

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part IV—Distribution

Sponsor
**Surge-Protective Devices Committee
of the
IEEE Power Engineering Society**

Reaffirmed March 20, 2002
Approved December 5, 1992

IEEE Standards Board

Reaffirmed August 28, 2002
Approved July 13, 1992

American National Standards Institute

Abstract: The neutral grounding of single- and three-phase ac electric utility primary distribution systems with nominal voltages in the range of 2.4–34.5 kV is addressed. Classes of distribution systems grounding are defined. Basic considerations in distribution system grounding—concerning economics, control of temporary overvoltages, control of ground-fault currents, and ground relaying—are addressed. Also considered are use of grounding transformers, grounding of high-voltage neutral of wye-delta distribution transformers, and interconnection of primary and secondary neutrals of distribution transformers.

Keywords: distribution system grounding, distribution systems, electric utilities, grounding, neutral grounding, primary distribution systems

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Copyright © 1992 by the
Institute of Electrical and Electronics Engineers, Inc.

All rights reserved. Published 1992

Printed in the United States of America

ISBN 1-55937-20243

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 Technical Committees of 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 which 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 once 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 technical 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

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Introduction

(This introduction is not a part of IEEE C62.92.4-1991, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part IV—Distribution.)

This guide was prepared by the Working Group on the Neutral Grounding of Distribution Systems of the IEEE Surge-Protective Devices Committee. The guide deals with the neutral grounding of single- and three-phase ac utility primary distribution systems with nominal voltages of 2.4 kV through 34.5 kV. Not included are grounding of low-voltage secondary systems or consumer-owned facilities that are covered by other standards. At the time this guide was approved, the working group membership was as follows:

J. J. Burke, *Chair*

S. H. Cheng
J. L. Koepfinger
R. Richeda

D. C. Dawson
S. Mazumdar
D. R. Smith

G. S. Haralampu
M. Parente
E. R. Taylor

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

R. D. Ball
C. L. Ballentine
G. D. Breuer
J. J. Burke
S. Cheng
M. G. Comber
J. G. Dalton
D. C. Dawson
C. C. Erven
R. W. Flugum
H. E. Foelker
G. L. Gaibrois
E. A. Goodman
P. A. Goodwin
C. D. Hansell
G. S. Haralampu
D. E. Hedman

J. A. Hetrick
A. R. Hileman
W. W. Hines
D. W. Jackson
R. A. Jones
S. S. Kershaw
J. L. Koepfinger
G. E. Lee
F. Lembo, Jr.
D. W. Lenk
W. A. Maguire
J. A. Mambuca
E. H. Marrow, Jr.
F. D. Martzloff
D. J. Melvold
J. J. Napiorkowski
O. Nigol

R. Odenberg
J. C. Osterhout
M. Parente
J. B. Posey
S. A. Potocny
P. Richman
K. B. Stump
L. D. Sweeney
A. Sweetana
D. P. Symanski
E. R. Taylor, Jr.
R. Thallam
A. C. Westrom
S. G. Whisenant
E. J. Yasuda

At the time this standard was published, it was under consideration for approval as an American National Standard. The Accredited Standards Committee on Surge Arresters, C62, had the following members at the time this document was sent to letter ballot:

Joseph L. Koepfinger, *Chair*
John A. Gauthier, *Secretary*

<i>Organization Represented</i>	<i>Name of Representative</i>
Association of American Railroads	Wayne Etter
Bonneville Power Administration	G.E. Lee
Exchange Carriers Standards Association.....	Michael Parente
Electric Light and Power.....	R. A. Jones H. E. Foelker W. A. Maguire Dale Peters J. W. Wilson M.C. Mingoia(Alt.)
Institute of Electrical and Electronic Engineers	J. L. Koepfinger G. L. Gaibrois C. Nansell (Alt.) Dale Hedman W. H. Kapp S. S. Kershaw, Jr. Edgar Taylor (Alt.)
National Electrical Manufacturers Association.....	Scott Law Basil Dillon-Malone Dennis W. Lenk Bernhard Wolff D. Worden David Bell (Alt.) Larry Bock (Alt.)
Rural Electrification Administration	George J. Bagnall
Underwriters Laboratories	P. Notarian Larry Williams(Alt.)
Canadian Standards Association	D. M. Smith
Members-at-Large	Peter Goodwin F. D. Martzloff J. Osterhout B. Panesar

