

IEEE Guide for Protective Relay Applications to Distribution Lines

IEEE Power and Energy Society

Developed by the
Power System Relaying Committee

IEEE Std C37.230™-2020
(Revision of IEEE Std C37.230-2007)

Currently in preview, click buy full version



IEEE Guide for Protective Relay Applications to Distribution Lines

Developed by the

Power System Relaying Committee
of the
IEEE Power and Energy Society

Approved 3 December 2020

IEEE SA Standards Board

Currently in preview, click buy full version

Abstract: A review of generally accepted applications and coordination of protection for power system distribution lines is presented. The advantages and disadvantages of schemes presently being used in protecting distribution lines are examined in this guide. Identification of problems with the methods used in distribution line protection and the solutions for those problems is included.

Keywords: coordination, distribution, faults, IEEE C37.230™, protection, reclosing, sensitivity

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

Copyright © 2021 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 19 March 2021. 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 both registered trademarks and service marks of The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-7301-9 STD24557
Print: ISBN 978-1-5044-7302-6 STDPD24557

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <https://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 Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

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

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA, 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 makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. 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: THE NEED TO PURCHASE 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 is 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, nor 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 the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, 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 comments, 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 evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile and Interests area of the [IEEE SA myProject system](#). An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.

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 constitute 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.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US 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 being used, 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 licensing fees, 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; <https://www.copyright.com/>. 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 10 years. When a document is more than 10 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 [IEEE Xplore](#) or [contact IEEE](#). For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#). Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

Patents

IEEE Standards are developed in compliance with the [IEEE SA Patent Policy](#).

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 <https://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.

IMPORTANT NOTICE

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. IEEE Standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users 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.

Currently in preview, click buy full version

Participants

At the time this IEEE guide was completed, the D28 Working Group had the following membership:

Brian Boysen, Chair
Claire Patti, Vice Chair

David Aldrich	Michael Higginson	Michael Meisinger
Martin Best	Craig Holt	Hugo Monterrubio
Patrick Carroll	Jack Jester	Adi Mulawarman
Randy Crellin	Benjamin Kazimier	Greg Ryan
Ratan Das	Ljubomir Kojovic	Farajollah Soudi
Fredric Friend	Raluca Lascu	Christopher Walker
Matt Garver	Don Lukach	Joe Xavier
Juan Gers	Bruce Mackie	Karl Zimmerman

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

Ali AlAwazi	Vasudev Gharpure	R. Member
Dave Aldrich	Mietek Glinkowski	Bruce Muschlitz
Jay Anderson	Jalal Gohari	Richard Neubauer
Thomas Barnes	Stephen Grier	Joe Nims
Jeffrey Barsch	Randall Groves	James O'Brien
Michael Basler	Randy Hamilton	Lorraine Padden
Michael Bayer	Michael Higginson	Manish Patel
Philip Beaumont	Werner Hoelzl	Subhash Patel
Martin Best	Richard Hunt	Claire Patti
Wallace Binder	Jack Jester	Stephen Pell
Thomas Blair	Anthony Johnson	Robert Pettigrew
William Bloethe	Gerald Johnson	Craig Preuss
Joe Boyles	Peter Kelly	Iulian Profir
Brian Boysen	Tamara Madelwal	Lakshman Raut
Jeffrey Brogdon	Mari Karsonsky	Charles Rogers
Gustavo Brunello	James Kinney	Ian Rokser
Demetrio Bucaneg Jr.	Loris Kogan	Ryandi Ryandi
Jeffrey Burnworth	Jim Kulchisky	Nikunj Shah
William Byrd	Paneendra Kumar BL	Jerry Smith
Paul Cardinal	Saumen Kundu	Gary Smullin
Suresh Channarasappa	Chung-Yiu Lam	Wayne Stec
Michael Chirico	Raluca Lascu	Gary Stoedter
Randall Crellin	Lawrenc Long	Eric Thibodeau
Ratan Das	Don Lukach	Michael Thompson
Glenn Darr	Bruce Mackie	Demetrios Tziouvaras
Robert Dempsey	Omar Mazzoni	James Van De Ligt
Alla Eronov	William McBride	Benton Vandiver
Kevin DeMaio	Walter McCannon	John Vergis
Michael Dood	Michael Meisinger	Matthew Wakeham
Donald Dunn	Dean Miller	Christopher Walker
Paul Eaton	Jeff Mizener	Solveig Ward
William English	Daleep Mohla	Kenneth White
James Formea	Joe Mooney	Philip Winston
Fredric Friend	Adi Mulawarman	Jian Yu
Jean-Sebastien Gagnon	Jerry Murphy	Nicholas Zagrodnik
Kamal Garg		Karl Zimmerman

