



IEEE Standard for Liquid-Immersed Transformers Designed to Operate at Temperatures Above Conventional Limits Using High-Temperature Insulation Systems

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.154™-2022
(Revision of IEEE Std C57.154-2012)



STANDARDS

IEEE Standard for Liquid-Immersed Transformers Designed to Operate at Temperatures Above Conventional Limits Using High-Temperature Insulation Systems

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Transformers Committee
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IEEE SA Standards Board

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Abstract: Covered in this standard are all liquid-immersed distribution, power, and regulating transformers that are designed to operate at temperatures that exceed the normal thermal limits of IEEE C57.12.00™ under continuous load, in the designed average ambient, and at rated conditions. Specific requirements and guidance in the design, testing, and application of the transformers covered within the scope of this standard are provided. High-temperature insulation systems or systems that use a combination of high-temperature and conventional insulation are incorporated by these transformers.

Keywords: conventional, high-temperature, hybrid, IEEE C57.154, insulation system

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Introduction

This introduction is not part of IEEE Std C57.154–2022, IEEE Standard for Liquid-Immersed Transformers Designed to Operate at Temperatures Above Conventional Limits Using High-Temperature Insulation Systems.

The purpose of this document is to standardize the development of liquid-immersed transformers that use high-temperature insulation and operate at elevated temperatures. The solid insulation may encompass a broad range of materials with varying degrees of thermal capability. Key properties of insulating and cooling liquids also may vary substantially from mineral-oil insulating liquid.

This document is not intended to stand alone, but rather builds on the information and guidelines documented in the other parts of the IEEE C57 series. Accordingly, this document follows two guiding principles. The first principle is that liquid-immersed transformers are well known and are well defined in other parts of this series; therefore, the details of these transformers are not repeated in this document except where such reference has value or where repetition is considered appropriate for purposes of emphasis or comparison.

The second principle is that the usual liquid-immersed transformer, which has been defined as “conventional” insulated with thermally upgraded kraft paper, pressboard, wood, mineral oil, and many other commonly used materials, operating at established temperature limits, is well known. Conversely, other solid and liquid insulations that have a higher thermal capability than the materials used in this well-known system are considered “high-temperature.”

The document addresses loading, loading beyond nameplate rating, and testing in the same manner. Only selected information for the “conventional” transformers is included in this document for comparison purposes or for emphasis. All other references are directed to the appropriate standard document.

This is the second edition of this document and many changes have been driven by the latest revision of IEEE Std 1276™-2020, which is a guide. This revision to IEEE Std 1276-1997 incorporated most of the informative and tutorial text from the original version of IEEE Std C57.154, including all of the annexes and the detailed descriptions of various winding configurations, such as the mixed hybrid and full hybrid insulation systems. The IEEE Std C57.154 Working Group has also decided that high-temperature transformer design has reached a point in the industry such that specific details of every design variation are no longer necessary as part of the high-temperature liquid-immersed standard. This concept mirrors the main transformer documents where IEEE Std C57.12.00™ is valid for all types of transformers from pole mounted distribution transformers to large power transformers. The relationship of IEEE Std 1276-2020 is then similar to the product standards such as IEEE Std C57.12.10™.

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IEEE Standard for ~~the Design, Testing, and Application of~~ Liquid-Immersed ~~Distribution, Power, and Regulating~~ Transformers Designed to Operate at Temperatures Above Conventional Limits Using High-Temperature Insulation Systems ~~and Operating at Elevated~~ Temperatures

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1. Overview

1.1 Scope

This standard applies to all liquid-immersed ~~distribution, power, and regulating~~ transformers that are designed to operate at a temperature rise ~~temperatures~~ that exceeds ~~exceed~~ the ~~normal thermal~~ limits of IEEE Std C57.12.00™ 6 ¹ under continuous load, in the designed average ambient, and at rated conditions.

6 ¹Information on references can be found in Clause 2.

