

C57.119™

IEEE Recommended Practice for Performing Temperature Rise Tests on Oil-Immersed Power Transformers at Loads Beyond Nameplate Ratings

Power Engineering Society

Sponsored by the
Transformers Committee



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Abstract: Recommendations are made, where possible, regarding the performance and evaluation of temperature rise tests on oil-immersed power transformers beyond nameplate ratings. The intent is to assist power transformer manufacturers, and the ultimate users, in evaluating thermal performance of the transformers under varying loads.

Keywords: bottom oil temperature, conditioning loads, hottest spot factor, loading, load tap changer, mineral-oil-immersed, power transformers, rated load, thermal capacity, top oil temperature

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Introduction

(This introduction is not a part of IEEE Std C57.119-2001, IEEE Recommended Practice for Performing Temperature Rise Tests on Oil-Immersed Power Transformers at Loads Beyond Nameplate Ratings.)

This introduction provides background related to the development of this recommended procedure. Additional information may be found in Annex B.

Over the years, there has been a marked increase in the practice of loading transformers beyond their nameplate rating. In the past, many transformers were loaded beyond nameplate rating only during short time emergencies. Today, many users have established loading practices which subject transformers to loads beyond nameplate rating on a planned basis during periods of seasonal or daily peak loads, in addition to unexpected loads occurring during short or long time emergencies.

Former ANSI loading guide C57.91 provided loading guidelines for distribution transformers, ANSI C57.92 provided loading guidelines for power transformers rated 100 MVA and below, and IEEE Std C57.115TM provided loading guidelines for transformers rated above 100 MVA. All of these documents have been combined into a revised IEEE Std C57.91TM. These documents provide transformer loading guidelines based on judgment gained from years of experience of loading transformers. However, prior to this document, no standard test procedure existed to evaluate the consequences of loading a transformer at loads beyond nameplate rating.

Investigations carried out in the past by transformer users raised concern about the accuracy of the equations and empirical constants used in the transient loading equations of these loading guides. Their experience with monitoring operating transformers indicated that transformers could carry loads greater than nameplate rating, without apparent damage. Also, there has been concern that ancillary equipment, such as tap changers, bushings, and instrumentation may not have the same overload capabilities as the core and coil assembly.

The above conditions and concerns led to a desire for a test procedure that would:

- a) Provide data on the thermal characteristics of oil-immersed transformers to be used to evaluate the accuracy of the equations and empirical constants used in the loading equations in the oil-immersed transformer loading guides.
- b) Demonstrate that a transformer may be loaded with a specified sequence of loads, including loads beyond nameplate rating, without exceeding those temperatures specified or agreed upon by the user and manufacturer.
- c) Demonstrate that the ancillary equipment on an oil-immersed transformer would not impose limitations on those loading conditions recommended in the loading guides.

This guide describes three test procedures. Clause 9 describes a test procedure for determining the thermal characteristics of an oil immersed power transformer. Clause 10 describes a test procedure for performing load cycle temperature rise tests to assess the capability of a transformer to be loaded with a specific load cycle. Clause 11 describes a recommended integrated procedure for determining thermal characteristics and performing a load cycle temperature rise test.

It is anticipated that data obtained from tests performed in accordance with these procedures will be collected and analyzed by a future IEEE Working Group to establish a database that can be utilized to improve the accuracy of the assumptions and equations used in future loading guides.

References to other standards have been updated where applicable and all units of measurements are specified in metric units only, wherever practical

All cooling class designations have been replaced with new cooling class designations per Table 2 of IEEE Std C57.12.00TM.-2000.

