TLM material testing laboratory – analysis for transformers

TLM™ – Transformer Lifecycle Management™

Answers for energy.
100 years of know-how ensuring a long transformer life span

The challenge:

Transformers are one of the most important power supply elements. Even though their weight varies from a few hundred kilograms up to 800 tonnes they essentially always consist of the same main materials: copper, electrical steel and insulating materials (insulating paper, pressboard, laminated wood). Oil-cooled transformers also contain insulating liquid which is used for both insulation and cooling. When repairing and upgrading transformers it is essential that material weaknesses are reliably detected and effectively removed. In addition a comprehensive knowledge of materials together with specific and precise analysis is required.

Siemens can look back at over 100 years of experience in the production and operation of transformers. During all these years we have developed numerous methods and parameters so that ageing processes can be diagnosed early and reliably. With this know-how we are helping to prevent costly breakdowns, minimise idle time and extend the life of a transformer to well over today’s usual life span of 25–30 years.

The TLM material testing laboratory detects ageing processes in the transformer early.
The life span of a transformer is largely determined by the composition of the cellulose insulation and insulating oil. Of all the materials used they are the ones which are subjected the most to operation-dependent ageing processes. In a complex interaction with oil and paper temperature, moisture and oxygen lead to the formation of gases, acids, sludge and again to moisture which catalytically accelerates the ageing process.

We have numerous complementary methods available for reliably determining the different influencing quantities and with that the current condition of the transformer. These are Dissolved Gas Analysis (DGA), inspection of the characteristic oil values, furan analysis, determination of the DP value and of course the electrical tests.

With regular application and evaluation of these instruments the life span of each transformer can be extended considerably. We meet the requirements for this with our material testing laboratory and a highly qualified team of experts.

**Services offered by our laboratory**

The Siemens TLM material testing laboratory is completely focused on the laboratory diagnostics of oil-filled electrical equipment. The highly qualified personnel are continually developing new methods for ageing diagnostics and are using this knowledge for the benefit of our customers. Based on our great wealth of experience we prepare electrotechnical material specifications for solid insulating materials, electrically and magnetically conductive materials and insulating liquids. In addition we carry out supplier audits and assessments.

**Demonstrable competence**

Our technical competence can also be seen from our membership on various committees like for example:

- DKE 182 – liquids and gases for electrotechnical applications
- Cigre D1 – materials and emerging test techniques
- Various Cigre working groups on the subjects of the Dissolved Gas Analysis (DGA) and corrosive sulphur
- IEC TC 10 working groups – fluids for electrotechnical applications

Our services include insulating oil and material inspections. The diagnostic test procedures differentiate between the ageing analysis or state estimation of oils or rather insulating materials and the new state assessment of oils or rather insulating materials.

More freedom to act thanks to timely diagnosis – the TLM material testing laboratory helps extend the life span of your transformer.
Probably the most important method for the diagnosis of ageing processes as a result of dielectric, thermal, dynamic and chemical ageing in oil and oil-paper insulation is the Dissolved Gas Analysis (DGA). It provides information on the nature and extent of the undesired conditions. Other methods for early detection of complex fault scenarios are also available.

Dissolved Gas Analysis (DGA)
Thermal stress and electrical faults accelerate the natural ageing of the oil and insulating parts. At the same time cracked gases form, however, these are then dissolved in the oil. The rate of decomposition and the type of gases change during defective operation which could be a result of electrical faults or thermal overloading. The type of fault can be deduced from the quantity and type of the fault gases, the gas increase rates and the ratios of the gas types to one another.

Above all the Dissolved Gas Analysis (DGA) allows slowly developing faults to be detected. The analysis is carried out applying gas chromatography. On the basis of the temporal development of the gas concentrations it is possible to forecast the life span of the transformer.

Degree of Polymerisation (DP) and furan analysis
The DP value of the Kraft insulating paper is a measure for the number of polymerised glucose rings. A reduction in this value signifies ageing and with that a reduction in tensile strength. New cellulose has a DP value of 1000 – 1100. In contrast cellulose which has aged has a DP value of only 150 – 200.

As it is not possible to take paper samples during running operation the DP value is therefore determined on the basis of cellulose decomposition products i.e. furans. These are partly oil-soluble and give some indication of the rates of decomposition of the solid insulation.

Characteristic oil values
The basis for the maintenance of insulating liquids with a mineral oil base are the standard specifications VDE 0370 part 2 (= IEC 60422) and VDE 0370 part 1 (= IEC 60296). The following oil values are important:

- **Colour and appearance** help with the comparative evaluation: rapid darkening or dark oil indicate ageing of the oil.
- **The water content** of the oil is in balance with the moisture content of the solid insulation. It reduces the breakdown voltage and accelerates the ageing process.
- **The breakdown voltage** indicates how well an insulating oil can withstand the electrical load. It is decisive for the operational reliability of the transformer. The breakdown voltage is measured in accordance with IEC 60156 (= VDE 0370 part 5).

All values at a glance – the TLM material testing laboratory provides reliable and comprehensive information on the condition of the insulating oil.
Insulating fluid diagnostics – all the answers from a single source

**The dielectric dissipation factor** indicates the phase displacement of the current and voltage, ideally this will be 90°. If the displacement is greater then additional heat will arise. In the worst case this can lead to a thermally initiated breakdown. The dissipation factor is very strongly influenced by polar components and is therefore a very sensitive parameter.