1.2 Purpose

This standard provides specific requirements [for transformers which](#) ~~and guidance in the design, testing, and application of the transformers covered within its scope. These transformers~~ incorporate high-temperature insulation systems or systems that use a combination of high-temperature and conventional insulation.

1.3 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 \(*can equals is able to*\).](#)

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.

⁷[The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.](#)

⁸[The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.](#)

IEEE Std ~~1276TM~~, ~~1538TM~~, IEEE Guide for ~~the Application Determination of Maximum Winding~~ High-Temperature Insulation Materials Rise in Liquid-~~Immersed~~ Distribution, Power, and Regulating ~~Filled~~ Transformers.

IEEE Std C57.12.00TM, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers. 9.10 ~~2,3~~

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

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

IEEE Std C57.91TM, IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators.

IEEE Std C57.100TM, IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Liquid-Immersed Distribution and Power Transformers.

IEEE Std C57.129TM, IEEE Standard for General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers.

IEEE Std C57.169TM, IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid-Immersed Transformers.

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

~~IEEE Std C57.19.00TM, IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings.~~

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~~IEEE Std C57.19.03TM, IEEE Standard Requirements, Terminology, and Test Code for Bushings for DC Applications.~~

~~IEEE Std C57.131TM, IEEE Standard Requirements for Tap Changers.~~

3. Definitions

For the purposes of this document, the following terms and definitions apply. For other terms, the standard transformer terminology in IEEE Std C57.12.80TM shall apply. ~~Other electrical terms are defined in~~ The IEEE Standards Dictionary Online.⁴ should be consulted for terms not defined in this standard or this clause.¹¹ Refer to IEEE Std 1276 for additional definitions.

conventional: insulation system: Solid ~~A description applied to temperature rise limits,~~ insulation materials used throughout the transformer and insulating liquid, ~~or insulation systems~~ operating at temperatures within the ~~normal~~ thermal limits of IEEE Std C57.12.00.

NOTE—The thermal limits for the winding are defined as 65 °C average temperature rise, and 80 °C hottest spot temperature rise, Given a 30 °C average ambient, this results in a ~~and~~ 110 °C hottest spot temperature. The thermal limits for the insulating liquid are defined as 65 °C top liquid oil temperature rise.¹²

~~**conventional insulation system:** Solid insulation materials used throughout the transformer and insulating liquid, operating at temperatures within the normal thermal limits of IEEE Std C57.12.00.~~

~~NOTE—The thermal limits for the winding are defined as 65 °C average temperature rise, 80 °C hottest spot temperature rise, and 110 °C hottest spot temperature. The thermal limits for the insulating liquid are defined as 65 °C top oil temperature rise.~~

¹¹ ⁴ IEEE Standards Dictionary Online ~~subscription~~ 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.~~ http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

¹² ⁵ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

full hybrid insulation winding: A winding composed of conventional solid insulation with high-temperature solid insulation used in areas in contact with the winding conductor to allow higher than conventional average winding and hottest spot temperature rises.

high-temperature: A description applied to temperature rise limits, insulation materials or insulation systems operating at higher temperatures than conventional.

high-temperature insulation system: High temperature insulation used throughout the transformer, except for some minor insulation components in lower temperature areas, together with high temperature insulating liquid operating at higher than conventional top liquid, average winding and hottest spot temperature rises.

high-temperature insulation winding: A winding composed of high temperature insulation used throughout the winding to allow higher than conventional average winding and hottest spot temperature rises.

hybrid insulation system: High temperature solid insulation operating above conventional temperatures, combined with conventional solid insulation and an insulating liquid operating at conventional temperatures.

mixed hybrid insulation winding: A winding composed of conventional solid insulation with high-temperature solid insulation used only selectively to allow higher than conventional hottest spot temperatures, while operating at conventional average winding temperature rises.

reference temperature: The standard temperature to which calculations and measurement are referred shall be defined as 20 °C plus the base rated average winding rise. For multiple winding transformers that have more than one base rated average winding rise, the highest average winding rise shall be used to determine the reference temperature.

