

IEEE Guide for the Application of Protective Relaying for Phase-Shifting Transformers

IEEE Power and Energy Society

Sponsored by the
Power System Relaying and Control Committee

IEEE Guide for the Application of Protective Relaying for Phase-Shifting Transformers

Power System Relaying and Control Committee
of the
IEEE Power and Energy Society

Approved 23 October 2018

IEEE-SA Standards Board

Abstract: Protection methods for different types of phase shifting transformers (PST) are provided in this guide, and the interaction between protection and operating conditions of PSTs is discussed. Models representing PSTs to determine short circuit currents for relaying functions are presented. Sizing and location issues of protection current transformers employed in the protection of PSTs are included. Examples of appropriate relay applications and settings are provided.

Keywords: advance phase angle, application of multifunction relays for transformer protection, CT saturation, current transformers, differential protection, dual-core design, IEEE C37.245™, overcurrent protection, phase-shifting transformer, power transfer, protection of transformers, retard phase angle, series transformer, single-core design

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

Copyright © 2019 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 24 May 2019. 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.

PDF: ISBN 978-1-5044-5463-6 STD23498
Print: ISBN 978-1-5044-5464-3 STDPD23498

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 Notices and Disclaimers Concerning IEEE Standards Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/ipr/disclaimers.html>.

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. IEEE Standards are documents developed through scientific, academic, and industry-based technical working groups. Volunteers in IEEE working groups 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 Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. 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.

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 from time to time 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, and 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 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 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 U.S.A.

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 standard 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. A current 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 Explorer at <http://ieeexplore.ieee.org/> 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 IEEE standards can be accessed via <https://standards.ieee.org/standard/index.html>. 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: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

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 <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.

Participants

At the time this IEEE guide was completed, the K1 Working Group had the following membership:

Lubomir Sevov, *Chair*
Brandon Davies, *Vice Chair*

Abu Bapary
Stephen Conrad
Randall Crellin
Paul Elkin
Zoran Gajic
Charles Henville

Mahfooz Hilaly
Mohamed Ibrahim
Umar Khan
Dean Miller
Joe Mooney
Eli Pajuelo
Sam Sambasivan

Tony Seegers
Farajollah Souidi
Michael Thompson
Demetrios Tziouvaras
Tom Wiedman
Abu Zahid

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

Ali AlAwazi
Abu Bapary
Jeffrey Barsch
Barry Beaster
Philip Beaumont
W. J. (Bill) Bergman
Martin Best
Gustavo Brunello
Demetrio Bucaneg Jr.
Paul Cardinal
Arvind Chaudhary
Michael Chirico
Stephen Conrad
Luis Coronado
Randall Crellin
Randall Cunico
Brandon Davies
Glenn Davis
Alla Deronja
Dieter Dohnal
Gary Donner
Michael Dood
Paul Elkin
Dominick Fontana
Jean-Sebastien Gagnon
Kamal Garg
Jale Ghorri
Stephen Grier
Randall Groves

Nathan Gulczynski
Roger Hedding
Charles Henville
Scott Hietpas
Mahfooz Hilaly
Werner Hoelzl
Philip Hopkinson
Richard Jackson
John John
Brian Johnson
John Kay
Umar Khan
James Kinney
Boris Kojan
Jim Kucel
Chung-Yiu Lam
Educa Lascu
Don Lukach
Bruce Mackie
J. Dennis Marlow
William McBride
Dean Miller
Joe Mooney
Adi Mulawarman
R. Murphy
K. R. M. Nair
Rhonda Netzel
Michael Newman

Lorraine Odde
Rans Patel
Dhruv Patel
Robert Pettigrew
Alvaro Portillo
Iulian Profir
Lakshman Raut
Charles Rogers
Oleg Roizman
M. Sachdev
Bartien Sayogo
Tony Seegers
Lubomir Sevov
Hyeong Sim
Jerry Smith
Gary Smullin
Wayne Stec
Gary Stoedter
David Tepen
Michael Thompson
Demetrios Tziouvaras
James Van De Ligt
Jason Varnell
John Vergis
Quintin Verzosa
David Wallace
John Wang
Kenneth White
Philip Winston

When the IEEE-SA Standards Board approved this guide on 23 October 2018, it had the following membership:

Jean-Philippe Faure, *Chair*
Gary Hoffman, *Vice Chair*
John D. Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
Guido R. Hiertz
Christel Hunter
Joseph L. Koepfinger*
Thomas Koshy
Hung Ling
Dong Liu

Xiaohui Liu
Kevin Lu
Daleep Mohla
Andrew Myles
Paul Nikolich
Ronald C. Petersen
Annette D. Reilly

Robby Robson
Dorothy Stanley
Mehmet Ulema
Phil Wennblom
Philip Winston
Howard Wolfman
Jingyi Zhou

*Member Emeritus

Currently in preview, click buy full version

Introduction

This introduction is not part of IEEE Std C37.245™-2018, IEEE Guide for the Application of Protective Relaying for Phase-Shifting Transformers.

Phase shifting transformers (PSTs) are applied on the electric power system but typically represent only a small portion of a utility's overall transformer fleet. As such many protection engineers have limited familiarity with PSTs and the considerations behind properly applying relay protection to them. The variety of PST designs and configurations further complicates the process for new engineers to familiarize themselves with PST protection schemes.

