Dissolved gas analysis in on-load tap-changer oil

Scope

This product information deals with the use of Dissolved Gas Analysis (=DGA) as a condition indicator in conventional On-Load Tap-Changers (=OLTCs) in mineral oil. With conventional OLTCs means OLTCs with arc quenching in mineral oil. The content in this document is thus not valid for electronic OLTCs and OLTCs with vacuum interrupters. It is also not valid for OLTCs using other insulating liquids than mineral oil.

It is also mainly valid for OLTCs that has dehydrating breathers as interface against the atmosphere. In case so-called one-way breathers are used, please contact ABB Power Technologies, Components for advise!

History

Historically, DGAs in OLTCs have been considered rather worthless due to the large amount of gases normally generated by the arcs. This has however been reconsidered the recent years and the opinion today is that quite a lot of information is gained by DGAs of OLTC oils.

The gases

The gases that are considered interesting as condition indicators in transformers are:

- Hydrogen (H₂)
- Acetylene (C₂H₂)
- Methane (CH₄)
- Ethene (C₂H₄)
- Ethane (C₂H₆)
- Propene (C₃H₆)
- Propane (C₃H₈)
- Carbon monoxide (CO)
- Carbon dioxide (CO₂)

In addition to these, oxygen (O₂) and nitrogen (N₂) are analyzed. These are normally not interesting as indicator gases.
What generates the gases?

The gases have three sources:

- The surrounding atmosphere
- The decomposition/oxidation of the oil
- Other materials in the apparatus

New transformer oil has no or a very small content of combustible gases. Combustible gases mean all hydrocarbon gases and carbon monoxide. Atmospheric gases such as oxygen, nitrogen and carbon dioxide might exist in large amounts depending on the treatment and storage of the oil. Degassed oil has a very low content of all gases.

- Hydrogen (H₂). Is generated by partial discharges and arcings.
- Acetylene (C₂H₂). Is generated by arcings.
- Methane (CH₄). Is generated at elevated temperatures. Generation starts at low temperature (approx. 150 °C)
- Ethene (C₂H₄). Is generated by higher temperatures (300°C and higher).
- Ethane (C₂H₆). Is generated by higher temperatures (300°C and higher).
- Propene (C₃H₆). Not in use by now.
- Propane (C₃H₈). Not in use by now.
- Carbon monoxide (CO). Is generated by the oxidation of cellulose insulation.
- Carbon dioxide (CO₂). Is generated by the oxidation of cellulose insulation. Also comes from the atmosphere.

Faults in OLTCs possible to indicate by DGA

There are three basic faults that can be detected by DGA:

- Discharges and arcings
- Thermal faults
- Ageing of cellulose insulation

Discharges and unwanted arcs can’t be detected because the OLTCs work with arcs in oil as their normal operation.

Ageing of cellulose is of no importance in the ABB OLTCs since cellulose insulation isn’t used.

Thermal faults are possible to detect. The arcs during normal switching generate both acetylene and hydrogen but also the three gases indicating thermal faults, methane, ethane and ethene.

The temperature in the center of the arc is several thousands centigrade and the molecules are totally degraded and the recombination afterwards results in mainly hydrogen and acetylene. However, there is a temperature gradient from the plasma channel in the center of the arc to the surrounding oil where all the temperatures between the oil temperature and the plasma temperature exist. Thus, even the thermal fault gases are generated by the arc but in certain percentages of the hydrogen and acetylene generation.
This relation between the gases is fairly constant as long as the gases are generated by the arcs only. If there is another source of thermal fault gases, such as an overheated contact, the relation will change and a fault can be detected in an early stage before any severe faults occur.

The Stenestam ratio

This ratio, named after its inventor, is the following ratio:

\[
\frac{[\text{CH}_4] + [\text{C}_2\text{H}_4] + [\text{C}_2\text{H}_6]}{[\text{C}_2\text{H}_2]} \]

This is the relation between the thermal fault gases and the arc gas acetylene. Hydrogen is not used since it is not reliable due to its high volatility and low solubility in the oil.

Important principals for interpretation of DGAs

There are some important things to bear in mind before an interpretation is made:

- Never try to interpret DGAs where the gas amounts are very low. For a useful ratio the amount of acetylene should be at least 500 ppm.
- A single sample does not give reliable information. The most reliable information is gained when samples are taken within certain intervals giving a trend. In case where the ratio is in the grey zone between normal and faulty, new samples with certain intervals are always recommended to give a trend.
- Sampling and storage of samples are important for getting a correct result.

Interpreting the Stenestam ratio

These intervals are important:

- <0.5. No overheating indicated.
- 0.5-5. New samples taken. The higher the value, the shorter the interval.
- =>5. An overheating has occurred. The unit should be taken out of service and be repaired as soon as possible. Contact ABB Power Technologies, Components for advise!

In the range 0.5-5, intervals for new samples are recommended to be like this:

- 0.5-1 => 3-6 months
- 1-3 => 1-3 months
- 3-5=> within one month.
Typical gas concentrations

The gas concentrations themselves do not give any useful information since the concentrations are dependent on a large number of factors, such as load, number of operations, piping, breathing, temperature variations, oil volumes, type of connection, OLTC type, etc.

However, to give an idea of what the levels are in some typical cases, the following examples can be given (all values in ppm v/v):

<table>
<thead>
<tr>
<th>Gas</th>
<th>Low current/few operations</th>
<th>“Normal operation”</th>
<th>Industrial service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1000-5000</td>
<td>1000-15000</td>
<td>&lt;35000</td>
</tr>
<tr>
<td>Acetylene</td>
<td>500-5000</td>
<td>2000-30000</td>
<td>30000-150000</td>
</tr>
<tr>
<td>Methane</td>
<td>&gt;300</td>
<td>300-2000</td>
<td>&lt;20000</td>
</tr>
<tr>
<td>Ethane</td>
<td>&lt;100</td>
<td>&lt;500</td>
<td>&lt;30000</td>
</tr>
<tr>
<td>Ethene</td>
<td>50-300</td>
<td>300-5000</td>
<td>&lt;70000</td>
</tr>
<tr>
<td>Propene</td>
<td>&lt;100</td>
<td>100-1000</td>
<td>&lt;15000¹</td>
</tr>
<tr>
<td>Propane</td>
<td>&lt;10</td>
<td>10-200</td>
<td></td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>&lt;700</td>
<td>&lt;700</td>
<td>&lt;700</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>500-3500</td>
<td>500-3500</td>
<td>1000-3500</td>
</tr>
<tr>
<td>Oxygen</td>
<td>15000-35000</td>
<td>10000-35000</td>
<td>1000-35000</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>40000-70000</td>
<td>40000-70000</td>
<td>40000-70000</td>
</tr>
</tbody>
</table>

1) The sum of propene and propane

As can be seen the levels can vary very much. In case questions are raised concerning the gas concentrations, you are always welcome to consult us. But remember, to give advises we need some information:

- OLTC type designation (from the rating plate on the motor drive mechanism)
- Serial No. of the OLTC (from the rating plate on the motor drive mechanism)
- No. of operations since last oil replacement.
- Rated load and average load since last oil replacement
- Type of breather for the conservator
- Daily load variations
- Daily oil temperature variations
- Faults, if any, that has occurred since last oil replacement

Important to bear in mind

The interpretation of DGA in OLTC oils is a new field of knowledge that still is in an early stage. The information in this product information is however the best of our knowledge today. In the future, new information will complete and perhaps also revise the content in this document.