4. Insulation systems

4.1 General

An insulation system used in liquid-immersed transformers ~~contains~~ ~~shall contain~~ one or more solid materials ~~to electrically insulate~~ ~~for insulating~~ the conductive parts and a liquid ~~to provide electrical~~ ~~for~~ insulation and heat transfer. These insulation materials shall withstand electrical, mechanical, chemical, and thermal stresses for the expected life of the ~~transformers.~~ ~~device~~ The insulation systems used in transformers covered by this standard may be assigned an electrical insulation system (EIS) temperature rating based on service experience or based on an accepted test procedure that can demonstrate an equivalent life expectancy ~~to the conventional insulation system.~~ The thermal class of ~~an~~ ~~the~~ insulation system ~~shall~~ ~~may~~ be determined by the test procedures defined in IEEE Std C57.100, which establishes the thermal index associated with the maximum hottest spot temperature for which ~~the insulation system is expected to provide normal transformer life.~~ In general, this Relative Thermal Index (RTI) test procedure defined in IEEE Std C57.100 uses failure of the solid insulation during accelerated aging in the liquid insulation as a determining factor in defining the hottest spot temperature capability of the insulation system, since solid insulation failure often defines the life of a transformer. The thermal class of the insulation system is then determined from the established thermal index (hottest spot temperature limit) and is defined as 10 °C higher than this limit. ~~that insulation system is expected to provide normal life.~~ See Table 1 for a list of preferred insulation system thermal classes and the associated hottest spot temperature limits and thermal indices.

Table 1 — Preferred insulation system thermal classes

Thermal class	Hottest spot temperature limits °C
105	95
120	110
130	120
140	130
155	145
180	170
200	190

(New)

Thermal class	Hottest spot temperature °C
105	95
120	110
130	120
140	130
155	145
180	170
200	190

(Deleted)

4.2 Insulation system requirements

Since the aging and lifetime of the insulation system strongly depend on temperature, different insulation systems ~~combinations of insulating materials~~ with different thermal classes are generally used in order to optimize the thermal and economical design of the transformer. Several ~~In order to simplify and standardize, three~~ distinct types of high-temperature insulation systems are defined in IEEE Std 1276-2020, based on the degree of high-temperature insulation content. Note that the conventional insulation system is not within the scope of this document, except for comparison purposes. Specific high-temperature insulation system descriptions are also detailed in IEEE Std 1276-2020, along with specific examples of possible winding types associated with each system. However, it is important to describe here the fundamental concepts of the two main insulation systems that are the topic of this standard: hybrid, and high-temperature insulation systems. Since many variations of these systems are possible, it is not practical to try to detail every combination. However, adherence to the fundamental concepts described here shall be ~~even if high-temperature materials are used, when all conventional temperatures are~~ maintained.

~~NOTE—Although a core form transformer is used to illustrate the various insulation systems in the following clauses, the application of this standard is not limited to this type of transformer. Each of the systems described is an illustration of the definition, and the description may be applied to a distribution layer type winding or a shell form transformer pancake winding as well.~~⁵

4.2 ~~Winding insulation types~~

4.2.1 ~~General~~

~~The transformer winding insulation is a component of the insulation system. The following clauses illustrate different insulation winding types with examples based on power transformers, which have a high degree of winding separation. Table 2 in 4.2.2 summarizes and compares the different variations.~~

~~NOTE—The insulation systems may be explained by considering the transformer as an assembly of individual isolated windings separated by insulation barriers and cooling channels. A series of winding types can then be used to illustrate how parts of different systems may be combined in a single transformer.~~