When the IEEE Standards Board approved this standard on December 5, 1991, it has the following membership:

Marco W. Migliaro, *Chair*
Donald C. Loughry, *Vice Chair*
Andrew G. Salem, *Secretary*

Dennis Bodson
Paul L. Borrill
Clyde Camp
James M. Daly
Donald C. Fleckenstein
Jay Forster*
David F. Franklin
Ingrid Fromm
Thomas L. Hannan

Donald N. Heirman
Kenneth D. Hendrix
John W. Horch
Ben C. Johnson
Ivor N. Knight
Joseph Koepfinger*
Irving Kolodny
Michael A. Lawler
John E. May, Jr.

Lawrence V. McCall
T. Don Michael*
Lloyd A. "Pete" Morley
Stig L. Nilsson
John L. Rankine
Ronald H. Reimer
Gary S. Robinson
Terrance R. Whittemore

*Member Emeritus

Also included are the following nonvoting IEEE Standards Board liaisons:

Fernando Aldana
Satish K. Aggarwal

James Beall
Richard B. Engelman

Stanley Warshaw

Mary Lynne Nielsen
IEEE Standards Project Editor

CLAUSE	PAGE
1. Scope	1
2. Classes of Distribution Systems Grounding	1
2.1 Ungrounded Systems	1
2.2 Grounded Systems	1
2.3 Four-Wire Ungrounded Systems	2
2.4 Three-Wire Ungrounded Systems	2
2.5 Use of Grounding Transformers	2
3. Basic Considerations in Distribution System Grounding	2
3.1 Economics	3
3.2 Control of Temporary Overvoltages	3
3.3 Control of Ground Fault Currents	6
3.4 Ground Relaying	9
4. Special Considerations in Distribution System Grounding	10
4.1 Coordination With Communication Facilities	10
4.2 Use of Grounding Transformers	12
4.3 Grounding of High-Voltage Neutral of Wye-Delta Distribution Transformers	12
4.4 Interconnection of Primary and Secondary Neutrals of Distribution Transformers	13
5. Bibliography	13
Annex A (Informative) Specifying a Zig-Zag Grounding Transformer	16
Annex B (Informative) Techniques for Interconnecting Primary and Secondary Neutrals	20

IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part IV—Distribution

1. Scope

This section of the guide is concerned with the neutral grounding of single- and three-phase alternating current (ac) electric utility primary distribution systems with nominal voltages in the range of 2.4 kV to 34.5 kV. For the purpose of this guide, the term “distribution” includes the substation providing power to distribution feeders, the distribution feeders, and the distribution transformers providing service at utilization voltages. The scope of this guide does not include the grounding of the low-voltage secondary systems supplied by distribution transformers, or consumer-owned facilities that are covered by other standards such as the National Electrical Code (NEC) [B6].

2. Classes of Distribution Systems Grounding

Distribution systems are classified as being either grounded or ungrounded.

2.1 Ungrounded Systems

Ungrounded systems have the secondary windings of the distribution substation transformer connected either in ungrounded delta or ungrounded wye, with the former connection being more common. The distribution feeders are three-wire three-phase and two-wire single-phase circuits. Surge arresters are connected from phase conductor directly to earth, or to the grounded equipment tank or frame, either directly or through a spark gap.

2.2 Grounded Systems

Grounded systems usually are derived from a distribution substation transformer with wye-connected secondary windings and with the neutral point of the windings solidly grounded or connected to ground through a noninterrupting, current-limiting device such as a reactor, etc. A grounding transformer may also be used to establish a grounded system. The circuits associated with grounded distribution systems generally have a neutral conductor connected to the supply grounding point. The neutral conductor of the distribution circuits may be connected to earth at frequent intervals (multigrounded), or it may be fully insulated and have no other earth connection except at the

source (ungrounded). In three-wire ungrounded systems, a neutral conductor is not run with each circuit, but the system is grounded through the connections of the substation transformer or grounding transformer. The neutral conductor associated with the primary feeders of multigrounded neutral distribution systems is connected to earth at intervals specified by national or local codes. It is also common practice to bond this neutral conductor to surge-arrester ground leads and to all noncurrent-carrying parts, such as equipment tanks and guy wires, and to interconnect it with the secondary neutral conductor or grounded conductor. In some situations, the same neutral conductor is used for both the primary and secondary systems. There is some variation in this practice, however, and some utilities do not interconnect the primary and secondary neutral conductors nor bond the neutral to the guy wire. If no direct interconnection is made, the secondary neutral conductor may be connected to the primary neutral conductor through a spark gap or arrester.