Participants

The working group that coordinated the final compilation of this standard had the following membership:

Subhash Tuli, *Chair*

Kenneth J. Fleming

At the time this recommended procedure was completed, the Thermal Test Working Group had the following membership:

Robert L. Grubb, *Chair*

Donald J. Fallon, *Secretary*

Jacques Aubin
Donald E. Ayers
Ronald L. Barker
Michael F. Barnes
Barry L. Beaster
William E. Boettger
Jerry L. Corkran
James Cross
Frank David
Jeff Fleeman
Michael A. Franchek
Monroe L. Frazier
David F. Goodwin
George Henry

Keith R. Highton
John J. Hinkson
Virendra Jhonsa
Eugene Kallaur
Jim Long
Donald L. Lowe
John W. Matthews
C. J. McMillen
William J. McNutt
C. K. Miller
R. E. Minkwitz, Sr.
Steve P. Moore
Ed Norton

Dennis Orten
Mark D. Perkins
V. Q. Pham
Linden W. Pierce
Donald W. Platts
Vallamkonda Sankar
Vic Shenoy
Hyeong Jin Sim
Ronald W. Stoner
Malcolm Thaden
Subhash C. Tuli
Robert A. Veitch
Felipe N. Weffer
Robert J. Whearty

Other individuals who have made significant contributions to the development of this document as former members of the Thermal Test Working Group are the following:

John J. Bergeron
Orion O. Chew

David H. Douglas

James J. Kunes
Dave Takash

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

Paul Ahrens	Roger R. Hayes	Dan D. Perco
Dennis J. Allan	William R. Henning	Mark D. Perkins
Jim C. Arnold	Keith R. Highton	Linden W. Pierce
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James H. Harlow	Paulette A. Payne	F. N. Young

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IEEE Recommended Practice for Performing Temperature Rise Tests on Oil-Immersed Power Transformers at Loads Beyond Nameplate Ratings

1. Overview

This document consists of three recommended test procedures, each to determine or verify transformer thermal capabilities for different purposes. Clause 1 through Clause 8 include information applicable to all three test procedures. Clause 9 is a recommended test procedure for determining the thermal characteristics of an oil-immersed power transformer from data obtained from three temperature rise tests at three specified loads. Clause 10 is a recommended procedure for performing a temperature rise test while applying a varying load, conforming to a specified loading profile, to verify that specified transformer temperatures do not exceed guaranteed values when the transformer is loaded to the specified loading profile. Clause 11 is a recommended procedure, combining the procedures in Clause 9 and Clause 10, with the objective of achieving the purpose of both clauses with reduced test time. Clause 11 is similar to Clause 10, except that the three loads are selected to simulate the temperatures expected to occur during a specific load cycle. Each of the procedures may be performed independent of the other. However, it is recommended that tests per Clause 9 be performed before Clause 10, if both tests are to be performed.

1.1 Scope

This recommended practice covers temperature rise test procedures for determining those thermal characteristics of power transformers needed to appraise the transformer's load carrying capabilities at specific loading conditions other than rated load.

1.2 Purpose

These recommended test procedures for performing temperature rise tests on power transformers are for the purpose of

- a) Determining the thermal characteristics of a transformer needed to appraise the thermal performance of a transformer at loads other than nameplate rating
- b) Verifying that a transformer can be loaded with a specified load profile without exceeding specified temperature rise

- c) Assessing a transformer's performance during transient loading, simulating a load cycle that includes loads in excess of nameplate rating

Tests performed in accordance with Clause 9 are for the purpose of determining transformer thermal characteristics in a consistent manner. Data may then be accumulated from a large number of transformers and used to evaluate the accuracy of the equations and the empirical constants used in the loading guides.

Tests performed in accordance with Clause 10 are for the purpose of demonstrating the thermal effects of loading a transformer with a specified sequence of loads, including loads beyond nameplate rating.

Tests performed in accordance with Clause 11 are for the combined purposes of determining the thermal characteristics of a transformer and demonstrating the thermal effects of loading with a designated load cycle. This is accomplished by performing temperature rise tests at three loads, similar to Clause 9, except the three loads are selected to simulate the thermal effects of a specific load cycle.