~~The barrier insulation between the individual windings shall be treated as a separate entity when properly designed cooling channels separate the material from the winding itself. In this case, the liquid circulation provides sufficient cooling to avoid exceeding the lower thermal capability of the barrier insulation. If the barrier insulation touches the winding, it shall be considered part of that winding. This is especially important for layer type windings when the layer insulation touches the winding conductor. In this application, the layer insulation shall be treated in the same manner as the winding conductor insulation.~~

4.2.2 Summary of insulation system types

~~Table 2 summarizes the key attributes that identify the different winding insulation systems.~~

Table 2—Insulation winding/system comparison

		Conventional insulation system	Hybrid insulation systems		High-temperature insulation system ^b
			Mixed hybrid	Full hybrid	
Type of insulating component ^a	Liquid	C or H	C or H	C or H	H
	Wire insulation	C	C & H combination	H	H
Conventional (C) or high-temperature (H)	Spacers/strips	C	C & H combination	H	H
	Barrier solid	C	C	C	H
Insulating component application temperature	Top liquid rise	C	C	C	H
	Average winding rise	C	C	H	H
Conventional (C) or high-temperature (H)	Hottest spot winding rise	C	H	H	H

~~(Deleted)~~

^a ~~Only basic winding components are shown and other high temperature insulation may be required depending on the results of the thermal mapping.~~

^b ~~Some conventional insulation is acceptable in locations where conventional temperatures are maintained.~~

4.2.3 Hybrid insulation winding types

There shall be two hybrid insulation winding types that share the use of conventional barrier insulation and the use of high temperature insulation on the windings.

4.2.3.1 Mixed hybrid insulation winding

The mixed hybrid insulation winding shall use high temperature insulation for certain components or parts of windings, such as the conductors in regions operating at temperatures above conventional limits. However, the majority of the solid insulation shall be conventional. The average winding temperature is conventional while a portion of the winding exceeds conventional hottest spot temperatures. See Figure 1 for an illustration of this type of winding.

NOTE—This winding type uses high temperature insulation to protect only a portion of the winding from temperatures that exceed the conventional hottest spot temperature limit. The key to this winding type is that the average winding temperature remains equal to or below conventional limits and only a portion of the winding exceeds the conventional hottest spot temperature limit. Examples of winding zones with extra losses and higher heat development that could benefit from high temperature insulation:

- a) Winding ends due to the radial component of the magnetic leakage field
- b) Zones of rectifier or converter transformer windings where harmonic currents might be concentrated

Type of material in winding

High temperature insulation applied to minor selected areas of the winding and used with the specific intent to protect strategic locations from excessive aging

