

# IEEE Guide for Safety in AC Substation Grounding

IEEE Power and Energy Society

Sponsored by the  
Substations Committee

---

IEEE  
3 Park Avenue  
New York, NY 10016-5997  
© SA

**IEEE Std 80™-2013**  
(Revision of  
IEEE Std 80-2000/  
Incorporates  
IEEE Std 80-2013/Cor 1-2015)

Currently in preview, click buy full version

**IEEE Std 80™-2013**  
(Revision of  
IEEE Std 80-2000/  
Incorporates  
IEEE Std 80-2013/Cor 1-2015)

# **IEEE Guide for Safety in AC Substation Grounding**

Sponsor

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

Approved 11 December 2013

**IEEE-SA Standards Board**

**Copyrights and permissions:** Annex E translated by T. W. Stringfield from Koch, W., “Erdungsmassnahmen fur Hochstspannungsanlagen mit Geerdetem Sternpunkt,” *Electrotechnische Zeitschrift*, vol. 71, no. 4, pp. 8–91, Feb. 1950.

Annex F is taken from Dawalibi, F., and Mukhedkar, D., “Parametric analysis of grounding systems,” *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, no. 5, pp. 1659–1668, Sept./Oct. 1979; and Dawalibi, F., and Mukhedkar, D., “Influence of ground rods on grounding systems,” *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-98, no. 6, pp. 2089–2098, Nov./Dec. 1979.

Annex G translated by T. W. Stringfield from Koch, W., “Erdungsmassnahmen fur Hochstspannungsanlagen mit Geerdetem Sternpunkt,” *Electrotechnische Zeitschrift*, vol. 71, no. 4, pp. 8–91, Feb. 1950.

**Abstract:** This guide is primarily concerned with outdoor ac substations, either conventional or gas-insulated. These include distribution, transmission, and generating plant substations. With proper caution, the methods described herein are also applicable to indoor portions of such substations, or to substations that are wholly indoors. No attempt is made to cover the grounding problems peculiar to dc substations. A quantitative analysis of the effect of lightning surges is also beyond the scope of this guide.

**Keywords:** ground grids, grounding, IEEE 80™, substation design, substation grounding

---

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

Copyright © 2015 by The Institute of Electrical and Electronics Engineers, Inc.  
All rights reserved. Published 15 May 2015. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

National Electrical Safety Code and NESC are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-0-7381-8850-8 STD98495  
Print: ISBN 978-0-7381-8851-5 STDPD98495

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

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.

## Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

### Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

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.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

### Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

## Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

## Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive 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 comment or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board  
445 Hoes Lane  
Piscataway, NJ 08854 USA

## Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standards are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

## Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

## Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

## Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, 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.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at <http://ieeexplore.ieee.org/xpl/standards.jsp> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

## Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

## Patents

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 by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

## Participants

### IEEE Std 80-2013

At the time this IEEE guide was completed, the Grounding (PE/SUB/WGD7) Working Group had the following membership:

**Richard P. Keil**, *Chair*  
**Curtis R. Stidham**, *Secretary*

Hanna Abdallah  
Stan J. Arnot  
Thomas Barnes  
Bryan Beske  
Dale Boling  
Steven Brown  
James Cain  
Bill Carman  
K. S. Chan  
Koushik Chanda  
Carson Day  
Dennis DeCosta  
E. Peter Dick

William K. Dick  
Marcia Eblen  
D. Lane Garrett  
Joseph Gravelle  
Steven Greenfield  
Charles Haahr  
Thomas Harger  
Martin Havelka  
Dave Kelley  
Donald N. Laird  
Henri Lemeilleur  
Cary Mans  
Sakis Meliopoulos

Mike Noori  
Shashi G. Patel  
Christian Robles  
Jesse Rorabaugh  
Hamid Sharifnia  
William Sheh  
Douglas Smith  
David Stemm  
Greg J. Stegman  
Brian Strydom  
Yancey Syarif  
Keith Wallace  
Alexander Wong

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman  
Michael Adams  
Ali Al Awazi  
Ficheux Arnaud  
Stan J. Arnot  
Adam Bagby  
Thomas Barnes  
George Bartok  
George Becker  
W. J. (Bill) Bergman  
Bryan Beske  
Steven Bezner  
Wallace Binder  
Michael Bio  
Derek Brown  
Steven Brown  
William Bush  
William P. Card  
James Cain  
Thomas Callse  
K. S. Chan  
Koushik Chanda  
Robert Christman  
Pandy Clelland  
Cindanyou Dai  
Ray Davis  
Dennis DeCosta  
Charles DeNardo  
Gary Donner  
Michael Dood  
Douglas Dorr