It is not intended that all of these procedures be performed on a transformer design. It is intended that only one of the following combination of test procedures be specified:

- a) Clause 9 only, when thermal characteristics are to be determined.
- b) Clause 10 only, when only verification of complying with temperatures limits when loaded to a specific load profile is needed.
- c) Clause 9 plus Clause 10, when both thermal characteristics and verification of compliance with temperature limits when loaded to a specific load profile are needed.
- d) Clause 11 when both thermal characteristics and verification of compliance with temperature limits when loaded to a specific load profile are required, and the load profile can be represented with three steady state loads.

The user should specify which of the test procedures are required at the time of specification.

A further purpose of these procedures is to obtain information with respect to possible loading limitations imposed on the transformer by oil levels and ancillary equipment when the transformer is operated at loads beyond nameplate rating.

2. References

This recommended practice shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI C57.12.10-1997, American National Standard for Transformers 230 kV and Below 833/958 through 8333/10 417 kVA, Single-Phase, and 750/862 through 60 000/80 000/100 000 kVA, Three-Phase without Load Tap Changing; and 3750/4687 through 60 000/80 000/100 000 kVA with Load Tap Changing—Safety Requirements.¹

IEEE PC57.130/D13, Draft Guide for the Detection and Identification of Gases Generated in Oil Immersed Transformers During Factory Tests.²

¹ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

²This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

IEEE Std C57.12.00™-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.^{3, 4}

IEEE Std C57.12.80™-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90™-1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short Circuit Testing of Distribution and Power Transformers.

IEEE Std C57.91™-1995, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

IEEE Std C57.104™-1991, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.

NOTE—At the time this guide was approved, IEEE PC57.130, Draft Guide for Gas Analysis During Factory Tests was in the development process. When issued, it should be used as a reference instead of IEEE Std C57.104-1991.

3. Definitions and symbols

3.1 Definitions

For the purposes of this recommended practice, the following terms and definitions apply. Unless otherwise specified, transformer-related terms are defined in IEEE C57.12.80-1978.⁵ *The Authoritative Dictionary of IEEE Standards Terms* [B10]⁶ should be referenced for terms not defined in this clause.

3.1.1 average winding temperature: The average temperature of the hottest winding as determined from the ohmic resistance measured across the terminals of the winding in accordance with the cooling curve procedure specified in IEEE Std C57.12.90-1999.

3.1.2 average winding temperature rise: The arithmetic difference between the average winding temperature and the average temperature of the air surrounding the transformer.

3.1.3 directed flow (oil-immersed forced oil cooled transformers): This indicates that the principal part of the pumped oil from heat exchangers or radiators is forced, or directed, to flow through specific paths in the winding.

3.1.4 equilibrium temperature: A temperature of a measured quantity that does not vary by more than 2.5% or 1 °C, whichever is greater, during a consecutive 3-hour period.

3.1.5 exponent m : One-half of the exponential power of per unit load current K versus winding temperature rise.

NOTE—This definition of m is not in strict accordance with the definition in previous loading guides IEEE Std C57.92-1981 and IEEE Std C57.115-1991. These loading guides defined the exponent m as a function of losses but used it as an exponent of the load [see Annex A, Equation (A.2)]. The definition above is in accordance with the use of the exponent in the equations in these documents and with the definition in IEEE Std C57.91-1995.

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⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁵Information on references can be found in Clause 2.

⁶The numbers in brackets correspond to those of the bibliography in Annex D.

3.1.6 exponent n : The exponential power of $(K^2R + 1)/(R + 1)$ versus top oil temperature rise.

NOTE—This definition of n is not in strict accordance with previous loading guides IEEE Std C57.92-1981 or IEEE Std C57.115-1991TM. These loading guides defined n as an exponent of the total loss versus top oil temperature rise. However, the loading guides calculate the ultimate top oil temperature rise at any per unit load K using a function of load, $(K^2R + 1)/(R + 1)$, to estimate the total losses. Because of assumptions made to simplify this loss function, the exponent obtained experimentally from a plot of measured losses versus temperature rise may be different than an exponent determined as a function of $(K^2R + 1)/(R + 1)$. In this procedure, n is defined and experimentally determined as a function of $(K^2R + 1)/(R + 1)$ rather than the losses, to be consistent with its use in the equations in the previous loading guides and with IEEE Std C57.91-1995TM.

