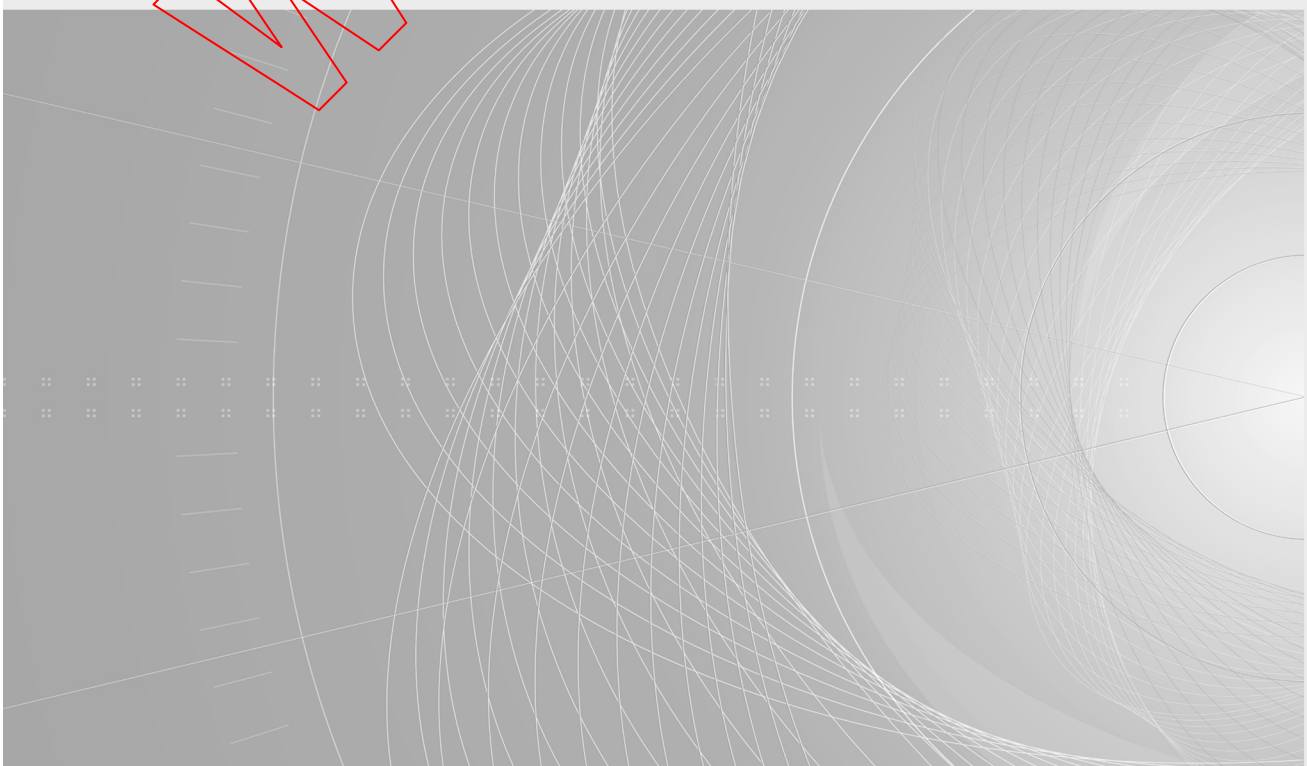
IEC/TS 60076-14

Edition 2.0 2009-05

TECHNICAL SPECIFICATION

Power transformers –
Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials



IEC/TS 60076-14:2009(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub

The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, withdrawn and replaced publications.

- IEC Just Published: www.iec.ch/online_news/justpub

Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.

- Electropedia: www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.

- Customer Service Centre: www.iec.ch/webstore/custserv

If you wish to give us your feedback on this publication or need further assistance, please visit the Customer Service Centre FAQ or contact us:

Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00

IEC/TS 60076-14

Edition 2.0 2009-05

TECHNICAL SPECIFICATION

Power transformers –
Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE X

ICS 29.180

ISBN 978-2-88910-042-2

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 14: Design and application of 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 in 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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60076-14, which is a technical specification, has been prepared by IEC technical committee 14: Power transformers.

