



IEEE Guide for Temperature Measurements for Liquid-Immersed Transformers and Reactors

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.165™-2024

STANDARDS

IEEE Guide for Temperature Measurements for Liquid-Immersed Transformers and Reactors

Developed by the

Transformers Committee
of the
IEEE Power and Energy Society

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IEEE SA Standards Board

Abstract: The function and life expectancy of a transformer or reactor are directly related to the temperatures experienced by its components and structures. While temperature control schemes and data-gathering activities may be employed in an effort to keep temperatures within favorable levels, the accurate and timely measurement of temperature must be achieved before any controls or gathering of data can be effective. At the center of a transformer's thermal performance is winding temperature. It is the primary factor that drives thermal activity in every other structure and material in the transformer. Thus, this topic is well covered in this guide. Other structures, such as ties, taps, and bushings, do produce some local heat and are also topics that are discussed. Thermal modifying elements such as insulating liquid, fans, and pumps are discussed but only insofar as temperature measurements are affected by them. The temperature of the ultimate heat sink, typically air, water, or some other liquid, is particularly important, since the effective removal of the heat produced by the windings is predicated on efficient transfer of heat energy to a lower energy mass. To help ensure temperature-moderating functions are being properly performed by auxiliaries such as fans and pumps, measurements of motor temperatures or motor current are sometimes employed. All of these topics are discussed along with recommended equipment for and methods of making accurate and timely temperature measurements.

Keywords: bushing, IEEE C57.165™, liquid, load tap changer, reactor, tap, temperature, tie, transformer, winding

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

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Mark Tostrud, *Chair*
Zan Kiparizoski, *Vice Chair*

Gilles Bargone	Balakrishnan Mani	Steven Schappell
Jean-Noel Berube	Martin Munoz Molina	Stefan Schindler
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Hakim Dulac	Ryan Musgrove	Mark Shem-Tov
John John	Parminder Panesar	Babanna Suresh
Sheldon Kennedy	Oleg Roizman	Trenton Williams

The working group gratefully acknowledges the contributions of previous chair Phil McClure and previous vice chair Bob Thompson to the creation of this guide.

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

Stephen Antosz	Richard Jackson	Jean-Christophe Riboud
Peter Balma	John John	Pierre Riffon
Gilles Bargone	Laszlo Kadar	Charles Rogers
Thomas Barnes	Kurt Kaineder	Oleg Roizman
Barry Beaster	John Kay	Rodrigo Ronchi
Jean-Noel Berube	Gael Kennedy	Marnie Roussell
Enrique Betancourt	Sheldon Kennedy	Maresh Sampat
Steven Bezner	James Kinney	Daniel Sauer
Wallace Binder	Zan Kiparizoski	Roderick Sauls
Thomas Blackburn	John Lackey	Bartien Sayogo
W. Boettger	Chung-Yiu Lam	Jaber Shalabi
Thomas Callsen	Donald Lamontagne	Samuel Sharpless
Paul Cardinal	Moonhee Lee	Hyeong Sim
Stuart Chambers	Aleksandr Levin	Jimmy Smith
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Evgenii Ermakov	Darrell Mangubat	Eduardo Tolcachir
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Niklas Gustavsson	Bansi Patel	David Wallach
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Sergio Hernandez	Howard Penrose	Daniel Weyer
Thang Hochanh	Matthew Pinard	Kenneth White
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Introduction

This introduction is not part of IEEE Std C57.165-2024, IEEE Guide for Temperature Measurements for Liquid-Immersed Transformers and Reactors.

This guide is applicable to the measurement of temperatures in and around liquid-immersed transformers and reactors, that affect their performance, capacity, or life. This guide does not limit measurements to mineral oil, since the temperatures are observed in real-time, rather than being calculated from physical and thermodynamic properties of the material. Existing documents depend upon those properties for accurate calculation results. While the properties of mineral oil are well known and understood, the properties of natural and synthetic esters, silicone or fluorocarbon and vegetable-based insulating fluids are less established for transformers and reactors. The variations in these properties and their effects on calculated liquid temperatures are obviated by taking actual measurements.

This guide is applicable to power transformers, distribution transformers, and reactors regardless of their capacity rating.

This guide was begun as a technical paper that was written over a number of years by the Task Force on Winding Temperature Indicators of the IEEE Power and Energy Society's, Transformers Committee's Insulation Life Subcommittee. During the period that the paper was being written, it was concluded that there was no guide that described methods of, equipment for and precautions for the measurement of winding temperature in liquid-immersed transformers. Many of the persons who were new to transformer operations attended the Task Force meetings to learn about winding temperature. They voiced their frustration very clearly with respect to literature, which was available that they could refer to, to further their knowledge of the subject. Following the completion of the technical paper, a working group was formed to create this new guide.

The annexes to this guide include descriptions of temperature measurement equipment, including thermometers, thermometer indicators, sensors, and their application.

The predominant guide at the time that the paper was being written was IEEE Std C57.91™-2011, IEEE Guide for Loading Mineral-Oil-Immersed Transformers [B6].⁶ The guide now includes step voltage regulators in its scope. This guide was and continues to be an excellent source of information for determining what factors contribute to transformer temperatures and how to use transformer design information and projected local climatic conditions to determine a transformer's response to loading conditions at, near, or over nameplate levels. However, IEEE Std C57.91 [B6] does not provide information on how to take measurements, what equipment to use, or what precautions to observe when taking the measurements.

