

IEEE Guide for Temporary Protective Grounding Systems Used in Substations

Sponsor
**Substations Committee
of the
IEEE Power Engineering Society**

Approved 1 August 1997
IEEE Standards Board

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.

Keywords: grounding, personnel safety, protective grounding, safety, temporary grounding, ultimate rating, withstand rating

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA
Copyright © 1997 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 1997 Printed in the United States of America
ISBN 1-55937-954-5

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (508) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

(This introduction is not a part of IEEE Std 1246-1997, 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 F855-96, IEC61230 (1993-09), and IEEE Std 1048-1990, as well as from field experience derived from line maintenance practices. This guide was developed to bring together all the necessary information for the utility to develop sound personnel safety grounding practices in substations. This guide provides information on the physical construction, application, and testing of TPGs as they are used in substations.

This guide was developed by Working Group D9 of the Distribution Substations Subcommittee, which is part of the Substations Committee. At the time of completion, the Working Group had the following membership:

David Lane Garrett, *Chair*
Gary Di Troia, *Secretary*

Hanna E. Abdallah
Al Alexander
Stan J. Arnot
Nelson Barbeito
Thomas M. Barnes
Milton M. Bostic
Larry Bowie
Alan Byrd
John B. Cannon
A. C. Cockerham
Eugene F. Counsel
Carlton J. Daiss
Farid P. Dawalibi
Frank A. Denbrock
William K. Dick
Kevin Eldridge

John A. Farrington
Larry Fisher
Minje P. Ghim
Roland Heinrichs
Richard J. Hellweg
Richard P. Keil
Clayton C. King
Alan Kollar
Donald N. Laird
William Liverant
Maria Ly
Jinxi Ma
William M. Malone
A. P. Sakis Meliopoulos
Jeffrey D. Merryman
James Mumper

Benson P. Ng
James Ted Orrell
S. G. Patel
Sam Perkins
Dennis W. Reisinger
Klaus H. Schilling
Frank C. Shainauskas
Yitzhak “Gingi” Shertok
Gary Simms
Richard E. Singer
Greg J. Steinman
W. Keith Switzer
Baldev Thapar
Mark Vainberg
L. F. Volf, Jr.
R. J. Wehling

The following persons were on the balloting committee:

William J. Ackerman
Stan J. Arnot
A. C. Baker
Michael H. Baker
Nelson Barbeito
George J. Bartok
Burhan Becer
Michael J. Bio
Kenneth L. Black
Charles Blattner
Wayne R. Block
Philip C. Bolin
Steven D. Brown
James C. Burke
Dennis L. Carr
Daniel Charbonnet
Frank Y. Chu

D. Mason Clark
John R. Clayton
Robert Corlew
Richard Cottrell
Eugene F. Counsel
William Daily
John W. Dean
Frank A. Denbrock
W. Bruce Dietzman
Terry Doern
Micheal Dood
Gary R. Engmann
James W. Evans
Ron J. Farquharson
Lenard N. Ferguson
David Lane Garrett
Floyd W. Greenway

Daniel C. Gregory
David L. Harris
R. J. Hellweg
Mike L. Holm
Kenneth Jackson
Gerhard W. Juette
Zlatko Kapelina
Richard P. Keil
D. F. Koenig
Alan E. Kollar
Terry L. Krummery
Donald N. Laird
Lawrence M. Laskowski
Alfred A. Leibold
C. T. Lindeberg
H. Peter Lips
Rusko Matulic

John D. McDonald
A. P. Sakis Meliopoulos
Addul M. Mousa
Philip R. Nannery
R. S. Nowell
Edward V. Olavarria
J. Ted Orrell
James S. Oswald
Shashi G. Patel

Raymond J. Perina
Kjell Pettersson
Walter Prystajecy
J. F. Quinata
Jakob Sabath
Samuel C. Sciacca
Frank C. Shainauskas
Lee H. Smith
Robert C. Sodergren
Bodo Sojka

Robert P. Stewart
W. Keith Switzer
Stanley R. Sykes
John T. Tengdin
Hemchand Thakar
Duane R. Torgerson
Mark Vainberg
L. F. Volf
Tony Watson

When the IEEE Standards Board approved this standard on 1 August 1997, it had the following membership:

Donald C. Loughry, *Chair*
Richard J. Holleman, *Vice Chair*
Andrew G. Salem, *Secretary*

Clyde R. Camp
Stephen L. Diamond
Harold E. Epstein
Donald C. Fleckenstein
Jay Forster*
Thomas F. Garrity
Donald N. Heirman
Jim Isaak
Ben C. Johnson

Lowell Johnson
Robert Kennelly
E. G. "Al" Kiener
Joseph L. Koepfinger*
Stephen R. Lambert
Lawrence V. McCall
L. Bruce McClung
Marco W. Migliaro

