

IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid-Filled Transformers

Sponsor

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Abstract: Provides guidance for determining the hottest-spot temperature in distribution and power transformers built in accordance with IEEE Std C57.12.00-2000. Describes the important criteria to be evaluated by an thermal model that can accurately predict the hottest-spot temperatures in a transformer. Provides guidance for performing temperature-rise tests with direct measurement of the hottest-spot temperatures, and explains the importance of developing an accurate thermal model to properly locate the temperature sensors.

Keywords: distribution transformer, hottest-spot temperature, power transformers. temperature-rise test, thermal model

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Introduction

(This introduction is not part of IEEE Std 1538-2000, IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid-Filled Transformers.)

It is required by IEEE Std C57.12.00-1993 that the hottest-spot temperature rise not exceed 80 °C. The hottest-spot temperature rise at rated load is a necessary parameter for determining the loading capability of all transformers. Since there was no approved test or calculation method to demonstrate compliance with the IEEE standard, an IEEE Working Group on Hottest-Spot Temperature Rise Determination in Liquid-Filled Transformers was formed to develop this guide.

This guide provides information to determine the maximum (hottest-spot) temperature rise by calculation and testing. Modern computer technology permits calculation of hottest-spot temperature. Most manufacturers use computers for their design calculations, and it is reasonable to incorporate a thermal subroutine into the programs that would calculate hottest-spot temperature rises. Current personal computers have capabilities that were present only in mainframe computers decades ago. Fiber-optic temperature sensors now permit direct measurement of the temperature of a specific point. By prior analysis of the winding, the sensor can be placed to read the maximum winding temperature. For distribution transformers, thermal testing may be conducted using embedded thermocouples.

This guide applies to liquid-filled power, network, and distribution transformers manufactured in accordance with IEEE Std C57.12.00-1993. Although thermal gradients may be low in properly designed small (10–25 kVA) distribution transformers, the thermal gradients may not be low in the wide range of transformers classified as distribution transformers, which may extend in range to 5000 kVA.

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- a) *Standards*: documents with mandatory requirements.
- b) *Recommended practices*: documents in which procedures and positions preferred by the IEEE are presented.
- c) *Guides*: documents in which alternative approaches to good practice are suggested but no clear-cut recommendations are made.

This document is classified as a guide. Documents with mandatory requirements such as standards use the verb *shall* whereas the other documents use the word *should*. This practice is followed in this guide unless the requirements are mandatory in IEEE Std C57.12.00-1993. Mandatory requirements taken from IEEE Std C57.12.00-1993 are enclosed in quotation marks.

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IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid-Filled Transformers

1. Overview

1.1 Scope

This guide provides guidance for developing mathematical models and test programs to determine the steady state maximum (hottest-spot) and average winding temperature rise over ambient for all liquid-immersed distribution, power, network, and regulating transformers manufactured in accordance with IEEE Std C57.12.00-2000.¹

1.2 Purpose

IEEE Std C57.12.00-2000, subclause 5.11.1.1, states, “the maximum (hottest-spot) winding temperature rise above ambient temperature shall be determined by either

- a) Direct measurement during a thermal test in accordance with IEEE Std C57.12.90-1999. A sufficient number of direct reading sensors should be used at expected locations of the maximum temperature rise as indicated by prior testing or loss and heat transfer calculations.
- b) Direct measurement on an exact duplicate transformer design per a).
- c) Calculations of the temperatures throughout each active winding and all leads. The calculation method shall be based on fundamental loss and heat transfer principles and substantiated by tests on production or prototype transformers or windings.”

This guide describes recommendations for a manufacturer’s test program or mathematical model to demonstrate compliance with the above requirements.

¹Information on references can be found in Clause 2.

2. References

This guide should be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision should apply.

IEEE Std C57.12.00-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.²

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.

3. Definitions

3.1 average winding temperature rise: The arithmetic difference between the average winding temperature and the ambient temperature as determined from the change in the ohmic resistance measured across the terminals of the winding in accordance with the test procedures specified in IEEE Std C57.12.90-1999.

