

IEEE Guide for Transformer Loss Measurement

IEEE Power and Energy Society

Developed by the
Transformer Committee

IEEE Std C57.23™-2019
(Revision of IEEE Std C57.123-2010)

Currently in preview, click buy full version

IEEE Guide for Transformer Loss Measurement

Developed by the

Transformer Committee
of the
IEEE Power and Energy Society

Approved 7 November 2019

IEEE SA Standards Board

Currently in preview, click buy full version

Abstract: Information and general recommendations of instrumentation, circuitry, calibration, and measurement techniques of no-load losses (excluding auxiliary losses), excitation current, and load losses of power and distribution transformers are provided. The guide is intended as a complement to the test code procedures given in [Clause 8](#) and Clause 9 of IEEE Std C57.12.90™.

Keywords: calibration, IEEE C57.123™, load loss, no-load loss, testing, transformers

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

Copyright © 2020 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 10 February 2020. 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 978-1-5044-6327-0 STD23989
Print: ISBN 978-1-5044-6328-7 STDPD23989

IEEE prohibits discrimination, harassment, and bullying.
For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

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, conferences, 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 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 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 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 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 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 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/>. Users are encouraged to periodically check for errata.

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 draft guide was completed, the Performance Characteristics—Transformer Loss Measurement Working Group had the following membership:

Ed TeNyenhuis, *Chair*
Anthony Franchitti, *Vice Chair*

Tauhid Ansari
Reto Fausch
Ramsis Girgis

Mark Perkins
Bertrand Poulin
Eddy So

Andy Steineman
Craig Stiegemeier
Ajith Varghese

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

Samuel Aguirre
Roy Ayers
Peter Balma
Barry Beaster
Jason Bellamy
Thomas Bishop
Thomas Blackburn
Demetrio Bucaneg Jr.
William Byrd
Thomas Callsen
Paul Cardinal
Juan Castellanos
Kurt Clemente
Stephen Conrad
Randall Crellin
John Crouse
Gary Donner
Donald Dunn
Jorge Fernandez Daher
George Frimpong
Nancy Frost
Eduardo Garcia
Ali Ghafourian
Ramsis Girgis
Jalal Gohari
Edwin Goodwin
Randall Groves
Randy Hamilton
John Harlow
William Jennings

Werner Hoelzl
Philip Hopkinson
Christel Hunter
Laszlo Kadar
Peter Kelly
Gael Kennedy
Sheldon Kennedy
Vladimir Khalin
Gary King
James Kinney
Jim Kulchisky
Deepak Kumaria
John Lackey
William Larzelere
Lawrence Long
Bruce Mackie
Darrell Mangiat
Lee Matthews
James McBride
William McBride
Daniel Mulkey
Jerry Murphy
Ali Naderian Jahromi
K.R.M. Nair
Kris K. Neild
Joe Nims
Lorraine Padden
Bansi Patel
Dhiru Patel
Brian Penny
Harry Pepe

Christopher Petrola
Alvaro Portin
Bertrand Poulin
Jean-Christophe Riboud
Zoltan Roman
Rodrigo Ronchi
Daniel Sauer
Bartien Sayogo
Hyeong Sim
George Slama
Jerry Smith
Gary Smullin
Craig Stiegemeier
Gary Stuedter
Allan St. Peter
Vijay Tendulkar
Ed TeNyenhuis
David Tepen
Malcolm Thaden
James Thompson
Jason Varnell
Roger Verdolin
John Vergis
David Wallace
David Wallach
John Wang
Joe Watson
Kenneth White
Jian Yu
Waldemar Ziomek

When the IEEE-SA Standards Board approved this guide on 7 November 2019, it had the following membership:

Gary Hoffman, *Chair*
Ted Burse, *Vice Chair*
Jean-Philippe Faure, *Past Chair*
Konstantinos Karachalios, *Secretary*

Masayuki Ariyoshi
Stephen D. Dukes
J. Travis Griffith
Guido Hiertz
Christel Hunter
Thomas Koshy
Joseph L. Koepfinger*
Thomas Koshy

John D. Kulick
David J. Law
Joseph Levy
Howard Li
Xiaohui Liu
Kevin Lu
Daleep Mohla
Andrew Myles

Annette D. Reilly
Dorothy Stanley
Sha Wei
Phil Wennblom
Philip Winston
Howard Wolfman
Feng Wu
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std C57.123, IEEE Guide for Transformer Loss Measurement.

This guide was originally initiated to explain in more detail the accuracy requirements, test code procedures, various available test methods, methods to diagnose test anomalies, and the procedures for calibration and safety.

In this latest revision, the following updates were made:

- Better explanation of parameters affecting core loss measurement in [3.2](#)
- Added explanation in [3.5.3](#) for the usage of capacitors in parallel with the voltage source to reduce voltage distortion during no load loss measurement
- Added [3.8](#) about no-load loss measurements using three phase power analyzer to recognize that most measurements are now made with digital instruments
- Added an alternate load loss wattmeter-voltmeter-ammeter test method in [4.6](#)
- Updated modern power loss measurements systems in [Clause 5](#)
- Added explanation of system calibration versus component calibration in [Clause 7](#)
- Added new references to the bibliography
- Removed [8.3](#) on safety