When the IEEE SA Standards Board approved this guide on 3 December 2020, it had the following membership:

Gary Hoffman, *Chair*
Jon Walter Rosdahl, *Vice Chair*
John D. Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
Doug Edwards
J. Travis Griffith
Grace Gu
Guido R. Hertz
Joseph L. Koepfinger*

David J. Law
Howard Li
Dong Liu
Kevin Lu
Paul Nikolich
Damir Novosel
Dorothy Stanley

Mehmet Ulema
Lei Wang
Sha Wei
Philip B. Winston
Daidi Zhong
Jingyi Zhou

*Member Emeritus

Currently in preview, click buy full version

Introduction

This introduction is not part of IEEE Std C37.230-2020, IEEE Guide for Protective Relay Applications to Distribution Lines.

This guide compiles information on the application considerations of protective relays to power distribution lines. This guide presents a review of generally accepted distribution line protection schemes. Its purpose is to describe various schemes to assist relay engineers in selecting the most appropriate scheme for a particular installation. It is intended for engineers who have a basic knowledge of power system protection. This is an application guide and does not cover all of the protective requirements of all distribution line configurations in every situation. Additional reading material is suggested so the reader can evaluate the protection for the individual application.

Contents

1. Overview	15
1.1 Scope	15
1.2 Purpose	15
1.3 Word usage	15
2. Definitions, acronyms, and abbreviations	16
2.1 Definitions	16
2.2 Acronyms and abbreviations	16
3. Fundamentals	17
3.1 Fault characteristics	17
3.2 Load characteristics	20
3.3 Harmonics	20
3.4 Interrupting ratings	21
4. System configuration and components	21
4.1 System	21
4.2 Lines	38
4.3 Distribution transformers	38
4.4 Protective devices	39
4.5 Switching	42
4.6 Instrument transformers (sensing)	42
5. Protective schemes	49
5.1 Overcurrent scheme	49
5.2 Fuse saving/blowing schemes	49
5.3 Voltage scheme	53
5.4 Impedance and communications-assisted schemes	56
6. Criteria and examples	56
6.1 Reach/sensitivity	57
6.2 Coordination	62
6.3 Clearing time	70
6.4 Reclosing	70
6.5 Cold load pickup	72
7. Special applications	73
7.1 Simultaneous or intercircuit feeder faults	73
7.2 Loop schemes	74
7.3 Underfrequency load shedding	75
7.4 Undervoltage load shedding	78
7.5 Adaptive relaying schemes	79
7.6 Distributed energy resources	80
7.7 Communications-assisted protection applications	83
7.8 Multiple source configurations	86
7.9 Directional overcurrent protection	87
7.10 Motors (effects of unbalance)	88
7.11 Breaker failure	90
7.12 Single-phase tripping	91
7.13 Methods of detecting ground faults in resonant-grounded systems	92
7.14 Selective ground fault protection of an ungrounded system	94
7.15 Arc flash hazards	95
7.16 Locating faults on distribution lines	97

Annex A (informative) Bibliography.....	99
Annex B (informative) Glossary	104

List of Figures

Figure 1—Fault on radial system	18
Figure 2—Four-wire multigrounded system	22
Figure 3—Ungrounded system	22
Figure 4—Ground fault in ungrounded system	23
Figure 5—Voltage and ground fault currents in ungrounded system	23
Figure 6—Solidly uni-grounded system	24
Figure 7—Resonant-grounded system	26
Figure 8—Ground fault in resonant-grounded system	27
Figure 9—Voltages and ground fault currents in resonant-grounded system	27
Figure 10—Resistively or reactively grounded system	28
Figure 11—Typical distribution system with a radial feeder	28
Figure 12—Single transformer distribution bus	30
Figure 13—Two-transformer distribution bus	30
Figure 14—Partial bus differential scheme	31
Figure 15—Main-bypass bus with high side interrupter	31
Figure 16—Dual-operation bus	32
Figure 17—Dual-operation bus with two transformers	33
Figure 18—Generator connected to distribution substation bus	34
Figure 19—Typical phase and ground relay connections	34
Figure 20—Ground relay and residually connected CTs	35
Figure 21—Zero-sequence CT and ground relay: (a) three-wire system and (b) four-wire system	36
Figure 22—Application of a neutral CT to a cable with sheath	37
Figure 23—Grounding transformers	37
Figure 24—Three-phase and single-phase transformer connections	39
Figure 25—CT and VT location in a distribution station	43
Figure 26—CT connection, three-wire	44
Figure 27—VT connections	45
Figure 28—CT equivalent circuit	46
Figure 29—Typical excitation curves for a multiratio C class CT	46
Figure 30—CT saturation at rated burden and reduced burden	47

