

1246™

IEEE Guide for Temporary Protective Grounding Systems Used in Substations

IEEE Power Engineering Society

Sponsored by the
Substations Committee



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Substations Committee
of the
IEEE Power Engineering 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, personnel safety, protective grounding, safety, temporary grounding, ultimate rating, withstand rating

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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 1048TM-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.

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^aInformation 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 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

¹ASTM 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/>).

²IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, 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.

³IEEE 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/>).

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⁵The 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.