Louis-François Pau
Gerald H. Peterson
John W. Pope
Jose R. Ramos
Ronald H. Reimer
Ingo Rüschi
John S. Ryan
Chee Kiow Tan
Howard L. Wolfman

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Satish K. Aggarwal

Alan H. Cookson

Kim Breitfelder, *IEEE Standards Project Editor*

CLAUSE	PAGE
1. Overview	1
1.1 Scope.....	1
1.2 Purpose.....	1
2. References.....	1
3. Definitions.....	2
4. Design of temporary protective grounding systems	2
4.1 General TPG	2
4.2 Permanent or mobile substation.....	2
4.3 Current magnitude and duration	3
4.4 Special areas of concern.....	4
4.5 TPG assemblies.....	5
4.6 TPG cable.....	9
4.7 Clamps	12
4.8 Multiple assemblies.....	14
4.9 Attachment points	15
5. Application.....	16
5.1 General TPG assemblies	16
5.2 Types of TPG systems	16
5.3 Ratings and selections.....	17
5.4 Methods.....	17
6. Installation and removal.....	18
6.1 General procedures	18
6.2 Tools.....	18
6.3 Testing for voltage	19
6.4 Placing and removing TPGs	19
6.5 Equipment grounding.....	20
7. Static, capacitive coupled, and electromagnetically coupled voltage protection.....	21
7.1 Protective garments.....	21
7.2 Attachments	21
8. Testing.....	22
8.1 New TPG component and assembly testing	22
8.2 In-service inspection, maintenance, and testing of TPGs	22
Annex A (informative) Terminology	24
Annex B (informative) Bibliography	30

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

These guidelines are intended to provide the user with acceptable 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 should be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ASTM F855-96, Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment.¹

IEC 60227-1 (1993-02), Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 1: General requirements.²

IEC 60227-2 (1979-01), Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V. Part 2: Test methods.

¹ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

²IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse. 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 60245-2 (1994-07), Rubber insulated cables – Rated voltages up to and including 450/750 V – Part 2: Test methods.

IEC 60502 (1994-08), Extruded solid dielectric insulated power cables for rated voltages from 1 kV up to 30 kV.

IEC 61230 (1993-09), Live working – Portable equipment for earthing or earthing and short-circuiting.

IEEE Std 100-1996, The IEEE Standard Dictionary of Electrical and Electronics Terms.³

IEEE Std 1048-1990, IEEE Guide for Protective Grounding of Power Lines (ANSI).

3. Definitions

Most of these definitions pertain solely to the application of this guide. No further references will be made to any of the definitions, unless necessary for clarity. For additional definitions refer to IEEE Std 100-1996 .

3.1 ground potential rise: The maximum voltage that a station grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth.

3.2 temporary protective ground (TPG): Devices to limit the voltage difference between any two accessible points at the work site to a safe value, and having sufficient withstand rating.

3.3 TPG assembly: A combination of cables, cable terminations, and clamps assembled for use in temporary protective grounding.

3.4 ultimate rating (capacity): A calculated maximum symmetrical current that a TPG is capable of carrying for a specified time without fusing or melting. TPGs are generally rated by this value.

3.5 withstand rating: The current a TPG should conduct for a specified time without being damaged sufficiently to prevent reuse.

4. Design of temporary protective grounding systems

4.1 General TPG

Temporary protective grounds (TPGs) are required when grounding a substation power bus and equipment to protect personnel from high voltages that may be induced or applied because of equipment failure or operating error. The temporary protective grounds 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.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

4.3 Current magnitude and duration

The current magnitude and duration of the fault are critical factors in sizing TPGs. The protective ground must 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 an 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 (6–60 cycles) fusing current ratings of grounding cables calculated using Onderdonk's equation as considered in ASTM F855-96⁴ may not be conservative. The additional heating from the dc current component reduces the cable current carrying capability. The cable current carrying capability for the 6 cycle rating is reduced about 28% when the X/R ratio is changed from 0 to 40 as shown in Tables 2 and 5, 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 ratio 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.

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 will minimize 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 will provide 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 8–12 cycles to the primary clearing time. Second zone or remote backup relaying can add from 12–24 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.

⁴Information on references can be found in Clause 2.

Table 1— Typical fault clearing times for various system voltages

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

4.3.3 Circuit breaker reclosure considerations

Tests [B3]⁵ 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

Subclauses 4.4.2 through 4.4.6 may 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:

- 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 may come from continuity checking instruments, insulation checking apparatus, and electric arc welders.
- Shortening of current transformer (CT) secondary leads, and opening of disconnect switches or removal of fuses located in voltage transformer (VT) secondary leads.
- 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 may the hose pick up an induced current, but the oil flowing in the hose may build up a static charge, unless prevented.