3.1.7 heat exchanger: An oil-to-air, or oil-to-water, heat exchanging device attached to an oil-filled transformer for the purpose of exchanging heat from the transformer oil to the ambient media, typically requiring pumps for oil circulation and fans for circulation of the ambient air across the heat exchanging surfaces.

3.1.8 hottest spot temperature: The maximum temperature of the surface of any current-carrying conductor in contact with oil or insulation. *See also:* **winding hottest spot temperature.**

3.1.9 nondirected flow (oil-immersed forced oil cooled transformers): This indicates that the pumped oil from heat exchangers or radiators flows freely inside the tank, and it is not forced to flow through the winding.

3.1.10 oil-immersed transformer: A transformer in which the core and coils are immersed in an insulation oil.

3.1.11 radiator: An oil-to-air heat exchanging device attached to a transformer for the purpose of exchanging sufficient heat from the transformer oil to the ambient air by natural convection of oil and air to comply with the ONAN rating temperature rise requirements. Additional heat may be exchanged by the addition of forced circulation of the ambient air or oil.

3.1.12 transformer: An oil-immersed power transformer rated in accordance with IEEE Std C57.12.00-2000 and ANSI C57.12.10-1997.

3.1.13 top oil temperature: The temperature measured below the top surface of the oil in a transformer in a location to represent the average temperature of the topmost layer of oil in the transformer. It is the temperature of the mixed oil that has circulated across the various heated surfaces inside the transformer and risen toward the top surface.

3.1.14 winding hottest spot temperature: The maximum temperature of the surface of any winding conductor in contact with insulation or oil.

3.2 Symbols

Symbols listed in this clause and used in equations throughout this document have been selected in accordance with standard symbols adopted by the IEEE Transformers Committee, October 1988. Additional symbols, when required, were assigned following the style of the adopted symbols.

Users of this procedure are cautioned that some of these symbols may be different from those used in the referenced loading guides, which do not use symbols consistently. These loading guide equations have been rewritten in Annex A using symbols consistent with this document.

Unless otherwise expressed, all temperatures and temperature differences are in degrees Celsius, and all times and time constants are in hours.

- C is the thermal capacity of transformer (watt-hours/°C). Also used as an abbreviation for degrees Celsius, as in °C.
- e is the base of natural logarithm, 2.71828, (dimensionless).
- F_H is the hottest spot factor (dimensionless).
- IL_1, IL_2, IL_3 are the load currents corresponding to loads L_1, L_2, L_3 (A).
- $n_1, I_{n2}, I_{n3}, \dots, I_{nj}$ is the incremental current added to the load current for each interval of the load cycle test (A).
- I_R is the rated line current at 100% of maximum nameplate rating.
- I_{T1}, I_{T2}, I_{T3} is the total current during tests simulating loads, L_1, L_2 , and L_3 , equal to the sum of the load current and an additional current to simulate no-load losses (A).
- K is the ratio of load L to rated load (dimensionless).
- K_c is the ratio of conditioning load to rated load (dimensionless).
- K_{T1}, K_{T2}, K_{T3} is the ratio of per unit loads simulated by the three temperature rise tests, 9.5, 9.6, and 9.7, to the rated load (dimensionless).
- K_{L1}, K_{L2}, K_{L3} is the ratio of per unit current (reduced currents) held at the ends of the tests 9.5, 9.6, and 9.7 to the rated load current (dimensionless).
- L is the load under consideration in any units.
- L_c is the RMS load of a 12-hour period preceding the period in the load cycle selected for the initial load (kVA).
- L_R is the rated load (kVA).
- L_1, L_2, L_3 are the loads simulated by temperature rise tests at reduced load (10.6), rated load (10.5), and load beyond nameplate rating (10.7) (kVA).
- $L_1, L_2, L_3, \dots, L_j$ are the loads held during time intervals, $t_1, t_2, t_3, \dots, t_j$ (kVA).
- m is (oil exponent) one-half the exponential power of per unit load current K versus winding temperature rise (see NOTE in 3.1.5).
- n is the exponential power of $(K^2R + 1)/(R + 1)$ versus top oil temperature rise (see NOTE in 3.1.6).
- ΔP is the change in total loss due to change in load current (W).
- P_{NL} is the no-load loss corrected to the reference temperature specified in IEEE Std C57.12.00-2000.
- P_R is the total loss at rated load current equal to the sum of the load loss at rated current and no-load loss, both determined per IEEE Std C57.12.90-1999 and corrected to reference temperatures as specified in IEEE Std C57.12.00-2000.

