126.65                                      | 74                    | 52                    | 43                    | 37                 | 21                  |
| 350                             | 177.36                                      | 104                   | 73                    | 60                    | 52                 | 30                  |

NOTE 1—This information applies to the cable only, not the entire TPG assembly. TPGs cannot withstand the ultimate rating of the conductor. When rating a TPG assembly all the components need to be evaluated and sufficient margin applied.

NOTE 2—The current values in Table 2 through Table 5 were calculated from the computer program RTGC, Reichman et al. [B23]. This computer program can be used directly to determine the grounding cable size requirements for known  $X/R$  ratio and short-circuit clearing time.

NOTE 3—Angle of current initiation selected for maximum dc offset. Initial conductor temperature = 40 °C; final conductor temperature = 1083 °C, which is the fusing temperature of copper.

NOTE 4—These current values 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 5—For derating of multiple cables, refer to 4.8.3.

NOTE 6—Metric values are soft conversions. Soft conversion is a direct area calculation in metric units from the AWG size.