3.2 bottom-oil temperature: The temperature of the liquid as measured at an elevation below the bottom of the coils or in the oil flowing from the liquid cooling equipment.

3.3 bottom-oil temperature rise: The arithmetic difference between the bottom-oil temperature and the ambient air temperature.

3.4 core form transformer: A transformer in which those parts of the magnetic circuit surrounded by the windings have the form of legs with two common yokes.

3.5 directed flow: Indicates that the principal part of the pumped oil from heat exchangers or radiators is forced to flow through the windings.

3.6 distribution transformer: A transformer for transferring electrical energy from a primary distribution circuit to a secondary distribution circuit or consumer's service circuit.

3.7 flow direction: A pattern of flow in disc or helical windings caused by alternately blocking the vertical ducts inside and outside the winding to cause the liquid to flow in a zigzag pattern. This construction is used with either directed or non-directed flow transformers.

3.8 H-factor: A dimensionless number for predicting the maximum winding temperature rise over fluid due to increased eddy losses and other factors at the winding hottest-spot location.

3.9 hot-spot: A nonrecommended abbreviated term frequently used as a synonym for the maximum or hot-test-spot temperature rise of a winding.

3.10 maximum (hottest-spot) winding temperature: The maximum or hottest temperature of the current carrying components of a transformer winding and leads in contact with insulation or insulating fluid. The hottest-spot temperature is a naturally occurring phenomena due to the generation of losses and the heat-transfer phenomena. It is the highest temperature inside the transformer winding and leads and is

²IEEE 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/>).

greater than the measured average winding temperature. All transformers have a maximum (hottest-spot) winding temperature.

NOTE—In this guide the hottest-spot rise is not considered to be due to localized manufacturing defects. Defects that affect long term performance or cause the hottest-spot rise to exceed the limits set in IEEE Std C57.12.00-2000 should be corrected.

3.11 maximum (hottest-spot) winding temperature rise: The arithmetic difference between maximum (hottest-spot) winding temperature and the ambient temperature.

3.12 network transformer: A transformer designed for use in a vault to feed a variable capacity system of interconnected secondaries. A network transformer may be of the submersible or of the vault type.

3.13 nondirected flow: Indicates that the pumped fluid from the heat exchangers or radiators flows freely inside the tank, and is not forced to flow through the windings.

3.14 oil: A shortened term for mineral oil that is a specially refined mineral-oil for use as an insulating liquid and coolant in transformers. For the purposes of this document, when terms such as “top oil rise” are used, “oil” should be considered synonymous with “fluid” since fluids other than mineral oil are used. See IEEE Std C57.12.00-2000.

3.15 power transformer: A transformer that transfers electric energy in any part of the circuit between the generator and the distribution primary circuits.

3.16 prototype transformer: A transformer manufactured primarily to obtain engineering data or evaluate manufacturing or design feasibility. Prototypes may be preproduction units or units typical of current designs manufactured for test purposes to obtain data to comply with changes in industry standards or for other reasons.

3.17 radiator: A fluid to air heat exchanging device attached to a transformer for the purpose of exchanging heat from the transformer fluid to the ambient air.

3.18 shell-form transformer: A transformer in which the laminations constituting the iron core surround the windings and usually enclose the greater part of them.

3.19 temperature rise: The difference between the temperature of the part under consideration (commonly the “average winding rise” or the “maximum (hottest-spot) winding temperature rise”) and the ambient temperature.

3.20 top-oil rise: *See: top-oil temperature rise.*

3.21 top-oil temperature: The temperature of the top layer of the insulating fluid in a transformer, representative of the temperature of the top fluid in the cooling flow stream, generally measured 50 mm below the surface of the fluid.

3.22 top-oil temperature rise: The arithmetic difference between the top fluid temperature and the ambient temperature. *Syn: top-oil rise*