**The neutralisation value** is a measure for the acid components in the oil as a result of ageing. They impair the dielectric properties of the insulation system. It is important to detect the start of any acid and sludge formation early so that timely counteractive measures can be initiated.

Alongside the neutralisation value and the dissipation factor the **interfacial tension** is an indicator for sludge formation in the transformer. The interfacial tension is a measure for the concentration of polar molecules in the oil which arise during the ageing process. The higher the concentration the lower the interfacial tension and the greater the tendency of the insulating oil to form sludge.

**Inhibitors** are age-protecting agents which delay the decomposition of the insulating oil. Only DBPC (di-tertiary-butyl-para-cresol) as per IEC 60666 is permitted. The DBPC is used with a weight percentage of 0.3 ± 0.05. The inhibitor content is determined using infrared spectrometry or gas chromatography with MS-detector.

**Approval of new insulating liquids**

For old transformers with heavily decomposed oil replacing the insulating liquid is often the last option to further extend the life span of the transformer. For the approval of the new insulating liquid the oil quality must be checked before filling the transformer. We will carry out the required inspections and determine the oxidation resistance (as per DIN 51554, IEC 61125, ASTM D2440, DIN EN 14112). Using our computer-controlled and -monitored oxidation equipment we are able to set and monitor the test conditions much more precisely than required by the standard specifications. The result is much better reproducibility and a safe assessment.
Material inspections – from the tank to the core

Transformers contain beside insulating fluid also conductive materials (copper, electrical steel) and solid insulating materials (paper, pressboard, laminated board and laminated wood). The insulating cellulosic materials are also subjected to considerable ageing processes during the service life of the transformer which can usually be a number of decades. We carry out inspections to examine the condition of these materials and with that offer our customers the possibility of being able to plan any necessary maintenance measures early.

Inspections of solid insulating materials, conductive metallic materials (grain-oriented electrical steel and copper materials), coating materials and sealing materials are carried out.

**Solid insulating materials**
The solid insulating materials in the transformers include natural solid materials like pressboard and insulating paper as well as laminates (e.g. laminated board, various fibre-reinforced synthetic resins). The physical properties of these materials in accordance with various standards (e.g. IEC 60641, DIN VDE 0311) are tested, which enables a precise picture of their current condition. Amongst others, the following tests are carried out:

- Determination of density
- Chemical analysis to ensure there is no metal contamination
- Shrinkage behaviour
- Moisture content
- Bending strength, compressive strength and tensile strength
- Compatibility with insulating liquids
- Impregnation behaviour
- Conductivity and pH value of the aqueous extract
- Ash content
Grain-oriented electrical steel
The core of transformers consists of grain-oriented electrical steel. There are three different qualities of steel, these are: conventional grain-oriented electrical steel, highly permeable grain-oriented electrical steel and domain-refined electrical steel. In the material testing laboratory the following tests are carried out on the grain-oriented electrical steel:

- Surface resistance using the Franklin Tester (as per IEC 60404-11)
- Magnetic loss measurement using a Single-Sheet Tester (SST) (as per IEC 60404-3)
- Magnetostriction

Copper materials
Copper materials are mainly used in the winding and at the leads as single flat conductors, multiple flat conductors and continuously transposed conductors. The condition of the enamelling and the paper wrapping is decisive for safe transformer operation. This is determined in the material testing laboratory using the following tests:

- Resistance of the enamel insulation after accelerated ageing in insulating liquids
- Thickness and hardness of the enamel insulation
- Adhesion and elasticity during bending and elongation
- Proof stress and elongation at break of the copper
- Breakdown voltage of varnished copper conductors
- Determination of the solidification factor of continuously transposed conductors with epoxy bonding

Surface resistance measurement of grain-oriented steel using a Franklin Tester
Shore-hardness testing

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Material inspections – from the tank to the core

Sealing materials
The tank, tank cover, manhole cover and valves of a transformer are sealed using sealing materials which are resistant to insulating liquid, e.g. nitrile butadiene rubber (NBR), fluoric rubber (FPM), fluorosilicone rubber (FMQ) and asbestos-free fibrous materials (FA 200). In outside areas, sealing materials have to possess weatherproofness and ultraviolet resistance.

In the material testing laboratory sealing materials are tested for:
- Hardness
- Resistance to cold and heat
- Compatibility with the insulating fluid

Coating materials
Outside coating materials are used as corrosion protection for tanks, radiators, coolers and other add-on parts. Interior coatings on the other hand are used to protect the transformer from possible metal particle contamination.

The main coating materials which are used are environmentally friendly, e.g. water-based or “high solid”. In the material testing laboratory we inspect the condition of the coatings using the following procedures:
- Layer thickness measurement
- Cross-cut test
- Effect of the internal coating materials on the insulating liquid (DGA/oil values)
Auxiliary production materials
Adhesives, cast resins, desiccants, glide waxes and detergents are only some of the numerous auxiliary materials used in transformer production or repair. The behaviour of each of these auxiliary materials must be understood to the smallest detail, particularly in their interaction with other materials. We therefore test the adhesion of glues, the adsorption behaviour of desiccants and the compatibility of different auxiliary materials in insulating liquids.

Conclusion
Whether it involves the inspection of an operational transformer or the optimisation of the various materials used in production with the support of the TLM material testing laboratory you are always on the safe side and you will considerably increase the life expectancy of your transformers.

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