Randall Dotson  
Gearoid O'hEidhin  
C. Erven  
Dan Evans  
Keith Florenza  
Rabiz Foad  
Dona Galal  
D. Lane Garrett  
Frank Gerleve  
David Giegel  
David Gilmer  
Jalal Gohari  
Edwin Goodwin  
James Graham  
Lance Grainger  
Joseph Gravelle  
Steven Greenfield  
Randall Groves  
Ajit Gwal  
Charles Haahr  
Thomas Harger  
Martin Havelka  
Lee Herron  
Scott Hietpas  
Robert Hoerauf  
Gary Hoffman  
Richard P. Keil  
Gael Kennedy  
Mohamed Abdel Khalek  
Yuri Khersonsky  
James Kinney

Joseph L. Koepfinger\*  
David Krause  
Jim Kulchisky  
Saumen Kundu  
Donald N. Laird  
Chung-Yiu Lam  
Benjamin Lanz  
Michael Lauxman  
Duane Leschert  
Hua Liu  
Debra Longtin  
Greg Luri  
Bruce Mackie  
John Mcalhaney, Jr.  
John Merando  
T. David Mills  
Georges Montillet  
Kimberly Mosley  
Adi Mulawarman  
Jerry Murphy  
Arun Narang  
Dennis Neitzel  
Arthur Neubauer  
Michael Newman  
Matthew Norwalk  
Robert Nowell  
Ted Olsen  
Lorraine Padden  
Shashi G. Patel  
Donald Platts  
Percy Pool

Moises Ramos  
Reynaldo Ramos  
Michael Roberts  
Charles Rogers  
Jesse Rorabaugh  
Thomas Rozek  
Steven Sano  
Bartien Sayogo  
Dennis Schlender  
Robert Schuerger  
Hamid Sharifnia  
Devki Sharma  
William Sheh  
Suresh Shrivavle  
Gil Shultz  
Hyeong Sim

Garry Simms  
David Singleton  
Douglas Smith  
Jerry Smith  
David Solhtalab  
Curtis R. Stidham  
Gary Stoedter  
Brian Story  
Raymond Strittmatter  
Peter Sutherland  
Michael Swearingen  
William Taylor  
David Tepen  
Wayne Timm  
John Toth  
Joe Uchiyama

Eric Udren  
Marcelo Valdes  
John Vergis  
Jane Verner  
Keith Wallace  
S. Frank Waterer  
Donald Wengerter  
Kenneth White  
James Wilson  
Alexander Wong  
Jonathan Woodworth  
Larry Young  
Roland Youngberg  
Jian Yu  
Luis Zambrano

When the IEEE-SA Standards Board approved this guide on 11 December 2013, it had the following membership:

**John Kulick, Chair**  
**David J. Law, Vice Chair**  
**Richard H. Hulett, Past Chair**  
**Konstantinos Karachalios, Secretary**

Masayuki Ariyoshi  
Peter Balma  
Farooq Bari  
Ted Burse  
Stephen Dukes  
Jean-Philippe Faure  
Alexander Gelman

Mark Halpin  
Gary Hoffman  
Paul Houz e  
Jim Hughes  
Michael Janezic  
Joseph L. Koepfinger  
Oleg Logvinov  
Ron Petersei.

Gary Robinson  
Jon Walter Rosdahl  
Adrian Stephens  
Peter Sutherland  
Yatin Trivedi  
Phil Winston  
Yu Yuan

\*Member Emeritus

Also included are the following non-voting IEEE-SA Standards Board liaisons:

Richard DeBlasio, *DOE Representative*  
Michael Janezic, *NIST Representative*

Don Messina  
*IEEE-SA Content Production and Management*

Erin Spiewak  
*IEEE-SA Technical Program Operations*

## IEEE Std 80-2013/Cor 1-2015

### Participants

At the time this IEEE corrigendum was completed, the Grounding (PE/SUB/WGD7) Working Group had the following membership:

**Richard P. Keil**, *Chair*  
**Curtis R. Stidham**, *Secretary*

Hanna Abdallah  
Stan J. Arnot  
Thomas Barnes  
Bryan Beske  
Dale Boling  
Steven Brown  
James Cain  
Bill Carman  
K. S. Chan  
Koushik Chanda  
Carson Day  
Dennis DeCosta  
E. Peter Dick

