

IEEE Guide for the Application of High-Temperature Insulation Materials in Liquid-Immersed Power Transformers

Sponsor

**Transformer Committee
of the
IEEE Power Engineering Society**

Reaffirmed 30 March 2006

Approved 26 June 1997

IEEE Standards Board

Abstract: Technical information is provided related to liquid-immersed power transformers insulated with high-temperature materials. Guidelines for applying existing qualified high-temperature materials to certain insulation systems, recommendations for loading high-temperature liquid-immersed power transformers, and technical information on insulation-system temperature ratings and test procedures for qualifying new high-temperature materials are included.

Keywords: high-temperature insulation material, hybrid insulation system, liquid-immersed power transformer, loading guide

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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ISBN 1-55937-939-1

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Introduction

(This introduction is not part of IEEE Std 1276-1997, IEEE Guide for the Application of High-Temperature Insulation Materials in Liquid-Immersed Power Transformers.)

Liquid-immersed transformers utilizing high-temperature insulation systems are being used increasingly by the industry, and current standards do not effectively cover their performance criteria. This guide is intended to give the user some background information on the application and use of high-temperature insulation in power transformers.

The highest allowable temperature of the transformer winding insulation is an essential parameter in determining the maximum load that a transformer may reliably carry. If the allowable winding hottest-spot temperature may be increased, the weight and size of a power transformer may be significantly reduced while maintaining the same rated power, or, for the same size unit, the allowable power output may be increased. However, the user must understand the consequences of allowing the transformer temperature to exceed the material's accepted limits. The operating life of conventional insulating materials—namely, paper, transformerboard, and mineral oil—is dependent upon the operating temperature and the contaminants, including moisture, in the transformer.

Existing transformer standards specify the maximum allowable winding hottest-spot temperature on the basis of an acceptable normal insulation life. A relationship between temperature and degradation of the dielectric insulation has been established in IEEE Std C57.91-1995. From this relationship, the loss of insulation life due to a temporary or permanent loading beyond normal operating temperatures may be calculated. The actual life of a transformer depends only indirectly on the thermal aging of solid insulation materials. Laboratory tests of cellulose materials (i.e., paper and transformerboard) have demonstrated that overheating can significantly reduce their tensile strength with only a slight reduction in dielectric strength. Therefore, a likely failure mode caused by overheating of the cellulose is the mechanical breakdown of embrittled insulation during a high-current fault, which can lead to a dielectric breakdown of the damaged insulation. This phenomenon may hold for other insulating materials as well.

One method of reducing the weight and size of a liquid-immersed transformer without sacrificing its life or reliability is the use of materials with higher temperature capability. The first step in this direction was made some 40 years ago when thermally upgraded cellulose was developed for transformer insulation. This technological improvement increased the rated power of liquid-immersed transformers by 12%, allowing the average winding rise to increase from 55 °C to 65 °C.*

During the last 30 years, materials with even higher temperature capability, such as aramid papers and transformerboards and high-temperature enamels, have been developed. To date, these materials have been used in some specialty transformers, such as traction or mobile units, and some have been used to uprate liquid-immersed transformers rebuilt after a failure. There are potential applications for new transformers using these high-temperature insulation materials. For example, instead of installing a cellulosic-insulated transformer with a rating equal to the overloads, a smaller-rated unit with high-temperature insulation materials can be installed that can withstand the desired overload.

It is important to note that high-temperature insulation materials must meet a number of criteria to be suitable for use in power transformers. They must operate at elevated temperatures in transformer oil while maintaining their mechanical and dielectric properties. They must also demonstrate compatibility with all other components of the transformer, as well as have suitable characteristics for the mechanical stresses encountered in a power transformer, such as adequate compressive strength.

*Discussions of 55 °C rise systems are included in this guide for historical reference only.

Combining high-temperature and cellulosic materials to form a hybrid high-temperature insulation system is another viable option. This hybrid insulation system is usually composed of high-temperature materials adjacent to winding conductors, where temperatures are hottest, with cellulose-based materials in other areas. This insulation system is possible because only insulation material in direct contact with the winding conductors, and perhaps the core, is exposed to the highest temperatures, while other parts of the insulation system operate at lower temperatures. To date, only aramid papers, aramid transformerboards, and high-temperature enamels in combination with cellulose have been used in this type of hybrid insulation system.

From the point of view of thermal aging, cellulose has been the limiting factor of traditional insulation systems composed of mineral oil, cellulose, and enamel. With the advent of high-temperature solid insulating materials, mineral oil becomes the limiting factor, establishing the highest allowable temperature of the insulation system. Other insulating fluids have been examined for the possible replacement of mineral oil, and many are used in applications where their dielectric and physical properties meet the needs of those applications. Until now there have been few instances where these other insulating fluids have been used in power transformers above 30 MVA. Certain fluids, such as silicones, high molecular weight hydrocarbons, non-PCB chlorinated hydrocarbons, polyolefins, and ester-based fluids, may offer particular advantageous characteristics for specific applications.

Future research may identify new fluids with broader applications for use in power transformers that can operate at higher temperatures due to high-temperature insulating materials. Other factors to consider when designing units that operate at high temperatures are, for example, load losses, tap changers, bushings, control wiring, paint, and adhesives.

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