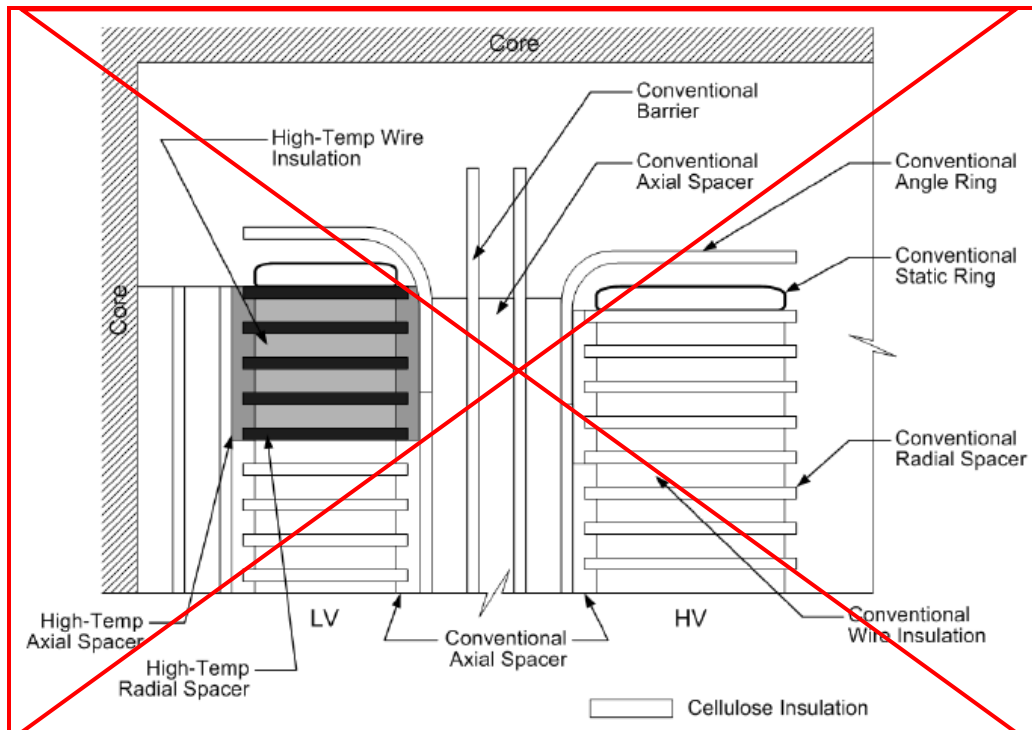
Type of material in barriers

Conventional

Temperature limits (see Table 3)

Average winding: ~~Conventional~~

Winding hottest spot: ~~Higher than conventional~~



(Deleted)

Figure 1 — Illustration of a mixed hybrid insulation winding

4.2.3.2 Full hybrid insulation winding

The full hybrid insulation winding shall use high temperature material throughout the winding, which operates above conventional temperatures. The conductor insulation and the radial and axial spacers separating the coil sections shall be composed of high temperature materials. Other insulation components shall also be composed of high temperature materials, where conventional temperatures are exceeded. Conventional insulation shall be used in all other areas, such as barrier cylinders and angle rings that operate at conventional temperatures. See Figure 2 for an illustration of this type of winding.

~~NOTE—The full hybrid insulation winding is similar to the high temperature winding. The differences are the barriers and peripheral insulation made of conventional material.~~

~~Type of material in winding~~

~~High temperature for all insulation operating at temperatures higher than conventional~~

