Dissolved gas analysis and supervision of oil condition in transformers and reactors

Transformers Diagnostic Services at ABB performs dissolved gas analysis and supervision of oil condition in power transformers, reactors, instrument transformers, circuit breakers and oil-insulated cables.

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 the method of analysing gases dissolved in the oil has been used as a tool in transformer diagnostics in order to detect incipient faults, to supervise suspect transformers, to test a hypothesis or explanation for the probable reasons of failures or disturbances which have already occurred and to ensure that new transformers are healthy. Finally, DGA could be used to give scores in a strategic ranking of a transformer population used in condition assessments of transformers.

In this respect the dissolved gas analysis is regarded as a fairly mature technique and it is employed by several ABB transformer companies around the world either in own plant or in cooperation with an affiliated or independent laboratory.

The idea with dissolved gas analysis is based on the fact that during its lifetime the transformer generates decomposition gases, essentially from the organic insulation, under the influence of various stresses, both normal and abnormal.

The gases that are of interest for the DGA analysis are the following:

- $H_2$ - hydrogen
- $CH_4$ - methane
- $C_2H_4$ - ethylene
- $C_2H_6$ - ethane
- $C_2H_2$ - acetylene
- $C_3H_6$ - propene
- $C_3H_8$ - propane
- $CO$ - carbon monoxide
- $CO_2$ - carbon dioxide
- $O_2$ - oxygen
- $N_2$ - nitrogen

TCG – total combustible gas content ($H_2$, $CH_4$, $C_2H_4$, $C_2H_6$, $C_2H_2$, $CO$, $C_3H_6$, $C_3H_8$)

All these gases except oxygen and nitrogen may be formed during the degradation of the insulation. 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:

- sampling of oil from the transformer
- extraction of the gases from the oil
- analysis of the extracted gas mixture in a gas chromatography, GC.
- interpretation of the analysis according to an evaluation scheme.

The oil samples should preferably be taken in the moving oil so that the gas generated somewhere easily and rapidly is transported from the point of generation to the sampling point. 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 from the Buchholz relay.

In addition, it is very important that the sampling is made in such a way that the contamination of the sampling vessel is held at a minimum and that gas 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.
- by the headspace technique in which gases are “equalized” between a free gas volume and the oil volume.

ABB Transformers Diagnostic Services in Ludvika uses the headspace method (figure 2).

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

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

It should be emphasized that this extraction and analysis may involve analytical errors which mean that it may be difficult to directly compare the results from two different laboratories. One should not jump from one lab to another but try to stick to one well-reputed lab.

1.2 Interpretation

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

- Identification of the key gas. The key gas identifies a particular problem, e.g. H₂ indicate partial discharges (PD).
- Determination of ratios between gases, normally between gas levels.
- Determination of the gas level, either determined in ppm or ml gas.
- Determination of rates of increase („production rates“), in ppm/day or ml gas/day

Around the world and during the years several different schemes have been proposed as evaluation schemes for the DGA. The most commonly known schemes are the one proposed by Rogers forming the basis for the ANSI method and the scheme laid down in IEC Publication 60599. Both these methods are using ratios between gas concentrations.

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

One looks for the most prominent gas - the one which differs most from a tacitly expected „normal“ level (or change). For instance, at overheating of cellulose the main decomposition gases are CO and CO₂. At a partial discharge of corona H₂ is formed (PD in cellulose involves the formation of carbon oxides). At a more severe electric 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). Finally, at overheated oil it is the hydrocarbons that are formed – normally the saturated hydrocarbons such as C₆H₁₄ at lower temperatures and unsaturated such as C₇H₈ at higher temperatures. 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:

\[
\frac{C_2H_2}{C_2H_4} \quad \frac{CH_4}{H_2} \quad \frac{C_2H_4}{C_2H_6}
\]

CH₄/H₂ is used to discriminate between a thermal fault and an electric fault. C₂H₂/C₂H₄ indicates the presence of a strong discharge or very severe electric problem and C₂H₄/C₂H₆ is an indication of the oil temperatures.

1. Overheating of cellulose
   CO, CO₂

2. Overheating of oil
   Increasing temperature
   \[
   \begin{align*}
   C_2H_6 &\quad C_2H_4 &\quad C_2H_2 \\
   CH_4 &\quad CH_4 &\quad CH_4 \\
   \end{align*}
   \]

3. Partial discharges (PD)
   Increasing intensity
   \[
   \begin{align*}
   H_2 &\quad H_2 &\quad C_2H_2 \\
   \end{align*}
   \]

4. Discharges
   \[
   \begin{align*}
   C_2H_2, H_2 \\
   \end{align*}
   \]
1.3 Application
How often one should take oil samples depends on the importance of the transformer.

- When we suspect a fault (e.g. abnormal sounds).
- In case of signals from gas or pressure relay.
- Directly after, and within some weeks, after a short circuit.
- When a transformer essential to the network is taken into operation, followed by further tests after some months in operation.
- After 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 recommendation are also available by a Web service (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 the detection of 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 ageing of the oil and the solid insulating with the formation of water, acids and sludge. Apart from impairing the insulating properties, these oxidation products also cause accelerated degradation of the cellulose insulation.

There are a number of different tests devised for detecting changes in electrical properties and chemical composition of the oil. Some are made in order to obtain information about the status of the oil itself, while others are made mainly for the assessment of 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 4).

2.1.2 Dielectric dissipation factor, \( \tan \delta \) (IEC 60247)
This is a measure of the dielectric losses of the oil (figure 5). These losses are due mostly to conductivity of the oil. It is not as such a very important parameter for the operation of the transformer (unless the value is extremely high), but it is a good indication of the presence of dissolved metal 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. There may also occur leakage of water into the transformer by various mechanisms. Measurement of the water content of the oil also allows the estimation of the water content of the solid insulation, which is where most of the water is bound. A high water content of the oil may lower the breakdown voltage, while the main problem with a high water content of the solid insulation is the increased aging rate of the paper (figure 6). Note, however, that the water content of oil and of solid insulation are 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 oxidation of the 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 down the oxidation of the oil. They act by reacting with certain intermediates in the oxidation process, thus preventing a chain reaction in which oxidation products 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 7).

2.3 Physical properties

2.3.1 Colour (ASTM D1500)
Colour is not itself a very important property of insulting oil. However, the colour is an indicator of degree of aging, and together with results from 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 products. 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 products (figure 8).

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 other problems due to the action of corrosive sulphur compounds in oil 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 in real life, in some cases with failure as a consequence.

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 gotten most of the attention in the last few years, the risk of sulphide formation on silver coated selector contacts should also 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 sampling of oil according to IEC 60567. In IEC 60475 the sampling procedure for the supervision of oil condition is described. ABB provides the appropriate test vessels and sampling instructions (figure 1).

The frequency of sampling for DGA is recommended to be performed once every year or as recommended by the laboratory.

The frequency of sampling for supervision of oil is recommended to be every fifth year for transformers up to 15 years age and then every third year or 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 sampling containers required. Follow carefully the instructions in documents 1ZSE 209 001-4 and 1ZSE 209 001-6, which are provided together with the sampling vessels.

It is very important that it is stated in the ordering if it is a normal routine test or if anything special has occurred in the transformer. Please give also the name of a contact person and the corresponding telephone number.
For more information please contact:

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