William K. Dick  
Marcia Eblen  
D. Lane Garrett  
Joseph Gravelle  
Steven Greenfield  
Charles Haahr  
Thomas Harger  
Martin Havelka  
Dave Kelley  
Donald N. Laird  
Henri Lemeilleur  
Cary Mans  
Sakis Meliopoulos

Mike Noori  
Shashi G. Patel  
Christian Robles  
Jesse Rorabaugh  
Hamid Sharifnia  
William Sheh  
Douglas Smith  
David Stumm  
Greg T. Stegman  
Brian Suter  
Yancey Yarif  
Kevin Wallace  
Alexander Wong

The following members of the individual balloting committee voted on this corrigendum. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman  
Michael Adams  
Ali Al Awazi  
Ficheux Arnaud  
Stan J. Arnot  
Adam Bagby  
Thomas Barnes  
George Bartok  
George Becker  
W. J. (Bill) Bergman  
Bryan Beske  
Steven Bezner  
Wallace Binder  
Michael Bio  
Derek Brown  
Steven Brown  
William Bush  
William E. Byrd  
James Cain  
Thomas Callseen  
K. S. Chan  
Koushik Chanda  
Robert Christman  
Andy Clelland  
Chuanyou Dai  
Ray Davis  
Dennis DeCosta  
Charles DeNardo  
Gary Donner  
Michael Dood  
Douglas Dorr

Randall Dotson  
Gearoid O'hEidhin  
C. Erven  
Dan Evans  
Keith Flowers  
Rahim Fouad  
Donald N. Laird  
D. Lane Garrett  
Frank Gerleve  
David Giegel  
David Gilmer  
Jalal Gohari  
Edwin Goodwin  
James Graham  
Lance Grainger  
Joseph Gravelle  
Steven Greenfield  
Randall Groves  
Ajit Gwal  
Charles Haahr  
Thomas Harger  
Martin Havelka  
Lee Herron  
Scott Hietpas  
Robert Hoerauf  
Gary Hoffman  
Richard P. Keil  
Gael Kennedy  
Mohamed Abdel Khalek  
Yuri Khersonsky  
James Kinney

Joseph L. Koepfinger\*  
David Krause  
Jim Kulchisky  
Saumen Kundu  
Donald N. Laird  
Chung-Yiu Lam  
Benjamin Lanz  
Michael Lauxman  
Duane Leschert  
Hua Liu  
Debra Longtin  
Greg Luri  
Bruce Mackie  
John Mcalhaney, Jr.  
John Merando  
T. David Mills  
Georges Montillet  
Kimberly Mosley  
Adi Mulawarman  
Jerry Murphy  
Arun Narang  
Dennis Neitzel  
Arthur Neubauer  
Michael Newman  
Matthew Norwalk  
Robert Nowell  
Ted Olsen  
Lorraine Padden  
Shashi G. Patel  
Donald Platts  
Percy Pool

Moises Ramos  
Reynaldo Ramos  
Michael Roberts  
Charles Rogers  
Jesse Rorabaugh  
Thomas Rozek  
Steven Sano  
Bartien Sayogo  
Dennis Schlender  
Robert Schuerger  
Hamid Sharifnia  
Devki Sharma  
William Sheh  
Suresh Shrimavle  
Gil Shultz  
Hyeong Sim

Garry Simms  
David Singleton  
Douglas Smith  
Jerry Smith  
David Solhtalab  
Curtis R. Stidham  
Gary Stoedter  
Brian Story  
Raymond Strittmatter  
Peter Sutherland  
Michael Swearingen  
William Taylor  
David Tepen  
Wayne Timm  
John Toth  
Joe Uchiyama

Eric Udren  
Marcelo Valdes  
John Vergis  
Jane Verner  
Keith Wallace  
S. Frank Waterer  
Donald Wengerter  
Kenneth White  
James Wilson  
Alexander Wong  
Jonathan Woodworth  
Larry Young  
Roland Youngberg  
Jian Yu  
Luis Zambrano

When the IEEE-SA Standards Board approved this corrigendum on March 26, 2015, it had the following membership:

**John D. Kulick**, *Chair*  
**Jon Walter Rosdah**, *Vice Chair*  
**Richard H. Hulett**, *Past Chair*  
**Konstantinos Karachalios**, *Secretary*

Masayuki Ariyoshi  
Ted Burse  
Stephen Dukes  
Jean-Philippe Faure  
J. Travis Griffith  
Gary Hoffman  
Michael Janezic

Joseph L. Koepfinger\*  
David J. Law  
Hung Ling  
Andrew Myles  
T. W. Olsen  
Glenn Parsons  
Ronald C. Petersen  
Annette D. Reilly

Stephen J. Shellhammer  
Adrian P. Stephens  
Yatin Trivedi  
Phillip Winston  
Don Wright  
Yu Yuan  
Daidi Zhong

\*Member Emeritus

Don Messina  
*IEEE-SA Content Production and Management*

Erin Spiewak  
*IEEE-SA Operational Program Management*

## Introduction

This introduction is not part of IEEE Std 80™-2013, IEEE Guide for Safety in AC Substation Grounding.

