IEC 60076-14

Edition 1.0 2013-09

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Power transformers –
Part 14: Liquid-immersed power transformers using high-temperature insulation materials

Transformateurs de puissance –
Partie 14: Transformateurs de puissance immergés dans du liquide utilisant des matériaux isolants haute température

IEC 60076-14:2013

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POWER TRANSFORMERS –

Part 14: Liquid-immersed power transformers using high-temperature insulation materials

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested yin the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60076-14 has been prepared by IEC technical committee 14: Power transformers.

This first edition of IEC 60076-14 is an International Standard which cancels and replaces the second edition of the Technical Specification IEC/TS 60076-14 published in 2009. It constitutes a technical revision.

This International Standard includes the following significant technical changes with respect to the Technical Specification:

a) the hot-spot relationship to thermal class is now defined;
b) a new 140 thermal class is defined;
c) the number of insulation systems is reduced to only three: conventional, hybrid and high-temperature;

d) homogeneous high-temperature insulation system has been changed to just high-temperature insulation system;

e) winding definitions were introduced to define variations in the hybrid insulation system;

f) the system example drawings have been revised for clarity;

g) all suggested limits corresponding to Part 7 loading guide have been defined in a similar format;

h) moisture equilibrium curves for high-temperature materials have been added to the moisture and bubble generation annex;

i) an annex has been added to introduce the concept of thermal enhancement of cellulose by ester;

j) some guide information, such as overload temperature limit suggestions was retained, but most of the other informative text was moved into informative annexes.

The text of this standard is based on the following documents:

FDIS	Report on voting
14/755/FDIS	14/759/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60076 series can be found, under the general title *Power transformers*, on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This part of IEC 60076 standardizes liquid-immersed transformers that use high-temperature insulation. As a system, the solid insulation may encompass a broad range of materials with varying degrees of thermal capability. The insulating and cooling liquids also vary substantially, ranging from mineral oil to a number of liquids that also have a range of thermal capability.

This international standard is not intended to stand alone, but rather builds on the information and guidelines documented in other parts of the IEC 60076 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 and therefore, the details of these transformers are not repeated in this international standard, except where reference has value, or where repetition is considered appropriate for purposes of emphasis or comparison.

The second principle is that the materials used in normal liquid-immersed transformers, typically kraft paper, pressboard, wood, mineral oil, paint and varnish, which operate within temperature limits given in IEC 60076-2, are well known and are considered normal or conventional. All other insulation materials, either solid or liquid that have a thermal capability higher than the materials used in this well-known system of insulation materials are considered high-temperature. Consequently, this standard or normal insulation system is defined as the “conventional” insulation system for comparison purposes and these normal thermal limits are presented for reference to illustrate the differences between other higher-temperature systems.

This international standard addresses loading, overloading, testing and accessories in the same manner. Only selected information for the “conventional” transformers is included for comparison purposes or for emphasis. All other references are directed to the appropriate IEC document.

POWER TRANSFORMERS –

Part 14: Liquid-immersed power transformers using high-temperature insulation materials

1 Scope

This part of IEC 60076 applies to liquid-immersed power transformers employing either high-temperature insulation or combinations of high-temperature and conventional insulation, operating at temperatures above conventional limits.

It is applicable to:

– power transformers in accordance with IEC 60076-1;
– convertor transformers according to IEC 61378 series;
– transformers for wind turbine applications in accordance with IEC 60076-16;
– arc furnace transformers;
– reactors in accordance with IEC 60076-6.

This part of IEC 60076 may be applicable as a reference for the use of high-temperature insulation materials in other types of transformers and reactors.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60076-1, *Power transformers – Part 1: General*

IEC 60076-2, *Power transformers – Part 2: Temperature rise*

IEC 60076-5, *Power transformers – Part 5: Ability to withstand short-circuit*

IEC 60076-7, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

IEC 60076-16, *Power transformers – Part 16: Transformers for wind turbine applications*

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 60137, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60214-1, *Tap-changers – Part 1: Performance requirements and test methods*

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60836, *Specifications for unused silicone insulating liquids for electrotechnical purposes*

IEC 61099, *Specifications for unused synthetic organic esters for electrical purposes*

IEC 61378-1, *Convertor transformers – Part 1: Transformers for industrial applications*

IEC 61378-2, *Convertor transformers – Part 2: Transformers for HVDC applications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60076-1 and IEC 60076-2 apply.