This second edition cancels and replaces the first edition published in 2004. It is a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- additional clarification added to the introduction;
- addition of an introduction to the ageing and lifetime of insulation materials;
- enhancement of insulation system descriptions;
- clarification of temperature rise limits and the addition of overload temperature limits.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
14/591A/DTS	14/600/RVC

Full information on the voting for the approval of this technical specification 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 maintenance result 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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The average temperature rise in liquid-immersed transformer windings has for several tens of years been limited to 65/70 K and the top oil temperature rise to 60 K, as specified in IEC 60076-2.

Winding conductors in these transformers have historically been insulated with cellulosic paper or enamel. Other solid insulation materials have also been cellulose-based products. The insulation liquid has, for the most part been mineral insulating oil. These materials are still dominant.

Consequently, most of the accumulated experience of transformers in service is based on these insulation materials and these temperature limits. In some cases, space or weight limitations require the designer to reduce the transformer dimensions with higher temperature rises as a consequence. The application of insulation materials (both solid and liquid) with better ageing properties at elevated temperatures than the traditional ones is necessary in order to provide an acceptable life expectancy. High-temperature solid insulation materials have also occasionally been used only in certain parts of the windings where high temperature has been expected.

Recent temperature measurements by means of fibre-optics have indicated that the hot-spot temperature may sometimes be higher than predicted, and in certain cases considerably higher. This has created concern regarding higher rate of ageing than expected. The measurements have provided knowledge regarding where the hot-spots are situated and where high-temperature materials might be applied.

High-temperature insulation, from enamel and tape wrap for conductors, to spacer and mechanical support materials are already used in power, distribution, mobile, locomotive and rectifier transformers. Class K liquids, with a fire point greater than 300 °C are suitable for temperatures higher than mineral insulating oil and have been used for decades. Their use and range of application is increasing rapidly. For many years, manufacturers have met the needs of special applications by designing transformers using high-temperature materials to achieve lower weight, higher power density, improved fire safety or increased life.

The purpose of this technical specification is to begin the process of standardizing the development of 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 from mineral oil to any of a number of new class K liquids that also have a broad range of thermal capability.

The liquid and solid insulation materials found in any standard type of modern liquid-immersed transformer compose an insulation system that has evolved and developed over more than 100 years. Accordingly, the rules and guidelines for application are also robust and rather well developed. In contrast, high-temperature insulation materials and applications for transformers that use these materials are relatively new in both development and application.

It should not therefore be surprising that much of the information is neither well developed nor completely understood. However, it is important to establish and maintain a document that provides a starting point for discussion between the manufacturer and the user. It is expected that this technical specification would be updated regularly as development progresses.

This document is not intended to stand alone, but rather builds on the wealth of information and guidelines documented in the 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 technical specification, except where 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, insulated with kraft paper, pressboard, wood, mineral oil and many other commonly used materials operating at established temperature limits, are well known and 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. Commonly used solid and liquid insulations are also tabulated in a general way to allow easy comparison of typical properties and to demonstrate the added range and capabilities of relatively unfamiliar materials.

This technical specification 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: Design and application of liquid-immersed power transformers using high-temperature insulation materials

1 Scope

This part of IEC 60076 provides specification, design, testing and loading information for use by both the manufacturer and user of liquid-immersed power transformers employing either high-temperature insulation or combinations of high-temperature and conventional insulation.

It is applicable to:

- power transformers designed in accordance with IEC 60076-1,
- convertor transformers designed to IEC 61378 series,
- arc furnace transformers,

and covers the use of various liquid and solid insulation combinations.

Whilst standards for traction transformers fall under the authority of IEC technical committee 9, this part of IEC 60076, however, may be applicable as a guideline for the use of high-temperature insulation materials in traction transformers.

