TRANSFORMER SERVICE

Dissolved gas analysis and oil condition testing
Transformer diagnostic services at ABB perform dissolved gas analysis and supervision of oil condition in power transformers, reactors, instrument transformers, circuit breakers and oil insulated cables.
Dissolved gas analysis and oil condition testing

This product information is divided into the following sections:
1. Dissolved gas analysis (DGA)
2. Supervision of oil condition
3. Sampling and frequency of analyses
4. Ordering of tests

1. DISSOLVED GAS ANALYSIS (IEC 60599)

For many years, analyzing gases dissolved in transformer oil has been used as a diagnostic tool. The method can detect incipient faults, supervise suspect transformers, test a hypothesis, explain reasons behind failures or disturbances that have occurred and ensure new transformers are healthy. In this respect dissolved gas analysis is regarded as a fairly mature technique and it is employed by several ABB transformer companies around the world, either in their own plants or in cooperation with an affiliated or independent laboratory. The idea that supports the value of dissolved gas analysis is the fact that during its lifetime a transformer generates decomposition gases, essentially from its organic insulation, under the influence of various stresses, both normal and abnormal. The gases that are of interest for a DGA analysis are the following:

H₂ – hydrogen
CH₄ – methane
C₂H₄ – ethylene
C₂H₆ – ethane
C₂H₂ – acetylene
C₃H₆ – propene
C₃H₈ – propane
CO – carbon monoxide
CO₂ – carbon dioxide
O₂ – oxygen
N₂ – nitrogen
TCG – total combustible gas content (H₂, CH₄, C₂H₄, C₂H₆, C₂H₂, CO, C₃H₆, C₃H₈)

All of these gases, except oxygen and nitrogen, can form as the insulation degrades. The amount and the relative distribution of these gases depend on the type and severity of the degradation and stress.

1.1 Procedure

The DGA procedure consists of essentially four steps:
• Sample oil from the transformer
• Extract gases from the oil
• Analyze the gas mixture in a gas chromatography, GC
• Interpret the analysis according to an evaluation scheme

Preferably, the samples should be taken from moving oil so that the gases produced are coming from the point of generation. Suitable locations are valves in the cooler/radiator circuit. To take samples from these locations is not always possible because of design limitations. Other places from which to draw samples are the cover, bottom valve, the conservator and the Buchholz relay.

In addition, it is very important that the sampling is carefully done to assure that contamination is kept to a minimum and that gases are not lost during sampling or transportation to the laboratory.
The removal of the gases from the oil can be accomplished by various methods:

- Partial degassing (single-cycle vacuum extraction)
- Total degassing (multi-cycle vacuum extraction)
- Stripping by flushing the oil with another gas
- The headspace technique in which gases are "equalized" between free gas volume and oil volume.

ABB Transformers Diagnostic Services in Ludvika uses the headspace method (figure 1).

The extracted gas mixture is fed into adsorption columns in a GC where the different gases are adsorbed and separated to varying degrees and consequently reach the detector after different periods of time.

The gas mixture is separated into individual chemical compounds, identified and their concentrations in volume gas STP/volume oil are calculated and expressed in ppm. (STP=standard temperature and pressure).

It should be emphasized that extraction and analysis may involve analytical errors, making it difficult to directly compare the results from two different laboratories. ABB advises working with just one highly reputable lab.

1.2 Interpretation

There are several different ways to explain and interpret the analyzed gas composition and to diagnose the condition of the transformer. Essentially the following methods are at hand:

- Identify the key gas to ascertain a particular problem, e.g. H₂ indicates partial discharges (PD)
- Determine gas ratios, normally between gas levels
- Determine gas levels in ppm or ml
- Determine rates of gas increase or "production rates" in ppm/day or ml gas/day

Around the world and over the years several different evaluation schemes have been proposed for DGA. The most commonly known include one proposed by Rogers, which forms the ANSI method, and another described in IEC Publication 60599. Both methods use ratios between gas concentrations.

In order to get a feeling for DGA interpretation, the key-gas method is appropriate (figure 3).

You are looking for the most prominent gas – the one that differs most from a tacitly expected "normal" level (or change). For instance when cellulose overheats, the main decomposition gases are CO and CO₂. With a partial corona discharge, H₂ is formed (PD in cellulose involves the formation of carbon oxides). With a more severe electrical discharge, such as arcing, C₂H₂ is formed (normally also H₂ is formed with smaller amounts of methane and ethane. If CO is present, cellulose is involved). Lastly, overheated oil produces saturated hydrocarbons (C₂H₆) at lower temperatures and unsaturated hydrocarbons (C₂H₄) at higher temperatures. The presence of acetylene indicates very high temperatures.

This scheme can also be used to understand the evaluation schemes based on ratios.

For instance, the IEC method uses three ratios:

$$\frac{C_2H_2}{C_2H_4} \quad \frac{CH_4}{H_2} \quad \frac{C_2H_6}{C_2H_4}$$

CH₄/H₂ is used to discriminate between a thermal fault and an electrical fault. C₂H₂/C₂H₄ indicates the presence of a strong discharge or very severe electrical problem and C₂H₆/C₂H₄ is an indication of oil temperatures.
1. Overheating of cellulose
   \[ \text{CO, CO}_2 \]

2. Overheating of oil
   Increasing temperature
   \[ \text{C}_2\text{H}_6, \text{C}_2\text{H}_4, \text{C}_2\text{H}_4, \text{CH}_4, \text{CH}_4, \text{C}_2\text{H}_2 \]

3. Partial discharges (PD) increasing intensity
   \[ \text{H}_2, \text{H}_2, \text{C}_2\text{H}_2 \]

4. Discharges
   \[ \text{C}_2\text{H}_2, \text{H}_2 \]

1.3 Application
Oil sampling frequency depends on the importance of the transformer.
- A suspected fault (e.g. abnormal sounds)
- Signals from gas or pressure relay
- Directly after, or within some weeks, a short circuit
- When an essential transformer is put into operation, followed by further tests after a few months
- Following an obvious overloading of the transformers

The analysis results are documented in reports that are sent to the customer. All recent and historical results and recommendations are also available online (iTrafo).