Figure 31—Effect of dc component on CT saturation	48
Figure 32—Residual current caused by CT saturation due to dc components	48
Figure 33—Fast time-current characteristic curve	49
Figure 34—Time-current curve showing fuse saving scheme	50
Figure 35—Time-current curve showing partial-range fuse saving scheme.....	52
Figure 36—Time-current curve showing fuse blowing scheme	53
Figure 37—Three-phase, four-wire connected VTs	54
Figure 38—Three-phase, three-wire (open delta) connected VTs	55
Figure 39—Wye-broken delta connected VTs for zero-sequence voltage sensing	56
Figure 40—Sample distribution feeder with large transformer	60
Figure 41—Coordination with large transformer with possible trip on inrush point at 1389 A.....	61
Figure 42—Coordination with large transformer with minimal possibility of trip on inrush point at 2315 A. 62	
Figure 43—Coordination using a coordination time interval (CTI)	64
Figure 44—Coordination using coordination response bands.....	65
Figure 45—Coordination between an inverse and extremely inverse device	66
Figure 46—Coordination for phase-to-ground faults	67
Figure 47—Cold load pickup	72
Figure 48—Faults involving two circuits.....	73
Figure 49—Loop scheme	74
Figure 50—Loop scheme with sectionalizing switches.....	75
Figure 51—Distribution with DER	81
Figure 52—Example of direct transfer trip scheme on a radial distribution circuit	84
Figure 53—Communications-enhanced trip and restore scheme on a looped-radial distribution system	84
Figure 54—Example of a communications-aided trip scheme on a closed-loop distribution system	86
Figure 55—Three-line diagram of a typical open-phase unbalance of a three-phase induction motor	89
Figure 56—Ungrounded system where ferroresonance could occur	92
Figure 57—Zero-sequence network diagram for a forward fault	92
Figure 58—Zero-sequence network diagram for a reverse fault	93
Figure 59—Phasor diagram for the wattmetric element	93
Figure 60—Current distribution in an ungrounded system with C-phase fault.....	94
Figure 61—Example arc flash TCC.....	97
Figure 62—Example of a distribution feeder structure.....	98

List of Tables

Table 1—Similarity between a harmonic quantity and a sequence component	20
Table 2—System voltages and currents during single-phase-to-ground faults for different neutral treatments (refer to Figure 11)	29
Table 3—BILs and percent impedance at self-cooled (OA) rating	39
Table 4—Theoretical currents for open-phase condition.....	89
Table 5—Line current measured by protective device in Figure 55 for normal and open-phase conditions...	90

IEEE Guide for Protective Relay Applications to Distribution Lines

1. Overview

This guide is divided into seven clauses. [Clause 1](#) provides the scope and purpose of this guide. [Clause 2](#) provides definitions that are not found in other standards. [Clause 3](#) gives an explanation of distribution fundamentals. [Clause 4](#) discusses system configuration and components. [Clause 5](#) explains the characteristics of protective schemes. Criteria and examples are discussed in [Clause 6](#), including margins and common considerations. [Clause 7](#) has several special applications and considerations for distribution line protection.

This guide also contains two annexes. [Annex A](#) provides the bibliography, and [Annex B](#) contains a glossary of terms defined in other IEEE standards.

1.1 Scope

This guide discusses the application and coordination of protection of power-system distribution lines. It includes the descriptions of the fundamentals, line configurations, and schemes. In addition to these, this guide identifies problems with the methods used in distribution line protection and the solutions to those problems.

1.2 Purpose

This guide educates and provides information on distribution protection schemes to utility engineers, consultants, educators, and manufacturers. The guide examines the advantages and disadvantages of schemes presently used in protecting distribution lines. This provides the user with the rationale for determining the best approach for protecting an electric power distribution system.

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).^{1,2}

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).

¹The use of the word *must* is deprecated and shall not be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

²The use of *will* is deprecated and shall not be used when stating mandatory requirements, *will* is only used in statements of fact.