2 Normative references

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

IEC 60076-1:1993, *Power transformers – Part 1: General*

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

IEC 60076-3, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

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

IEC 60076-7:2005, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

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

IEC 60216-1, *Electrical insulating materials – Properties of thermal endurance – Part 1: Ageing procedures and evaluation of test results*

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

IEC 60317 (all parts), *Specifications for particular types of winding wires*

IEC 60554-3 (all parts), *Specification for cellulosic papers for electrical purposes – Part 3: Specifications for individual materials*

IEC 60641-3 (all parts), *Pressboard and presspaper for electrical purposes – Part 3: Specifications for individual materials*

IEC 60674-3 (all parts), *Plastic films for electrical purposes – Part 3: Specifications for individual materials*

IEC 60819-3 (all parts), *Non-cellulosic papers for electrical purposes – Part 3: Specifications for individual materials*

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

IEC 60851-4, *Winding wires – Test methods – Part 4: Chemical properties*

IEC 60867, *Insulating liquids – Specifications for unused liquids based on synthetic aromatic hydrocarbons*

IEC 60893-3 (all parts), *Insulating materials – Industrial rigid laminated sheets based on thermosetting resins for electrical purposes – Part 3: Specifications for individual materials*

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

IEC 61100, *Classification of insulating liquids according to fire-point and net calorific value*

IEC 61212-3 (all parts), *Insulating materials – Industrial rigid round laminated tubes and rods based on thermosetting resins for electrical purposes – Part 3: Specifications for individual materials*

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

IEC 61629-1, *Aramid pressboard for electrical purposes – Part 1: Definitions, designations and general requirements*

ISO 2592, *Determination of flash and fire points – Cleveland open cup method*

ISO 2719, *Determination of flash-point – Pensky-Martens closed cup method*

3 Terms and definitions

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

3.1
insulation system
a 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 hours (or other specified time)

[IEV 212-02-08, modified]

3.3
halving interval HIC
numerical value of the temperature interval in degrees Celsius which expresses the halving of the time to end-point taken at the temperature equal to TI

[IEV 212-02-10, modified]

3.4
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

[IEC 60085, 3.11, modified]

3.5
conventional
adjective that refers to temperature rise limits and insulation materials applied in systems consisting of mineral oil and non-thermally upgraded paper

3.6
thermally upgraded paper (TUP)
cellulose-based paper which has been chemically modified to reduce the rate at which the paper decomposes. Ageing effects are reduced either by partial elimination of water forming agents (as in cyanoethylation) or by inhibiting the formation of water through the use of stabilizing agents (as in amine addition, dicyandiamide). A paper is considered as thermally upgraded if it meets the life criteria defined in ANSI/IEEE C57.100; 50 % retention in tensile strength after 65 000 hours in a sealed tube at 110 °C or any other time/temperature combination given by the equation:

$$\text{Time (h)} = e^{\left(\frac{15\,000}{(\theta_h + 273)} - 28{,}082\right)} \approx 65\,000 \times e^{\left(\frac{15\,000}{(\theta_h + 273)} - \frac{15\,000}{(110 + 273)}\right)} \quad (1)$$

Because the thermal upgrading chemicals used today contain nitrogen, which is not present in Kraft pulp, the degree of chemical modification is determined by testing for the amount of nitrogen present in the treated paper. Typical values for nitrogen content of thermally upgraded papers are between 1 % and 4 % when measured in accordance with ASTM D-982.

NOTE This definition was approved by the IEEE Transformers Committee Task Force for the Definition of Thermally Upgraded Paper on 7 October 2003.

[IEC 60076-7, 3.12]

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

3.8
hybrid insulation system
high-temperature solid insulation material adjacent to all winding conductors either bare or insulated (including all conductor insulation, spacers, strips and cylinders in direct contact with the winding conductor) and cellulose-based materials in lower temperature areas where thermal class 105 limits are met (see Figure 2)

3.9
semi-hybrid insulation system
high-temperature materials used only for conductor insulation (see Figure 3)