4.4.3 Circuit breakers and circuit switchers

When maintaining circuit breakers, circuit switchers, or other devices that may have a circuit disconnection not visible to the worker, TPG assemblies should be applied on both sides of the device, and as close to the device as possible.

NOTE — Consideration should be given to:

- Shortening of circuit breaker bushing CT secondary leads.

⁵The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex B.

- Applying a TPG assembly between the breaker and its free standing CTs in order to prevent creation of an electrical loop which may 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 back-fed. Back-feeding 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.

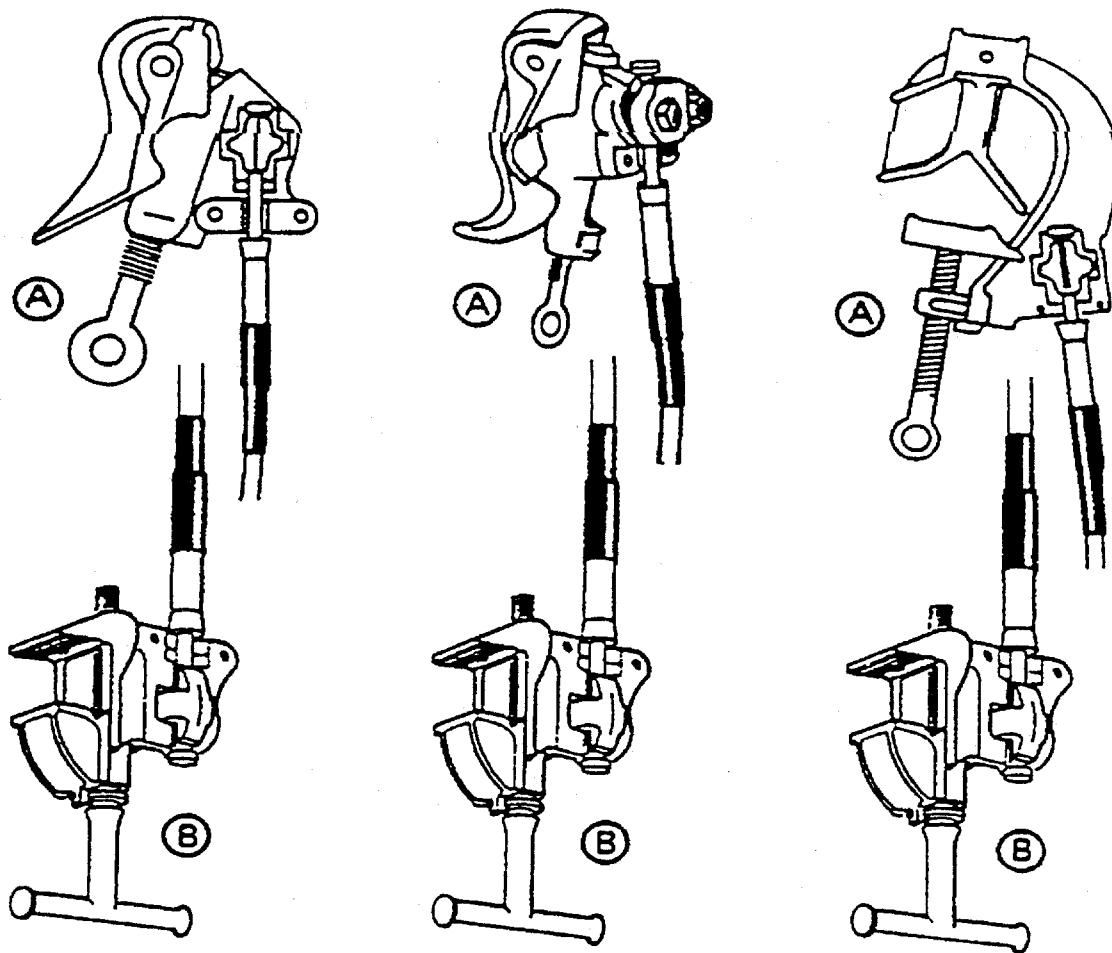
4.5 TPG assemblies

TPG 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 Tables 2–5 for selecting the appropriate TPG assemblies based on the fault clearing time and available fault current.

A TPG assembly consists of the following:

- a) *Ground end.* The ground end consists of a clamp (typically the 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 “eye” for handling and tightening) to be connected with the insulating stick to a de-energized conductor, bus, or to an attachment stud, a cable termination, and possibly heat shrinkable tubing to seal exposed cable strands.

Figure 1 shows various TPG assemblies.



A—Bus (conductor) end
B—Ground end

Source: Hubbell Power Systems

Figure 1— Typical TPG assemblies (Sheet 1 of 3)