Insulation materials

Author: Olle Särneroth
Document updated: 2001-01-30
e-mail: olle.sarneroth@se.abb.com

The insulation system of a power transformer is understood as the complete internal assembly of dielectric insulating materials. This includes parts and supporting structures that cover the winding wires, insulate the turns from each other in each winding, separate different winding bodies from each other and from the core and tank. Such insulation systems may be conceived according to different basic principles. The TrafoStar class of ABB power transformers are medium and large oil-immersed units for high and extra high system voltages. They use oil- and cellulose insulation, mainly arranged in a barrier-type structure.

Classic insulation materials

The internal insulation system is based on pure mineral oil, and cellulose in the form of paper, pressboard, and sometimes selected natural wood.

This combination of oil and fibrous cellulose materials has dominated the technology of power transformer insulation since electrification began about a hundred years ago. During the last 50 years, several designs of dry-type insulation systems have been used for distribution transformers of limited rating, up to a few MVA, and corresponding moderate system voltage levels. But, for large, high voltage transformers the traditional oil-filled design still prevails.

Many new insulation technologies have been proposed and tried. Some examples are modern plastic foils and tapes instead of paper, and synthetic insulating liquids instead of mineral oil. Strangely enough, these combinations have failed to outperform the classic combination of natural materials - mineral oil and cellulose fibres.

Pressboard production equipment.

Stable, chemically pure oil

There has certainly been successive improvement of the insulation materials over the years. The modern brands of insulating mineral oil from a few leading manufacturers in the world represent a highly refined product made from particularly selected crude oil sources.

The product must meet stringent international standards. Chemical purity, stability against deterioration by thermal aging, a satisfactory viscosity curve at low temperatures, and good dielectric withstand capability are some of the demands.

Recycling possibilities

Chemical regeneration of aged oil is possible with good results. Finally, discarded oil may otherwise be used as light, low-sulphur fuel oil.

Cellulose material

The cellulose material parts in modern transformers are thin paper tape for paper lap covering of the conductor, solid pressboard in the form of strips, spacers, large cylinders and moulded collars, and some structural massive pressboard supports for windings and connecting cables inside the tank.

The raw material for both paper and pressboard is pine from subarctic forests. The paper and board materials are made by the sulphate process and are unbleached. Because of inferior aging properties, alternative materials such as cotton or manila hemp fibres are no longer used in TrafoStar winding paper. Textile wrapping and impregnation varnishes for mechanical stabilisation of coils are for the same reason not used today. Selected natural wood is used for less critical mechanical support structures, e g paper-covered connecting cables.

Pressplate made from polyester laminated board.

Pressboard

The pressboard used in TrafoStar transformers appears in different grades.

Precompressed boards are made as large sheets. They are compressed and dried under heat in a hydraulic press from a soaking wet condition to full dryness. The maximum dry thickness is about 8 mm. It is a mechanically tough material that can be machined with sharp wood-working tools. Heavy blocks for structural parts are machined from blocks that are glued together from several sheets of precompressed material.

A softer pressboard variant is used to mould parts with complex geometries. The material is soaked, and will then be dried under compression on moulding madrels or between metal tools to form angle collars or snouts of various specified shapes.

Various details for winding insulation.

Cylinder for winding production.

Open barrier insulation structure

The insulation of TrafoStar transformers is built according to the open barrier type system. This means that the radial insulation distance, between the cylindrical winding bodies, mainly consists of open oil. But, by inserting a number of thin pressboard cylinders separated by longitudinal strips, this distance is subdivided into narrow interspaces.

Why? The distribution in the dielectric withstand strength of oil depends on the free volume exposed to an electric field strength. A large open oil space has a fairly high distribution in the withstand strength. Therefore, it is beneficial to subdivide the distance into many small interspaces. This is particularly importnant in places where the dielectric stress will be high, e g across the distance between the windings. The actual withstand field strength in such small interspaces is much higher than would have been the case in a larger, undivided slot. Any erratic small discharge avalanche in an individual interspace will be stopped by the barriers on both sides, which will eliminate its chances to develop further.

This simple explanation is valid as long as the direction of the electric field strength is perpendicular to the barrier system, or in other words, that the barriers approximately follow equipotential surfaces. Toward the ends of the cylindrical windings it is therefore necessary to install a labyrinthine system of pressboard collars that form a continuation of the barrier cylinders. The shape of the collars are approximately oriented in accordance with the electrostatic field that fans out in these regions of the transformer. These labyrinths are designed to provide free passage for the flow of cooling oil through the windings.

Mechanical forces on the winding system during system faults

The windings of TrafoStar transformers are designed to be self-supporting. They can withstand the radial electromagnetic forces from the winding currents even during recognised values of overcurrent through the transformer, a so called, system through fault. The inner winding will always be subjected to compressing forces inwards, while the outer winding will be stretched outwards. But, the principle is that these radial mechanical forces shall never be transmitted by the insulating structural parts to an adjacent winding.

The windings are meticulously centered axially with respect to each other, in order to minimise asymmetric axial forces between different windings. All windings together shall see axial compression as a result of current forces. These forces are taken up by the winding spacers in disc or helical windings.

Systematic analysis for optimal insulation design

The fundamental principles of the insulation system design have been known for more than 100 years, and there has not been much change in the empirical design criteria.

The systematic process for dimensioning the different parts of the system must account for both the rated voltage of each separate winding, and the combination of simultaneous voltages of adjacent windings. This should be done for a transformer in normal service, under system overvoltage faults, and under steep overvoltage transients, e g lightning or switching. The systematic procedure to review the different contingencies one by one and in combination, results in the smallest necessary insulation distances - radially, and towards the yokes - and indicates the correct standardised labyrinth configuration for different windings.

Testing of the insulation system

The dielectric tests of the transformer before delivery are entirely directed to verify the internal insulation system. The external insulation of the bushings is covered by separate component tests.

Impulse tests

The tests normally include impulse testing on the terminals, where a steep-fronted impulse waveshape simulates a lightning stroke close to a transformer in service. For very high voltage transformers an additional impulse test is applied, using a waveshape with longer duration and lower amplitude, but larger energy content. The impulse tests are monitored with oscillographs or equivalent transient recorders. This analysis is quite intricate but gives reliable information on any possible disturbances in the transformer.

Separate source voltage test

The correct assembly of the transformer is verified through tests using AC overvoltage. The separate source voltage test is a test in which the whole of a winding is brought up to the same AC potential by connecting one of its terminals to a test transformer. (With certain windings having ”non-uniform insulation” and a neutral terminal intended for direct earthing this test is not applicable directly.)

Induced voltage test

For the induced voltage test the transformer is connected for normal operation, and the transformer is tested at an elevated power frequency to avoid overexcitation of the core. The test is run either with a high voltage during less than a minute, or with a more moderate voltage during a longer application time with simultaneous observation of any possible partial discharge phenomena in the transformer. This test method is a relatively recent quality control addition to enhance the assessment of the transformer’s insulation system.