2. Supervision of oil condition
Even though it is generally acknowledged that dissolved gas analysis is normally the most powerful tool for diagnostic purposes, and for detecting incipient faults in a transformer, it is also very important to monitor the general status of the insulating oil. The oil may become contaminated with water, particles and other foreign substances. There is also a continuous aging of the oil and the solid insulation through the formation of water, acids and sludge. Apart from impairing the insulating properties, these oxidizing byproducts also cause accelerated degradation of the cellulose insulation.

There are a number of different tests devised for detecting changes in the electrical properties and chemical composition of the oil. Some are done to order to obtain information about the status of the oil itself, while others are done mainly to assess the status of the cellulose insulation. Only the most commonly used and important measurements are discussed here.

2.1 Electrical properties
2.1.1 Breakdown voltage (IEC 60156)
The ability of the oil to withstand electrical stress is obviously an important parameter in itself. A lowering of the breakdown voltage is usually due to the presence of particles in the oil, in particular in combination with a large water content (figure 3).

2.1.2 Dielectric dissipation factor, \( \tan \delta \) (IEC 60247)
This is a measure of the oil’s dielectric losses (figure 4), mostly due to its conductivity. As such, it is not a very important parameter for the transformer’s operation (unless the value is extremely high), but it is a good indicator of the presence of any dissolved ions and acids.
2.2 Chemical properties
2.2.1 Water content (IEC 60814)
Some buildup of water content is inevitable, due to the aging processes mentioned above. Water leakage into the transformer by a variety of mechanisms can also occur. Measuring the oil’s water content helps to estimate the amount of water in the solid insulation, which is where most of the water is bound. High water content in the oil may lower the breakdown voltage, while the main problem with high water content in the solid insulation is the increased aging rate of the paper (figure 6). Note, however, that the oil and solid insulation water content is strongly linked, and as the temperature changes, water is redistributed between the two.

2.2.2 Acidity (IEC 62021)
Acids are a product of the oxidizing oil. This is a process involving reactions very similar to those causing wine to turn into vinegar, or butter or vegetable oil becoming rancid. The acidity, which is the amount of potassium hydroxide needed to neutralize the acids in the oil, is an indicator of the degree of aging.

2.2.3 Inhibitor content (IEC 60666)
Inhibitors are added to the oil in order to slow oxidation. They react with certain intermediates in the oxidation process, thus preventing a chain reaction in which oxidizing agents promote further oxidation. Inhibited oils of good quality normally age very slowly as long as any inhibitor is still present. However, when the inhibitor is spent the oxidation will proceed relatively rapidly. For this reason it is important to monitor the inhibitor content, so that preventive maintenance actions can be taken before the onset of rapid oxidation (figure 6).

2.3 Physical properties
2.3.1 Color (ASTM D1500)
Color is not a very important property of insulating oil. However, it indicates the degree of aging and, when combined with the chemical analyses, it has some diagnostic value.

2.3.2 Interfacial tension (IFT) (ASTM D971-99)
The interfacial tension between oil and water is a measure of the amount of polar contaminants and degradation agents. It is a useful indicator of aging, and a good complement to the acidity, because, as opposed to the latter, it is also influenced by non-acidic oxidation agents (figure 7).

2.3.3 Corrosive sulphur (IEC 62535)
In recent years there have been a significant number of failures, in different types of equipment, due to the formation of copper sulphide in the cellulosic insulation. Also, due to the corrosive action of sulphur compounds in oil, other problems have been reported. It was realized that the tests for corrosive sulphur used in oil specifications, mostly ASTM D1275 (copper strip) or DIN 51353 (silver strip) were not adequate. Several oils passing these tests have caused copper sulphide formation on the site, in some cases resulting in failure. New tests have been developed that have higher sensitivity or are more relevant for the failure mechanisms involved. A new more severe copper strip test has been introduced (ASTM D1275 method B), and a covered conductor deposition test (CCD) was developed to identify oils that may cause copper sulphide precipitation in cellulosic insulation. A simplified version of the latter test is described in IEC 62535. Although the phenomenon of copper sulphide formation has attracted most of the attention in the last few years, the risk of sulphide formation on silver coated selector contacts should not be forgotten. The DIN 51353 silver strip test may be useful to detect this problem.
3. Sampling and frequency of analysis (IEC 60567, IEC 60475)

It is recommended to perform the oil sampling according to IEC 60567. The sampling procedure for oil condition supervision is described in IEC 60475. ABB provides the appropriate test vessels and sampling instructions (figure 1).

Sampling for DGA should be performed annually or as recommended by the laboratory.

Oil supervision sampling should take place every 5 years for transformers up to 15 years of age, then every 3 years as recommended by the laboratory.

4. Ordering of tests

Contact the laboratory at diagnostics@se.abb.com, or tel. +46 240 783307. We will provide the required sampling containers. Carefully follow the instructions in documents 1ZSE 209 001-4 and 1ZSE 209 001-6, which are provided with the sampling vessels.

It is very important to indicate in your order if this is for a routine test, or if anything special has occurred in the transformer. Please also provide the name and telephone number of a contact person.
Additional information

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