This fifth edition represents the third major revision of this guide since its first issue in 1961. Previous editions extended the equations for calculating touch and step voltages to include L-shaped and T-shaped grids; they introduced curves to help determine current division, changed the criteria for selection of conductors and connections, and provided more information on resistivity measurement interpretation; and added the discussion of multilayer soils.

This edition introduces the calculations to determine *TCAP* for materials not listed in Table 1. This information can be used to calculate *TCAP* for different combinations of bi-metallic electrodes used in grounding systems. This edition also introduces benchmarks. The benchmarks have two purposes. First, the benchmarks compare the equations in IEEE Std 80 to commercially available ground grid design software. The benchmarks show where IEEE Std 80 equations work well and their limitations. Second, the benchmarks provide software users a way to verify their understanding of the software.

The fifth edition continues to build on over 50 years of work by dedicated members of working groups: AIEE Working Group 56.1 and IEEE Working Groups 69.1, 78.1, and D7.

As required by IEEE Std 80-2013/Cor 1-2015, corrections were made to Clause 11, Clause 17, Annex C, Annex H as well as to Table 1 and Table 2; two equations following Figure 45; Table H.5 was replaced by a new Table H.5, and Table H.6 through Table H.10 were added.

## Contents

1. Overview .....	1
1.1 Scope .....	1
1.2 Purpose .....	1
2. Normative references.....	2
3. Definitions .....	3
4. Safety in grounding .....	8
4.1 Basic problem .....	8
4.2 Conditions of danger .....	10
5. Range of tolerable current .....	11
5.1 Effect of frequency .....	11
5.2 Effect of magnitude and duration .....	12
5.3 Importance of high-speed fault clearing .....	12
6. Tolerable body current limit.....	13
6.1 Duration formula .....	13
6.2 Alternative assumptions.....	14
6.3 Comparison of Dalziel's equations and Biegelmeier's curve.....	15
6.4 Note on reclosing.....	16
7. Accidental ground circuit .....	16
7.1 Resistance of the human body .....	16
7.2 Current paths through the body .....	17
7.3 Accidental circuit equivalents.....	17
7.4 Effect of a thin layer of surface material .....	21
8. Criteria of tolerable voltage .....	24
8.1 Criteria of tolerable voltage definitions .....	24
8.2 Typical shock situations for air-insulated substations .....	27
8.3 Typical shock situations for gas-insulated substations .....	28
8.4 Step and touch voltage criteria.....	28
8.5 Effect of sustained ground currents .....	30
9. Principal design considerations .....	30
9.1 Definitions .....	30
9.2 General concept .....	30
9.3 Primary and auxiliary ground electrodes .....	31
9.4 Basic aspects of grid design.....	31
9.5 Design in difficult conditions .....	32
9.6 Connections to grid.....	33
10. Special considerations for gas-insulated substations (GIS).....	33
10.1 Special considerations for GIS definitions .....	33
10.2 GIS characteristics .....	34
10.3 Enclosures and circulating currents .....	35
10.4 Grounding of enclosures.....	35
10.5 Cooperation between GIS manufacturer and user .....	36
10.6 Other special aspects of GIS grounding.....	37

