IEEE STANDARDS ASSOCIATION

IEEE Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability when Supplying Nonsinusoidal Load Currents

IEEE Power and Energy Society

Sponsored by the
Transformers Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std C57.110™-2018
(Revision of IEEE Std C57.110-2008)

IEEE Std C57.110™-2018
(Revision of IEEE Std C57.110-2008)

IEEE Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability when Supplying Nonsinusoidal Load Currents

Sponsor

Transformers Committee
of the
IEEE Power and Energy Society

Approved 14 June 2018

IEEE-SA Standards Board

Abstract: Provided in this recommended practice are calculation methods for conservatively evaluating the feasibility for an existing installed dry-type or liquid immersed transformer, to supply nonsinusoidal load currents as a portion of the total load. Also provided is necessary application information to assist in properly specifying a new transformer expected to carry a load, a portion of which is composed of nonsinusoidal load currents. A number of examples illustrating these methods and calculations are presented. Reference annexes provide a comparison of the document calculations to calculations found in other industry standards. Suggested temperature rise calculation methods are detailed for reference purposes.

Keywords: current harmonics, harmonic loss factor, IEEE C57.110™, k-factor, nonsinusoidal load currents

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

PDF: ISBN 978-1-5044-5007-2 STD23180
Print: ISBN 978-1-5044-5008-9 STDPD23180

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 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 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.

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. 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 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 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

At the time this IEEE recommended practice was completed, the C57.110 Working Group had the following membership:

Richard P. Marek, *Chair*
Samuel L. Sharpless, *Secretary*

Javier Arteaga
Robert Ballard
Jagdish Burde
Carl Bush
Derek Foster
Kenneth Harden
Gary Hoffman
Timothy Holdway
Thomas Holifield
Charles Johnson
Sheldon Kennedy
Lawrence Kirchner
Aleksandr Levin
Tim-Felix Mai
Hasse Nordman
Dhiru Patel
Rodrigo Ronchi
Amitabh Sarkar
Sanjib Som
David Stankes
Vijay Tendulkar
Kiran Vedante
David Walker

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

Samuel Aguirre
Tauhid Haque Ansari
Stephen Antosz
I. Antweiler
Donald Ayers
Robert Ballard
Peter Balma
Thomas Barnes
Barry Beaster
Enrique Betancourt
Steven Bezner
Wallace Binder
Thomas Blackburn
W. Boettger
Jon Brasher
Jeffrey Brogdon
Demetrio Bucaneg Jr.
Thomas Callsen
Paul Cardinal
Wen-Kung Chang
Michael Chirico
Stephen Conrad
Randall Crellin
John Crouse
Dieter Dohnal
Gary Donner
Jorge Fernandez Daher
Joseph Foldi
Derek Foster
Fredric Friend
Saurabh Ghosh
Ramsis Girgis
Jalal Gohari
Edwin Goodwin
Randall Groves
Said Hachichi
John Harley
Roger Hayes
Roger Hedding
Werner Hoelzl
Gary Hoffman
Thomas Holifield
John Houdek
Mohammad Iman
Richard Jackson
John John
Charles Johnson
Laszlo Kadar
C. Kalra
John Kay
Peter Kelly
Gael Kennedy
Sheldon Kennedy
Zan Kiparizoski
Axel Kraemer
Jim Kulchisky
John Lackey
Mikhail Lagoda
Chung-Yiu Lam
Aleksandr Levin
Thomas Lundquist
Tim-Felix Mai
Richard P. Marek
Lee Matthews
Omar Mazzoni
James McBride
Nigel McQuin
Charles McShane
Daleep Mohla
Daniel Mulkey
Jerry Murphy
K.R.M. Nair
Arthur Neubauer
Michael Newman
Raymond Nicholas
Joe Nims
Bansi Patel
Dhiru Patel
Christopher Petrola
Jim Phillips
Alvaro Portillo
Iulian Profir
Johannes Rickmann
Charles Rogers
Oleg Roizman
Rodrigo Ronchi
Thomas Rozek
Ryandi Ryandi
Daniel Sauer
Bartien Sayogo
Stephen Schroeder
Nikunj Shah
Samuel L. Sharpless
Hyeong Sim
Jeremy Smith
Jerry Smith
Gary Smullin
Sanjib Som
Brian Sparling
David Stankes
Gary Stoedter
Ed TeNyenhuis
David Tepen
Juan Thierry
James Van De Ligt
Jason Varnell
John Vergis
David Walker
Kenneth White
Jian Yu
Nicholas Zagrodnik

When the IEEE-SA Standards Board approved this recommended practice on 14 June 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

Introduction

This introduction is not part of IEEE Std C57.110-2018, IEEE Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability when Supplying Nonsinusoidal Load Currents.