Surge arresters on multigrounded neutral systems are connected directly to earth, and their grounding conductor may be interconnected directly to the primary neutral conductor and equipment tanks. They may also be interconnected with the secondary neutral at transformer installations.

2.3 Four-Wire Ungrounded Systems

Four-wire ungrounded systems are systems where the primary neutral conductor is insulated at all points except at the source. The neutral conductor in these systems is connected to the neutral point of the source transformer windings and to ground. Distribution transformers usually are connected between phase and neutral conductors, with the surge arrester connected between phase and ground. Some four-wire ungrounded systems use an arrester between the neutral conductor and ground. A spark gap may also be used at the distribution transformer between its secondary neutral and arrester ground to provide better surge protection to the transformer windings. The principal advantage of four-wire ungrounded systems is the greater ground relaying sensitivity that can be obtained in comparison to multigrounded systems (see 3.4).

2.4 Three-Wire Ungrounded Systems

On three-phase three-wire primary distribution circuits, single-phase distribution transformers are connected phase-to-phase. The connection three single-phase distribution transformers or of three-phase distribution transformers is usually delta-grounded wye or delta-delta. The floating wye-delta or T-T connections also can be used. The grounded wye-delta connection is generally not used because it acts as a grounding transformer. Surge arresters are generally connected phase-to-ground. However, the surge arrester rating is higher than those used on multigrounded neutral systems since the temporary 60 Hz overvoltages expected under fault conditions are also higher.

2.5 Use of Grounding Transformers

The feeders from an ungrounded systems may be grounded by the use of a grounding transformer, which may be connected in zig-zag or in grounded-wye delta. The grounding transformer provides a source for zero sequence current and will permit the addition of a neutral conductor to an existing ungrounded circuit.

3. Basic Considerations in Distribution System Grounding

The basic considerations in distribution system grounding are economics, control of overvoltages, control of fault current magnitude and return path, and ground fault protection.

3.1 Economics

Ungrounded and three-wire ungrounded systems generally result in the least investment when the load is mostly three-phase. On the other hand, costs favor multigrounded neutral systems when the loads are mostly single phase. Several factors must be given consideration to determine if the system should be grounded or ungrounded.

One factor to consider is the geographical area and the isokeraunic level in which the system will be operating. This will have considerable effect on the type of surge arresters required and the degree of direct-stroke protection that is considered necessary. In an area having a high isokeraunic level, it may be advantageous to use a static wire or an overhead shield wire for direct stroke lightning protection. The primary neutral conductor can very easily be used for the shield wire and may also function as a common neutral conductor with the secondary system. However, with the use of aerial cable for secondary circuits, there will be some duplication of neutral conductors that may not be objectionable compared with the reduced outages and reduction of trips for fuse replacement and repair of lightning-damaged equipment. Also, the number of ground connections on the neutral conductor per mile of line must be considered.

Generally, a minimum of four ground connections per mile is considered adequate for a four-wire multigrounded neutral system, but, with the use of a static or overhead shield wire, it may be necessary to install grounds on every pole.

Another method of providing lightning protection that is affected by the type of grounding is the use of surge arresters installed on each conductor at intervals of approximately every 394 m (1200 ft). The voltage rating of the arrester is directly related to the effectiveness of grounding employed on a particular system. For example, the arresters on a three-wire three-phase ungrounded system would need a voltage rating suitable for the phase-to-phase voltage. On the other hand, on an effectively grounded four-wire three-phase circuit, the arresters may have a voltage rating of only 75% of the phase-to-phase voltage. This may also allow the use of equipment having a lower Basic Insulation Level (BIL).

The use of multigrounded neutral distribution systems that satisfy the requirements of effectively grounded systems provides several areas in which reduced costs can be realized.