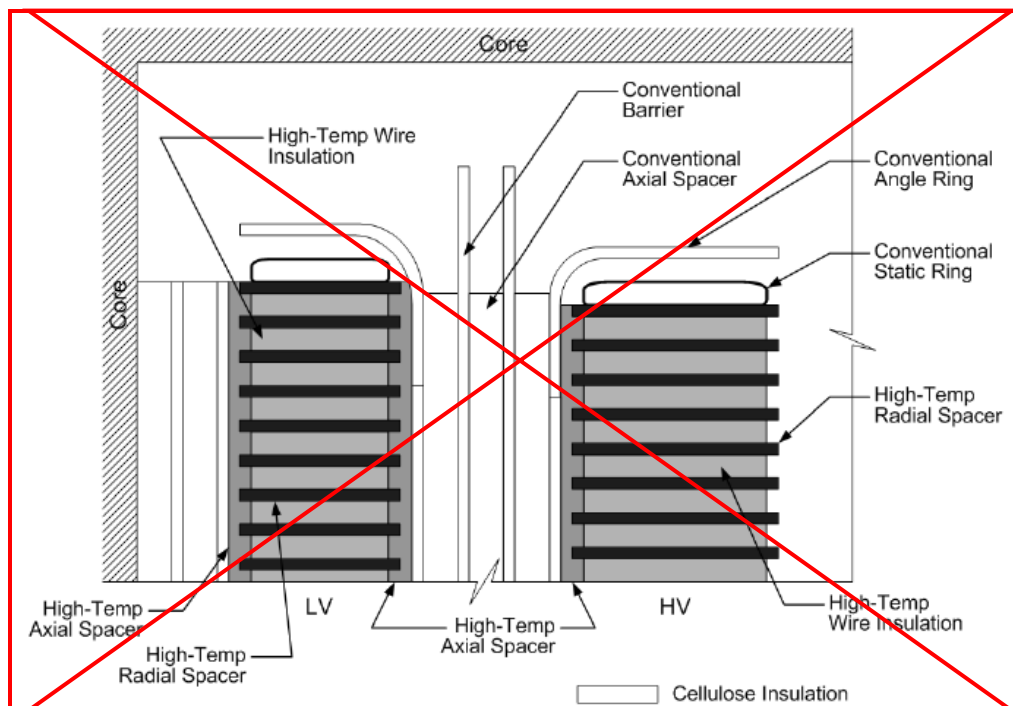
~~Type of material in barriers~~

~~Conventional~~

~~Temperature limits (see Table 3)~~

~~Average winding: Higher than conventional~~

~~Winding hottest spot: Higher than conventional~~



~~(Deleted)~~

~~Figure 2—Illustration of a full hybrid insulation winding~~

4.2.4 High-temperature insulation winding

This winding style shall use high temperature insulation material throughout the winding such as conductor insulation, radial and axial spacers separating the coil sections, barrier cylinders and angle rings. See Figure 3 for an illustration of this winding style.

Type of material in winding

High-temperature

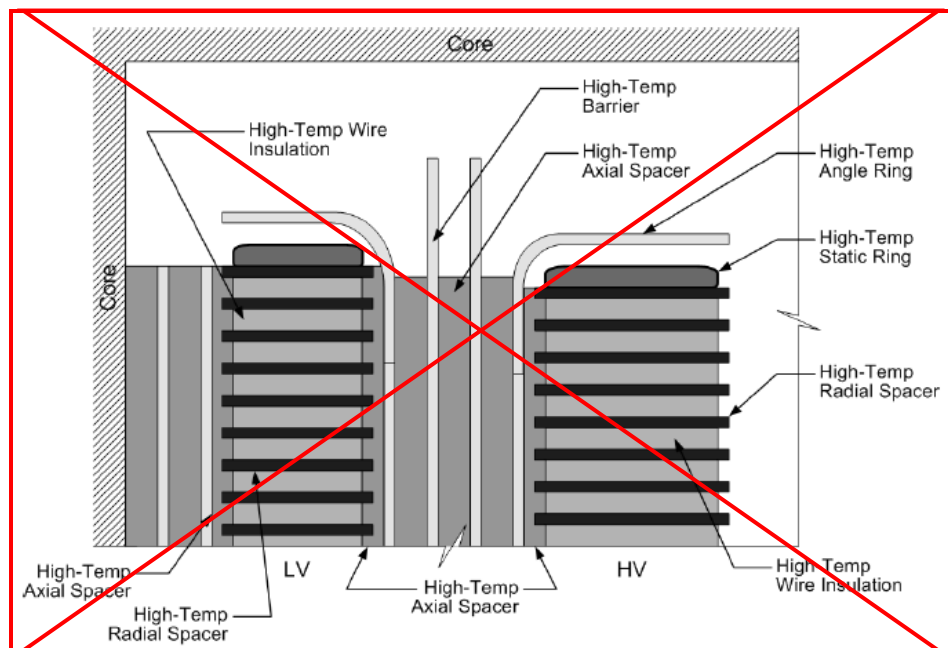
Type of material in barriers

High-temperature

Temperature limits (see Table 4)

Average winding: Higher than conventional

Winding hottest spot: Higher than conventional



(Deleted)

Figure 3—Illustration of a high-temperature insulation winding

4.3 Hybrid insulation system

The fundamental concept of a hybrid insulation system is that conventional insulation system liquid thermal limits, as defined in IEEE Std C57.12.00, shall be maintained. Insulation systems with different thermal classes may be used within a specific winding configuration as long as conventional insulation system liquid thermal limits are maintained. This requirement allows significant advantages in that all accessories, gaskets, and other temperature sensitive peripheral equipment remain conventional. Any combination of insulation system thermal classes may be used in a hybrid insulation system as long as the thermal profile of the design supports the thermal capability of the insulation system at any specific location and conventional insulation system liquid thermal limits are maintained.