3.1
insulation system
system composed of solid insulating materials and an insulating liquid

3.2
temperature index
TI
numerical value of the temperature in degrees Celsius derived from the thermal endurance relationship at a time of 20 000 h (or other specified time)

[SOURCE: IEC 60050-212:2010, 212-12-11, modified – Notes 1 and 2 have been deleted]

3.3
thermal class
designation of Electrical Insulation Materials (EIM) or Electrical Insulation Systems (EIS) equal to the numerical value of the maximum used temperature in degrees Celsius for which the EIM/EIS is appropriate

Note 1 to entry: See IEC 60085.

3.4
conventional
modifier applied to temperature-rise limits, insulation materials or insulation systems operating at temperature limits defined by IEC 60076-2

3.5
kraft paper
paper made almost entirely from pulp of high mechanical strength, manufactured from soft-wood by the sulphate process

[SOURCE: IEC 60050-212:2010, 212-16-03]

3.6
thermally upgraded paper
TUP
cellulose-based paper which has been chemically modified to reduce the rate at which the paper decomposes

Note 1 to entry: See IEC 60076-2 for the complete definition.

Note 2 to entry: This note applies to the French language only.

3.7
high-temperature
temperature rise limits and/or insulation materials applied in systems consisting of solid materials and/or liquid, capable of operating at higher temperatures than conventional

3.8
conventional insulation system
insulation system consisting of solid insulation materials used throughout the transformer and insulating liquid operating at temperatures within the normal thermal limits specified in IEC 60076-2

3.9
high-temperature insulation system
insulation system consisting of high-temperature insulation used throughout the transformer, except for some insulation components in lower temperature areas, together with high-temperature insulating liquid, capable of operating at higher than conventional top liquid, average winding and hot-spot temperature rises

3.10
high-temperature insulation winding
winding with high-temperature insulation used throughout, to allow higher than conventional average winding and hot-spot temperature rises

3.11
hybrid insulation system
insulation system consisting of high-temperature solid insulation capable of operating above conventional temperatures, combined with conventional solid insulation and an insulating liquid, operating at conventional temperatures

3.12
full hybrid insulation winding
winding with high-temperature solid insulation used for all parts in thermal contact with the conductor, combined with conventional solid insulation to allow higher than conventional average winding and hot-spot temperature rises

3.13
semi-hybrid insulation winding
winding with high-temperature solid insulation used only for the conductor insulation to allow higher than conventional average winding and hot-spot temperature rises

3.14
mixed hybrid insulation winding
winding with high-temperature solid insulation used only selectively, combined with conventional solid insulation to allow higher than conventional hot-spot temperature rises, while operating at conventional average winding temperature rises

3.15
normal cyclic loading
loading and ambient temperature cycle which, from the point of view of relative thermal ageing rate (according to the mathematical model), is equivalent to the rated load at yearly average ambient temperature.

Note 1 to entry: Higher ambient temperature or a higher-than-rated load current may be applied during part of the cycle. This is achieved by taking advantage of low ambient temperatures or low load currents during the rest of the load cycle.

Note 2 to entry: For planning purposes, this principle can be extended to provide for long periods of time whereby cycles with relative thermal ageing rates greater than unity are compensated for by cycles with thermal ageing rates less than unity.

[SOURCE: IEC 60076-7:2005, 3.5]

3.16
long-time emergency loading
loading resulting from the prolonged outage of some system elements that will not be reconnected before the transformer reaches a new and higher steady-state temperature

[SOURCE: IEC 60076-7:2005, 3.6]

3.17
short-time emergency loading
unusually heavy loading of a transient nature (less than 30 min) due to the occurrence of one or more unlikely events which seriously disturb normal system loading

[SOURCE: IEC 60076-7:2005, 3.7]

3.18
rated average winding temperature rise
contractually agreed upon average winding temperature rise as defined on the nameplate in contrast to calculated or actual tested value

3.19
reference temperature
rated average winding temperature rise +20 °C, or rated average winding temperature rise + yearly external cooling medium average temperature, whichever is higher

Note 1 to entry: When there is more than one power rating specified, the highest rating shall be used to determine the reference temperature.

Note 2 to entry: For transformers that have more than one rated average winding temperature rise, assigned for different windings at the same power rating, the highest average winding rise shall be used to determine the reference temperature for this power rating. In this case the losses in service will be lower than calculated.

Note 3 to entry: See IEC 60076-1 for complete details on reference temperature.

Note 4 to entry: The term “rated average temperature rise” is meant to be the same as guaranteed temperature rise.