10.7 Notes on grounding of GIS foundations .....	37
10.8 Touch voltage criteria for GIS .....	38
10.9 Recommendations .....	40
11. Selection of conductors and connections .....	40
11.1 Basic requirements .....	40
11.2 Choice of material for conductors and related corrosion problems .....	40
11.3 Conductor sizing factors .....	42
11.4 Selection of connections .....	52
12. Soil characteristics .....	52
12.1 Soil as a grounding medium .....	52
12.2 Effect of voltage gradient .....	53
12.3 Effect of current magnitude .....	53
12.4 Effect of moisture, temperature, and chemical content .....	53
12.5 Use of surface material layer .....	54
13. Soil structure and selection of soil model .....	55
13.1 Investigation of soil structure .....	55
13.2 Classification of soils and range of resistivity .....	55
13.3 Resistivity measurements .....	56
13.4 Interpretation of soil resistivity measurements .....	59
14. Evaluation of ground resistance .....	66
14.1 Usual requirements .....	66
14.2 Simplified calculations .....	66
14.3 Schwarz's equations .....	67
14.4 Note on ground resistance of primary electrodes .....	70
14.5 Soil treatment to lower resistivity .....	70
14.6 Concrete-encased electrodes .....	70
15. Determination of maximum grid current .....	74
15.1 Determination of maximum grid current definitions .....	74
15.2 Procedure .....	75
15.3 Types of ground faults .....	75
15.4 Effect of substation ground resistance .....	78
15.5 Effect of fault resistance .....	78
15.6 Effect of overhead ground wires and neutral conductors .....	79
15.7 Effect of direct buried pipes and cables .....	79
15.8 Worst fault type and location .....	79
15.9 Computation of current division .....	80
15.10 Effect of asymmetry .....	85
15.11 Effect of future changes .....	87
16. Design of grounding system .....	88
16.1 Design criteria .....	88
16.2 Critical parameters .....	89
16.3 Index of design parameters .....	90
16.4 Design procedure .....	90
16.5 Calculation of maximum step and mesh voltages .....	94
16.6 Refinement of preliminary design .....	96
16.7 Application of equations for $E_m$ and $E_s$ .....	97
16.8 Use of computer analysis in grid design .....	97
17. Special areas of concern .....	98

17.1 Service areas .....	98
17.2 Switch shaft and operating handle grounding.....	98
17.3 Grounding of substation fence.....	101
17.4 Results of voltage profiles for fence grounding.....	104
17.5 Control cable sheath grounding.....	110
17.6 GIS bus extensions .....	111
17.7 Surge arrester grounding.....	111
17.8 Separate grounds.....	111
17.9 Transferred potentials .....	111
18. Construction of a grounding system.....	114
18.1 Ground grid construction—trench method.....	114
18.2 Ground grid construction—conductor plowing method.....	115
18.3 Installation of connections, pigtails, and ground rods .....	115
18.4 Construction sequence consideration for ground grid installation.....	116
18.5 Safety considerations during subsequent excavations .....	116
19. Field measurements of a constructed grounding system .....	116
19.1 Measurements of grounding system impedance.....	116
19.2 Field survey of potential contours and touch and step voltages.....	118
19.3 Assessment of field measurements for safe design.....	119
19.4 Ground grid integrity test.....	119
19.5 Periodic checks of installed grounding system.....	120
20. Physical scale models.....	120
Annex A (informative) Bibliography .....	121
Annex B (informative) Sample calculations.....	129
B.1 Square grid without ground rods—Example 1 .....	130
B.2 Square grid with ground rods—Example 2.....	135
B.3 Rectangular grid with ground rods—Example 3.....	137
B.4 L-shaped grid with ground rods—Example 4.....	140
B.5 Equally spaced grid with ground rods in two-layer soil—Exhibit 1 .....	143
B.6 Unequally spaced grid with ground rods in uniform soil—Exhibit 2 .....	143
Annex C (informative) Graphical and approximate analysis of current division .....	146
C.1 Introduction.....	146
C.2 How to use the graphs and equivalent impedance table.....	147
C.3 Examples.....	148
C.4 Equations for computing line impedances .....	149
Annex D (informative) Simplified step and mesh equations.....	165
Annex E (informative) Equivalent uniform soil model for non-uniform soils .....	169
Annex F (informative) Parametric analysis of grounding systems.....	172
F.1 Uniform soil .....	172
F.2 Two-layer soil.....	183
F.3 Summary .....	185
Annex G (informative) Grounding methods for high-voltage stations with grounded neutrals .....	187
G.1 Summary.....	190

Annex H (informative) Benchmark .....	195
H.1 Overview .....	195
H.2 Soil analysis .....	195
H.3 Grounding system analysis .....	199
H.4 Grid current analysis (current division) .....	206

# IEEE Guide for Safety in AC Substation Grounding

*IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.*

*This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.*

## 1. Overview

### 1.1 Scope

This guide is primarily concerned with outdoor ac substations, either conventional or gas-insulated. Distribution, transmission, and generating plant substations are included. With proper caution, the methods described herein are also applicable to indoor portions of such substations, or to substations that are wholly indoors.

No attempt is made to cover the grounding problems peculiar to dc substations. A quantitative analysis of the effects of lightning surges is also beyond the scope of this guide.

### 1.2 Purpose

The intent of this guide is to provide guidance and information pertinent to safe grounding practices in ac substation design.