4.4 High-temperature insulation system

The fundamental concept of a high-temperature insulation system is that the liquid operates at temperatures above the conventional insulation system liquid thermal limits, as defined in IEEE Std C57.12.00. As with a hybrid insulation system, a high-temperature insulation system may use any combination or range of insulation system thermal classes for a specific winding configuration as long as the thermal capability of the insulation system is not exceeded at any specific location. Such elevated temperatures are driven by elevated liquid temperatures at some locations in the winding or in the winding end insulation structures. Therefore, it is critically important to understand the thermal capability, or maximum operating temperature, of the liquid when used at temperatures above the conventional insulation system liquid thermal limits. The maximum operating temperature of a liquid may be determined by an accepted test procedure or may be assigned by the liquid manufacturer and shall be agreed between liquid manufacturer and purchaser.

4.5 Insulation system thermal verification

Sufficient testing shall be performed to verify the thermal profile ~~of the transformer design, and to confirm the thermal suitability for the insulation systems used in specific locations.~~ This shall be accomplished by actual thermal measurements ~~measurement~~ of critical locations taken during prototype and/or unit testing ~~or using validated thermal calculations.~~ Once thermally mapped, insulation systems ~~materials~~ shall be selected appropriately to match the temperature requirements of the specific locations ~~location~~. Supporting test data sufficient to validate the manufacturer's thermal model shall be available upon request as part of the type testing. IEEE Std C57.169 ~~1538~~ provides guidance for the determination of maximum winding temperature-rise in liquid-immersed ~~filled~~ transformers.

5. Temperature limits

Continuous ~~Maximum~~ temperature limits for various insulation systems ~~combinations of solid and liquid insulating materials~~ are presented in Table 2 ~~3~~ and Table 3 ~~4~~. These limits are theoretical and are based on the insulation system thermal class. Any combination of temperatures of transformer windings and liquids can be selected as long as the values do not exceed the limits defined in Table 2 and Table 3. Rated temperature-rise values that are selected lower than the maximum shown shall be selected on 5 °C increments. An accurate thermal model verified by adequate test data shall be required to determine the actual maximum values of any specific transformer design.

The many different types of dielectric insulating liquids available offer a range of thermal capabilities, ~~and typical parameters are compared in Annex A.~~ However, due to the many different characteristics for simplification, this standard uses only three liquid thermal classes as examples: 105, 130, and 155. Each of high-temperature ~~these thermal classes is represented by mineral oil, ester, and silicone liquids,~~ and the lack respectively. This standard ~~does not make a distinction between ester liquids based on the source of the product.~~ Consequently, ~~both synthetic and natural ester liquids are considered thermally equivalent. Note that other liquids are not intended to be excluded, and limits appropriate to a~~ specific thermal test at the time of writing this document, it is not possible to specify ~~capability shall be applied according to~~ the thermal class for a generic class of liquids with any certainty. Consequently, this standard suggests maximum operating temperatures higher than that of the conventional insulation system liquid thermal limits. Thermal limits for a specific ~~of the liquid.~~ should be obtained from the liquid manufacturer.

See IEEE Std 1276 for more information on the thermal capabilities of different insulation systems.

NOTE 1—Some of the limiting factors to be considered in determining the permissible maximum temperatures are:

- a) Aging of materials such as cellulose-based insulation, which introduces moisture inside the transformer tank;
- b) Velocity of the liquid in the cooling ducts, since long exposure of the liquid to high temperature will accelerate degradation;
- c) Accelerated aging of the liquid and insulating materials due to catalytic action caused by the presence of bare copper and silver surfaces, which generate by-products, such as particles and copper derivatives dissolved in insulating liquids;
- d) Gas bubbles caused by overheated trapped moisture between the winding conductors and the conductor insulation;