- P_{L1}, P_{L2}, P_{L3} are the total measured losses at loads L_1, L_2, L_3 , respectively, when temperatures have stabilized (W).
- R is the ratio of load loss at rated load to no-load loss (dimensionless).
- t is the duration of load (h).
- $t_1, t_2, t_3, \dots, t_j$ are the time periods into which the load cycle is divided (h).
- $\Delta\Theta_{AO, W}$ is the average oil temperature rise of oil in winding over ambient temperature ($^{\circ}\text{C}$).
- $\Delta\Theta_{BO}$ is the bottom oil temperature rise over ambient temperature ($^{\circ}\text{C}$).
- $\Delta\Theta_H$ is the winding hottest-spot temperature rise over top oil temperature ($^{\circ}\text{C}$).
- $\Delta\Theta_{H, R}$ is the winding hottest-spot temperature rise over top oil temperature at rated load ($^{\circ}\text{C}$).
- $\Delta\Theta_{TO, R}$ is the top oil temperature rise over ambient temperature at rated load ($^{\circ}\text{C}$).
- $\Delta\Theta_{TO}$ is the top oil temperature rise over ambient temperature ($^{\circ}\text{C}$).
- $\Delta\Theta_{TO, i}$ is the initial top oil temperature rise at the beginning of the load cycle ($^{\circ}\text{C}$) test, $t = 0$ ($^{\circ}\text{C}$).
- $\Delta\Theta_{TO, 1}, \Delta\Theta_{TO, 2}, \Delta\Theta_{TO, 3}$ is the top oil temperature rise over ambient temperature when temperatures have stabilized during loads L_1, L_2, L_3 , respectively ($^{\circ}\text{C}$).
- $\Delta\Theta_{TO, U}$ is the ultimate top oil temperature rise for load L ($^{\circ}\text{C}$).
- $\Delta\Theta_{TO/A}$ is the temperature rise of top oil above the ambient air temperature ($^{\circ}\text{C}$).
- $\Delta\Theta_W$ is the average winding temperature rise over average oil temperature ($^{\circ}\text{C}$).
- $\Delta\Theta_{W1}, \Delta\Theta_{W2}, \Delta\Theta_{W3}$ are the average winding temperature rises over average oil temperatures when temperatures have stabilized during loads L_1, L_2, L_3 , respectively ($^{\circ}\text{C}$).
- Θ_A is the average temperature of the ambient air surrounding the transformer ($^{\circ}\text{C}$).
- Θ_H is the temperature of the hottest spot in the transformer winding ($^{\circ}\text{C}$).
- Θ_{TO} is the top oil temperature ($^{\circ}\text{C}$).
- τ_{TO} is the (oil time constant) thermal time constant of the transformer top oil temperature rise for any load L and for any specific temperature differential between the ultimate top oil rise and the initial top oil rise (h).
- τ_R is thermal time constant of transformer top oil temperature rise for rated load beginning with initial temperature rise of 0°C (h).
- τ_W is the winding time constant) thermal time constant of the average winding temperature rise above oil temperature (h).