One side effect of the trend toward energy efficiency is the increase in harmonic current flowing in the power system. The widespread use of solid state electronics in industrial and residential loads on small and medium power dry-type and liquid immersed transformers has resulted in a dramatic increase in the harmonic content of the load current of these transformers. It has become common for the harmonic factor of the current to exceed 0.05 per-unit, which is the limit specified for "usual service conditions" in IEEE Std C57.12.00™ and IEEE Std C57.12.01™. The higher harmonic content in the load current of these transformers causes higher eddy current loss in the windings and the structural parts linked by the transformer leakage flux and, consequently, higher operating temperatures. In addition, harmonic load currents reduce the efficiency of the transformer. Users of this document should also recognize that liquid immersed transformers may have different load limitations than dry-type transformers and that the harmonic loading practices should treat the two types of transformers differently when necessary.

This recommended practice provides guidance for the conservative loading of transformers carrying nonsinusoidal load currents so that overheating is avoided. The intent of this document is to provide simple methods of calculating these effects on either a new transformer or an existing transformer. More specifically, it is expected that this recommended practice would be used for the following situations:

a) A new transformer required to carry some nonsinusoidal load currents, but will not be entirely devoted to a rectifier load.

b) An existing transformer not originally specified for supplying nonsinusoidal load currents, but is now required to supply a load, a portion of which is nonsinusoidal.

Two methods are described in this recommended practice. The first method is intended to illustrate calculations by those with access to detailed information on loss density distribution within each of the transformer windings. The second method is less accurate and is intended for use by those with access to transformer certified test report data only. It is anticipated that the first method will emphasize the information necessary to specify a new transformer and show how this information is used by transformer design engineers, whereas the second method will be employed primarily by users. This recommended practice provides methods for conservatively evaluating the feasibility of applying nonsinusoidal load currents to existing transformers and clarifies the requirements for specifying new transformers to supply nonsinusoidal loads.

New transformers that are intended to supply loads with high harmonic content must be specified with a harmonic current spectrum. The designer cannot assume nor can the user expect the designer to use standard or typical current distribution tables. If the harmonic content of the load is unknown, then both the user and the transformer designer are at risk and reasonable steps should be taken to help ensure a conservative design for the application. Guidelines on how this information is used to develop proper transformer sizing is provided in this document, but appropriate calculations specific to the type of transformer design are the responsibility of the designer. Approximate calculation techniques that provide conservative results are provided for the typical user who has much less information than the transformer designer.

In the latest revision of this recommended practice, the document was updated to current IEEE styles, and general revisions were made. In addition, substantial additions were made to the references and three new annexes were added. Annex C provides information on skin effect in addition to eddy and other losses that were previously discussed. Annex F aids the user in understanding the impact of the highest eddy losses as compared to the average values, and Annex G provides sample loss data for eddy current and other stray losses across a range of distribution transformers.

Contents

IEEE Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability when Supplying Nonsinusoidal Load Currents

1. Overview

1.1 Scope

This recommended practice applies only to two winding transformers covered by IEEE Std C57.12.00, IEEE Std C57.12.01, and NEMA ST20.[1] It does not apply to rectifier transformers.[2]

1.2 Purpose

The purpose of this document is to establish uniform methods for determining the capability of transformers when supplying nonsinusoidal load currents of known characteristics.

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 C57.12.00™, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.[3,4]

IEEE Std C57.12.01™, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid Cast and/or Resin-Encapsulated Windings.

[1]Information on references can be found in Clause 2.
[2]Rectifier transformers are addressed by IEEE Std C57.18.10™, IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers.
[3]IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards/ieee.org/).
[4]The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.