4 Insulation systems

4.1 General

An insulation system used in liquid-immersed transformers contains one or more solid materials for insulating the conductive parts and a liquid, for insulation and heat transfer. This insulation shall withstand the electrical, mechanical, and thermal stresses for the expected life of the device. The thermal class ratings for solid insulation and wire enamels determined by test procedures performed in air are not acceptable for use in transformers conforming to this standard.

The solid insulation used in transformers covered by this standard shall have thermal performance and temperature ratings evaluated in combination with the intended liquid. The procedure for evaluating a combined solid and liquid insulation is described in IEC/TS 62332-1, which results in a thermal index, from which the thermal class is determined. By agreement between manufacturer and purchaser, service experience or other suitable test procedures are acceptable to verify thermal class. See Table 1 for a list of preferred insulation system thermal classes and the associated hot-spot temperature. Refer to IEC 60085 for more information on thermal evaluation procedures.

Table 1 – Preferred insulation system thermal classes

Thermal class	Hot-spot temperature °C
105	98
120	110
130	120
140	130
155	145
180	170
200	190
220	210

Since ageing and lifetime of the insulation system so strongly depend on the temperature, combinations of insulating materials with different thermal capabilities are used within a unit in order to optimise the thermal and economical design of the transformer. In order to simplify and standardize, three distinct insulation systems are defined, based on the degree of high-temperature insulation content. The conventional insulation system is the basis for reference and contains no high-temperature insulation. This system is used as a reference only in this document.

Although a winding with radial spacers, typical for a core-type power transformer is used to illustrate the various insulation systems, the application is not limited to this type of transformer. Each of the insulation systems described is an illustration of the definition and the description is applicable to any other type of transformer with different types of windings, such as layer-type and shell-type pancake windings.

4.2 Winding insulation types

4.2.1 General

The transformer winding insulation is a component of the insulation system. Subclauses 4.2.3 to 4.2.4 illustrate different low voltage (LV) and high voltage (HV) winding types with examples based on power transformers, which have a high degree of winding separation. Table 2 summarizes and compares the different variations.

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 thermal capability of the barrier insulation. If the barrier insulation touches the winding then 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.

Sufficient testing shall be performed to verify the thermal profile. This shall be accomplished by actual thermal measurement of critical locations taken during prototype and unit testing. Once thermally mapped, materials shall be selected appropriate to the temperature requirements of the specific location. Supporting test data sufficient to validate the manufacturer's thermal model shall be available upon request as part of the type testing.

NOTE The different insulation systems can 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 could then be used to illustrate how parts of different insulation systems can be combined in a single transformer. In some cases it might not be necessary to use high-temperature insulation in the same way for all windings.

4.2.2 Summary of winding/system insulation types

Table 2 summarizes the key attributes that identify the different winding types. These same attributes also define the corresponding insulation systems.

Table 2 – Winding/system insulation comparison

		Conventional insulation system	Hybrid insulation systems			High-temperature insulation system [b]
			Semi-hybrid winding	Mixed hybrid winding	Full hybrid winding	
Type of insulating component [a] Conventional (C) or high-temperature (H)	Liquid	C or H	C or H	C or H	C or H	H
	Conductor insulation	C	H	C and H combination	H	H
	Spacers/strips	C	C	C and H combination	H	H
	Barrier solid	C	C	C	C	H
Insulating component application temperature Conventional (C) or high-temperature (H)	Top liquid rise	C	C	C	C	H
	Average winding rise	C	H	C	H	H
	Hot-spot winding rise	C	H	H	H	H

a Only basic transformer parts are shown and the temperature of other parts will depend on the results of the thermal mapping.

b Since thermal gradients exist in all transformers, some conventional insulation is acceptable in locations where conventional temperatures are maintained.

4.2.3 Hybrid winding types

4.2.3.1 General

Three hybrid winding types share the use of conventional barrier insulation and the use of high-temperature insulation on the windings.

4.2.3.2 Semi-hybrid insulation winding

The semi-hybrid insulation winding shall use high-temperature insulation only on the winding conductor. For layer windings, the layer insulation shall also be high-temperature. Conventional cellulose-based insulation may be used in all other areas. See Figure 1 for an illustration of this winding style.

Type of material in winding

High-temperature for conductor insulation only

Type of material in barriers

Conventional

Winding temperature rise limits

Average winding: Higher than conventional

Winding hot-spot: Higher than conventional