- 1) The National Electrical Safety Code (NESC) [B2] permits neutral conductors that are multigrounded on systems of 50 kV and below to be attached directly to the structure surface. The same neutral conductor may be used for both the primary and secondary systems.
- 2) Lower surge-arrester voltage ratings can be used.
- 3) Lower surge-arrester voltage ratings may permit lower equipment BIL, especially at the higher distribution voltages.
- 4) Equipment costs are reduced since it is necessary to use only one fuse cutout, arrester, and primary bushing on a single-phase distribution transformer.
- 5) The earth acts as a conductor in parallel with the neutral, sometimes allowing reduced conductor size and a decrease in losses. A reduced neutral conductor size will increase ground current and may produce or increase neutral-to-earth voltage.
- 6) Single-phase distribution transformers with one high-voltage bushing may have a primary winding with reduced insulation at the neutral end. Three-phase distribution transformers with the primary windings connected in grounded wye may also have reduced insulation at the neutral end.

3.2 Control of Temporary Overvoltages

3.2.1 Faults to Ground

Faults to ground on power systems may cause fundamental frequency overvoltages on the unfaulted phases, which last for the duration of the fault. The grounding of the system determines the magnitude of these overvoltages, which in turn establishes the minimum voltage rating of surge arresters used on the system.

Based upon an evaluation of circuit parameters, operating voltage limits, type of construction, and distribution transformer magnetizing characteristics, a proposal for the selection of voltage ratings of silicon-carbide distribution-class surge arresters has been made by a working group of the IEEE Surge-Protective Devices Committee¹. The group proposed that the duty cycle voltage rating of surge arresters selected for open-wire multigrounded neutral systems be equal to or greater than the nominal line-to-neutral voltage multiplied by the product of the Range A factor 1.05 (from ANSI C82.1-1985 [B3]), and 1.2, which is the maximum voltage rise on the unfaulted phases of a loaded circuit. This is equivalent to 1.25 times nominal line-to-neutral system voltage.

Similarly, for spacer-cable systems, a factor not exceeding 1.58 appears reasonable as the maximum value of overvoltage on the unfaulted phases of a three-phase circuit during single phase-to-ground faults. Taking into account connected distribution transformers, the factor reduces to 1.46. Thus, for spacer-cable systems, the duty cycle voltage rating of arresters should be based on the nominal line-to-neutral voltage multiplied by the product of the Range A factor 1.05 and 1.46. This is equivalent to 1.5 times nominal line-to-neutral system voltage.

The highest voltage an arrester will normally experience has traditionally been computed by considering a single line-to-ground fault as shown in Fig 1 .

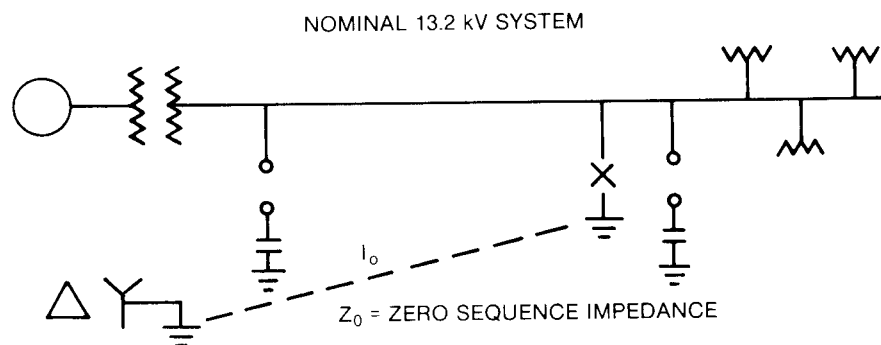


Figure 1—Single Line-to-Ground Fault

The voltage to ground on the unfaulted phases will increase by an amount that is a function of system impedances as illustrated in Fig 2 .

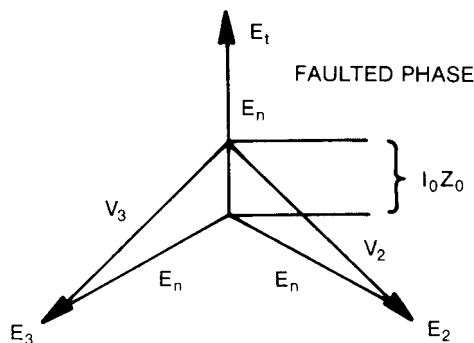


Figure 2—Phase Diagram for Single Line-to-Ground Fault

As an example, the voltage to ground on the unfaulted phases of a loaded four-wire multigrounded neutral system can increase by as much as 20%, the exact amount depending upon the location of the fault. In selection of the maximum

¹Paper No. 71 TP 542-PWR.