Dissolved gas analysis in tap-changer oil

Product information

This product information deals with the use of Dissolved Gas Analysis (DGA) as a condition indicator in On-Load Tap-Changers (OLTC) in mineral oil. The content in this document is thus not valid for tap-changers using other insulating liquids than mineral oil. It is also mainly valid for tap-changers that has dehydrating breathers as interface against the atmosphere. In case so-called one-way breathers are used, please contact ABB Components for advice.

New transformer oil has no or a very small content of combustible gases. Combustible gases mean all hydrocarbon gases, hydrogen 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, arcings and also in normal service by radiation, electrical field, etc.
- Acetylene (C₂H₂) is generated by arcings.
- Methane (CH₄) is generated at elevated temperatures. Generation starts at low temperature (approx. 150 °C).
- Ethene, also known as ethylene, (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 and possibly also by oxidation of the oil.
- Carbon dioxide (CO₂) is generated by the oxidation of cellulose insulation. Also comes from the atmosphere.

History
Historically, DGA of tap-changers have not been considered useful due to the large amount of gases normally generated by the arcs. This has however been reconsidered and the opinion today is that quite a lot of information is gained by DGA of tap-changers oils, especially for vacuum type tap-changers.

Gases in transformers and tap-changers
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 gases are useful to indicate degree of breathing and possible high operating temperatures.

Gas generation
The gases have three sources:
- The surrounding atmosphere
- The decomposition/oxidation of the oil
- Other materials in the apparatus
Faults in tap-changers that is possible to indicate by DGA

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

• Discharges and arcings
• Thermal faults
• Aging of cellulose insulation

Discharges and unwanted arcs cannot be detected in non-vacuum type tap-changers because the tap-changers work with arcs in oil as their normal operation. Ageing of cellulose is of no importance in the ABB tap-changers since cellulose insulation is not used.

Thermal faults are possible to detect for non-vacuum type tap-changers. 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 thousand degrees Celsius and the molecules are totally degraded. 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. Vacuum types generate extremely small amounts of gases compared to non-vacuum types since the main gassing source, the arc, is isolated in the vacuum interrupters. Only sparking from commutating contacts and heating from transition resistors and, for some types, also change-over selectors produces gases. This makes also faults such as arcing and high PD-levels possible to detect. Overheating will also be possible to detect at an earlier stage.

Non-vacuum type tap-changers

The Stenestam ratio

The ratio, named after its inventor, is as follows:

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

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

Important principals for interpretation of DGA

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 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.

Interpretation of the Stenestam ratio

These intervals are important:

• <0.5: No overheating indicated.
• 0.5–5: New samples should be taken. The higher the value, the shorter the interval (see below).
• ≥5: An overheating has occurred. The unit should be taken out of service and be repaired as soon as possible. Contact ABB Components for advice.

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 depending on a large number of factors, such as load, number of operations, piping, breathing, temperature variations, oil volumes, type of connection, tap-changers type, etc. However, to give an idea of what the levels are in some typical cases, the following examples are 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 operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1000–5000</td>
<td>1000–15 000</td>
<td>&lt;35 000</td>
</tr>
<tr>
<td>Acetylene</td>
<td>500–5000</td>
<td>2000–30 000</td>
<td>30 000–150 000</td>
</tr>
<tr>
<td>Methane</td>
<td>&lt;300</td>
<td>300–2 000</td>
<td>&lt;20 000</td>
</tr>
<tr>
<td>Ethane</td>
<td>&lt;100</td>
<td>&lt;500</td>
<td>&lt;30 000</td>
</tr>
<tr>
<td>Ethene</td>
<td>50–300</td>
<td>300–5 000</td>
<td>&lt;70 000</td>
</tr>
<tr>
<td>Propene</td>
<td>&lt;100</td>
<td>100–1 000</td>
<td>&lt;15 000</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>500–3 500</td>
<td>500–3 500</td>
<td>1000–3 500</td>
</tr>
<tr>
<td>Oxygen</td>
<td>15 000–35 000</td>
<td>10 000–35 000</td>
<td>1000–35 000</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>40 000–70 000</td>
<td>40 000–70 000</td>
<td>40 000–70 000</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, please contact ABB Components with the information listed in the final section.

**Vacuum type tap-changers**
For vacuum type tap-changers, hydrogen, acetylene and ethene (ethylene) are the gases to evaluate. An even increase of up to a few hundred ppm of hydrogen is expected every year. Interpretation of the ratios below should not be done until acetylene is at least 5 ppm.

**VUBB**
Hydrogen and acetylene are expected in the ratio of approximately 2–5 to 1 with normal operation pattern. Higher ratios might occur if few operations through middle position is made during long time.
- For VUBB.L: Up to a few ppm acetylene per year is expected.
- For VUBB.R and VUBB.D: Higher values are expected depending on the capacitive breaking stresses of the change-over selector and the no of operations of it.
Ethene (ethylene) concentration is normal as long it is lower than hydrogen concentration.

**VUCL**
Hydrogen and acetylen are expected in the ratio of approximately 2–5 to 1 with normal operation pattern. The concentration will follow the no. of operations and the load current. Ethene (ethylene) concentration is normal as long it is lower than hydrogen concentration.

For all above, operation with high oil temperatures over longer times (approximately >90 °C and >10 % of the time) might give higher ethene concentrations.

The recommendations are very general and can vary due to numerous service conditions. For values outside these recommended values, please send the result to ABB Components for evaluation, free of charge.
Support from ABB Components
The following information given as good as possible are needed for enabling a proper evaluation:

- Tap-changers type designation (from the rating plate on the motor-drive mechanism)
- Serial number of the tap-changer (from the rating plate on the motor drive mechanism)
- Number of operations since last oil treatment.
- Rated load and average load since last oil treatment.
- Type of breather for the conservator.
- Daily load variations
- Daily oil temperature variations
- Faults, if any, that has occurred since last oil treatment.