This document provides application guidelines for selecting and engineering protection schemes for a variety of commonly applied types of PSTs.

The guide provides a background on the theory and application of PSTs, as well as an overview of common types of both single-core and two-core PSTs. PST overload mitigation techniques, equivalent MVA calculations for use in estimating inrush currents, and PST fault modeling methods and considerations are also discussed. Considerations for current transformer (CT) and voltage transformer (VT) location and settings are provided.

The guide provides a detailed discussion on PST protection schemes, focusing on the microprocessor based protective schemes for both single-core and two-core PST designs.

Setting calculation examples are provided in [Annex A](#) and [Annex B](#).

Contents

1. Overview	13
1.1 Scope	13
1.2 Purpose	13
2. Normative references	13
3. Acronyms and abbreviations	13
4. Device numbers	14
5. Application and theory of PSTs	14
5.1 Introduction	14
5.2 Basic principle of application	14
5.3 Installation configurations	18
6. Types of PSTs	19
6.1 Single-core PSTs	20
6.2 Two-core PSTs	22
7. Equivalent MVA of the PST	24
7.1 MVA calculation for single-core PSTs	25
7.2 MVA calculation for two-core PSTs	25
8. PST overload mitigation	26
8.1 Tap changer switching contact overcurrent mitigation for extreme overloads	27
9. Instrument transformers	27
9.1 Current transformers (CTs)	27
9.2 Voltage transformers (VTs)	28
10. Short circuit study	28
10.1 General	28
10.2 Fault current transfer from load to source side	29
10.3 Modeling of PST for short circuit programs	31
10.4 Short circuit cases to consider	33
11. Protection	33
11.1 Introduction to PST protection	33
11.2 Differential protection	35
11.3 Circulating current (bypass off neutral) protection	50
11.4 Overcurrent protection	51
11.5 Current balance protection	52
11.6 Distance protection	53
11.7 Sudden pressure and Buchholz relays	54
11.8 Transmission line relays	55
Annex A (informative) Setting example, sequence component differential scheme	56
Annex B (informative) Setting example, 87S phase, and magnitude compensation	64
Annex C (informative) Bibliography	68

List of Figures

Figure 1—Quadrature voltage across a PST causes a shift in angle δ	15
Figure 2—Simple network	15
Figure 3—PST added to one branch	16
Figure 4—Phasor diagram with the addition of the PST	17
Figure 5—Three interconnected utilities	17
Figure 6—EHV transmission overlays HV transmission	17
Figure 7—Alternative arrangements of PST bypass and isolating switches and circuit breakers	19
Figure 8—Single-core asymmetric, with tap winding outside the delta, shown in the advanced position	20
Figure 9—Single-core symmetric, with tap winding outside the delta, shown in the advanced position	21
Figure 10—Single-core delta hexagonal, shown in the advanced position	22
Figure 11—Two-core symmetric, shown in the advanced position	23
Figure 12—Two-core asymmetric, shown in the advanced position	24
Figure 13—CT symbols	28
Figure 14—Current directions for external fault on L side of the PST	29
Figure 15—Source side currents for load side single phase to ground fault	30
Figure 16—Source side currents for phase to phase fault on load side	30
Figure 17—PST model typically used in short circuit programs	31
Figure 18—87P relay connections and zone of protection	36
Figure 19—87P three-phase relay connections	37
Figure 20—87S-ATB relay connections and zone of protection	38
Figure 21—PST series unit delta current	39
Figure 22—87S-ATB three-phase relay connections	41
Figure 23—87S-KCL relay connections and zone of protection	43
Figure 24—87S-KCL relay per phase zone of protection	43
Figure 25—87S-KCL three-phase relay connections	44
Figure 26—Differential single-core with three two-phase LTCs	45
Figure 27—Sequence component differential instrument transformer requirements	46
Figure 28—Source side currents for a BC fault on the source side of the PST	46
Figure 29—Load side currents for a BC fault on the source side of the PST	47

Figure 30—Positive sequence currents with angle compensation	48
Figure 31—Negative sequence currents with angle compensation	48
Figure 32—Circulating current element.....	50
Figure 33—PST distance protection.....	53
Figure A.1—Original protection	56
Figure A.2—New protection	57

List of Tables

Table 1—Device numbers and device identification	14
--	----

IEEE Guide for the Application of Protective Relaying for Phase-Shifting Transformers

1. Overview

1.1 Scope

This guide provides protection methods for different types of phase shifting transformers (PSTs) and discusses the interaction between protection and operating conditions of PSTs. Models representing PSTs to determine short circuit currents for relaying functions are presented. Sizing and location issues of protection current transformers employed in the protection of PSTs are included. This guide provides examples of appropriate relay applications and settings.

1.2 Purpose

The purpose of this guide is to provide protection engineers with information that helps them to properly apply relays and other devices to protect phase-shifting transformers.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std C37.91™, IEEE Guide for Protecting Power Transformers.^{1,2}

3. Acronyms and abbreviations

ARS	advance-retard-switch
AT	ampere-turns
ATB	ampere-turns balance
CCVT	capacitance coupled voltage transformer
CT	current transformer
EMTP	electromagnetic transient program

¹The IEEE standards or products referred to in [Clause 2](#) are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).