Precautions to be taken when using simulating and calculating winding temperature indicators under certain cooling modes are discussed, as are location of liquid and ambient temperature sensors.

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

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IEEE Guide for Temperature Measurements for Liquid-Immersed Transformers and Reactors

1. Overview

1.1 Scope

This guide discusses and recommends methods of temperature measurements for liquid-immersed transformers and reactors. Thermal well types as well as sensors for both indirect and direct temperature measurement are included. Temperature measurement applications including insulating liquid, winding, load tap changers (LTC), and other parts are discussed. Ambient temperatures on transformers, reactors, and accessories attached to the transformer or reactor are also discussed.

1.2 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*).^{7,8}

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*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

⁷The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁸The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

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 for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.^{9,10}

IEEE Std C57.12.10™, IEEE Standard Requirements for Liquid-Immersed Power Transformers.

IEEE Std C57.12.36™, IEEE Standard Requirements for Liquid-Immersed Distribution Substation Transformers.

IEEE Std C57.12.80™, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90™, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹¹

ambient temperature: The temperature of the medium such as air, water, or earth, into which the heat of the equipment is dissipated. (IEEE Std C57.12.80™-2010)¹²

ambient temperature sensor: Resistance temperature detectors (RTDs), thermocouples, thermistors, or digital components that are used to convert temperature into an electrical or digital value, which is used to measure ambient temperature. *See also:* **thermistor**; **thermocouple**.

analog current loop: An electrical or electronic circuit consisting of a current source and/or sink, which provides a current proportional to a specific measured quantity.

average winding temperature: The average temperature of a 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™. (IEEE Std C57.12.80™-2010)

average winding temperature rise of a transformer: The arithmetic difference between the average winding temperature of the hottest winding and the ambient temperature. (IEEE Std C57.12.80™-2010) *See also:* **average winding temperature**.

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¹⁰IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹¹*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

¹²Information on references can be found in [Clause 2](#).

bimetal helical coil probe: A metallic cylinder containing a bimetallic helical coil design element directly connected to a pointer drive assembly. As the temperature rises, the thermal expansion rate of the dissimilar materials causes the element to uncoil, driving the pointer indicator assembly.

NOTE—See [Figure A.2](#) in [Annex A](#).¹³

bulb-type probe: A metallic cylinder or bulb connected by small bore tubing to a spiral wound Bourdon tube in the measurement device. The bulb, connecting tubing and Bourdon tube are filled with a compressed gas or liquid, which has a large coefficient of thermal expansion. The Bourdon tube will unwind slightly when the gas expands in response to increasing temperature, and the torque generated by the unwinding tube is transmitted to a pointer by a simple linkage arrangement or by having the pointer shaft directly connected to the tip of the Bourdon tube.

NOTE—See [Figure A.1](#) in [Annex A](#).

calculated winding temperature indicator: *See: digital calculating winding temperature indicator (WTI).*

crystal-based extrinsic fiber-optic sensor: A specific type of extrinsic sensor in which the crystal that is attached to the end of the fiber reflects a color-shifted signal in proportion to the influence of temperature that surrounds it. The crystal is excited by a white light pulse from the measurement device.

current sensors: A category of sensor that measures the current responsible for transformer heating. These sensors can be current transformers (CTs) or based on the Hall effect principle. *See also: current transformer (CT).*

current transformer (CT): An instrument transformer intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled. (IEEE Std C57.12.80™-2010)

digital calculating winding temperature indicator (WTI): A specific type of winding temperature indicator (WTI) that uses sensors to collect analog values of various parameters, which include but are not limited to transformer temperatures and load current, which are immediately converted from analog to digital data, which are then mathematically operated on by a numeric computing engine such as a microcomputer. Using a system of equations that acts on these data inputs, the calculating WTI computes the winding temperature.

digital sensor: A device that converts a thermal input directly into a digital value, which can be used directly by digital measurement devices. The heart of the digital sensor is a semiconductor P-N junction, which has a defined voltage change proportional to temperature.

direct measurement (DM) winding temperature indicator (WTI): A type of winding temperature indicator (WTI) that uses sensors embedded in the transformer windings, and the instrumentation reports the measured temperature directly to various outputs, including displays, analog outputs, and digital communication outputs. *See also: winding temperature indicator (WTI).*

electronic differentiated sensing simulating winding temperature indicator (WTI): (A) A type of winding temperature indicator (WTI) that uses thermal sensors such as thermistors and resistance temperature detectors (RTDs), which translate thermal units into proportional analog electrical quantities. This type also employs a current signal drawn from load current transformers (CTs), which measure transformer proportional load current directly. The current signal locates per-unit load within the load profile. This type of WTI has the advantage of being faster and more accurate than integrated sensing simulating (ISS) type WTIs, regardless of whether the instrument is of a mechanical, electronic analog, or electronic digital design. (B) A specific type of WTI in which the measured quantities are combined internally in electronic circuits, such as multiplying and/

¹³Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.