Contents

1. Overview	12
1.1 Scope	12
1.2 Purpose	12
2. Normative references	13
3. Transformer no-load losses	13
3.1 General	13
3.2 Parameters affecting magnitude of no-load losses	13
3.3 Excitation current (no-load current)	17
3.4 Test requirements	17
3.5 Measurement of no-load losses	19
3.6 Measurement of excitation current	24
3.7 Measuring circuitry for three-phase transformers	24
3.8 No-load loss measurements using three phase power analyzers	28
4. Transformer load losses	29
4.1 General	29
4.2 Measuring circuitry	29
4.3 Load-loss measurement uncertainties	30
4.4 Corrections to measured load losses	31
4.5 Measuring circuitry for three-phase transformers	38
4.6 Alternate load loss wattmeter-voltmeter-ammeter method	41
5. Advanced power loss measuring systems	44
5.1 Enhanced conventional power loss measurement system	44
5.2 Advanced voltage and current transducers	44
6. Specified tolerances on losses	45
6.1 Specified tolerances on no-load losses	45
6.2 Specified tolerances on total losses	47
7. Traceability and calibration	48
8. Grounding and shielding	49
8.1 Grounding	49
8.2 Shielding	50
Annex A (informative) Bibliography	51

List of Figures

Figure 1—Transformer supply circuit at no-load test.....	14
Figure 2—A typical excitation current waveform and harmonic content.....	15
Figure 3—Vector diagram of the two main components of the excitation current.....	18
Figure 4—Excitation current components at different excitation voltage levels.....	18
Figure 5—Connections for no-load loss test of a single-phase transformer.....	20
Figure 6—Excitation voltage and current waveshapes for a low impedance source.....	22
Figure 7—Excitation voltage and current wave-shapes for a high impedance source.....	22
Figure 8—High impedance source with greater distorted voltage waveshape.....	23
Figure 9—High impedance source with highly distorted voltage waveshape and multiple voltage zero-line crossings.....	23
Figure 10—Three-wattmeter circuit.....	25
Figure 11—Phase-to-phase and phase-to-neutral voltage waveforms.....	26
Figure 12—Three-wattmeter method, energized winding wye-connected, with transformer neutral available, without instrument transformer.....	27
Figure 13—Three-wattmeter method, energized winding delta-connected, without instrument transformers.....	27
Figure 14—Three-wattmeter method, energized winding wye-connected, without instrument transformers (with transformer neutral unavailable).....	27
Figure 15—Three-wattmeter method, energized winding wye-connected with neutral grounded.....	28
Figure 16—Three-wattmeter method, energized winding delta-connected, grounded wye source.....	28
Figure 17—Load-loss measurement circuit for a single-phase transformer.....	30
Figure 18—Typical values of load-loss power factor for large power transformers.....	31
Figure 19—Percent error in measured losses per minute of phase-angle error.....	31
Figure 20—Vector diagram for a power transformer under load-loss test conditions (V_v is voltage across voltmeter).....	32
Figure 21—Measurement of shorting connection losses—approximate method.....	35
Figure 22—Measurement of shorting connection losses using a clamp-on wattmeter.....	35
Figure 23—Measurement of shorting connection losses using the wattmeter method.....	36
Figure 24—Circuitry for automatic correction for shorting connection losses.....	36
Figure 25—Example of magnitude and phase-angle errors of a typical current transformer used in load-loss measurements.....	37
Figure 26—Example of magnitude and phase-angle errors of a typical potential transformer used in load-loss measurements.....	38

Figure 27—Load-loss measurement circuitry using instrument transformers.....	39
Figure 28—Test of three-phase transformer with single-phase voltage.....	39
Figure 29—Alternate method for load loss measurement of a single-phase transformer using capacitive compensation at the terminals of the transformer under test.....	42
Figure 30—Alternate method of three-phase transformer connections for load loss and impedance voltage tests using wye-connected capacitors	43
Figure 31—Alternate method of three-phase transformer connections for load loss and impedance voltage tests using delta-connected capacitors	43
Figure 32—Measured no-load loss of a multi-unit order of small distribution transformers.....	46
Figure 33—Measured/calculated ratio of no-load loss of a multi-unit order of small distribution transformers	46
Figure 34—Measured/average measured ratio of no-load loss of a multi-unit order of medium size power transformers.....	47

IEEE Guide for Transformer Loss Measurement

1. Overview

1.1 Scope

This guide provides background information and general recommendations of instrumentation, circuitry, calibration, and measurement techniques of no-load losses (excluding auxiliary losses), excitation current, load losses of power, and distribution transformers. The test codes, namely, IEEE Std C57.12.90™, IEEE Std C57.12.91™, and the test code section of IEEE Std C57.15™ provide specifications and requirements for conducting these tests. This guide has been written to provide supplemental information for each test. More technical details of the measuring instruments and techniques presented in this guide can be found in the document developed by So [B23]. This guide applies to liquid-immersed power and distribution transformers, dry-type transformers, and step-voltage regulators. Additionally, it applies to both single- and three-phase transformers.

1.2 Purpose

The purpose of the guide is:

- To describe the basis and methodology by which the accuracy requirements of [Clause 8](#) and [Clause 9](#) of IEEE Std C57.12.90 for liquid-immersed transformers and IEEE Std C57.12.91 for dry-type transformers can be achieved.
- To explain why the test code specifies certain procedures and limits.
- To explain advantages and disadvantages of different test methods where alternative methods are available.
- To explain practical limitations and valid means of overcoming them.
- To give theoretical basis for interpolation/extrapolation of tested data and valid limits.
- To explain test anomalies—how they result, what they mean, and how to handle them.
- To give procedures for calibration, certification, and traceability of measurement processes to reference standards.
- To discuss procedures for grounding and shielding.
- To provide schematics and examples to clarify concepts and demonstrate methodologies.