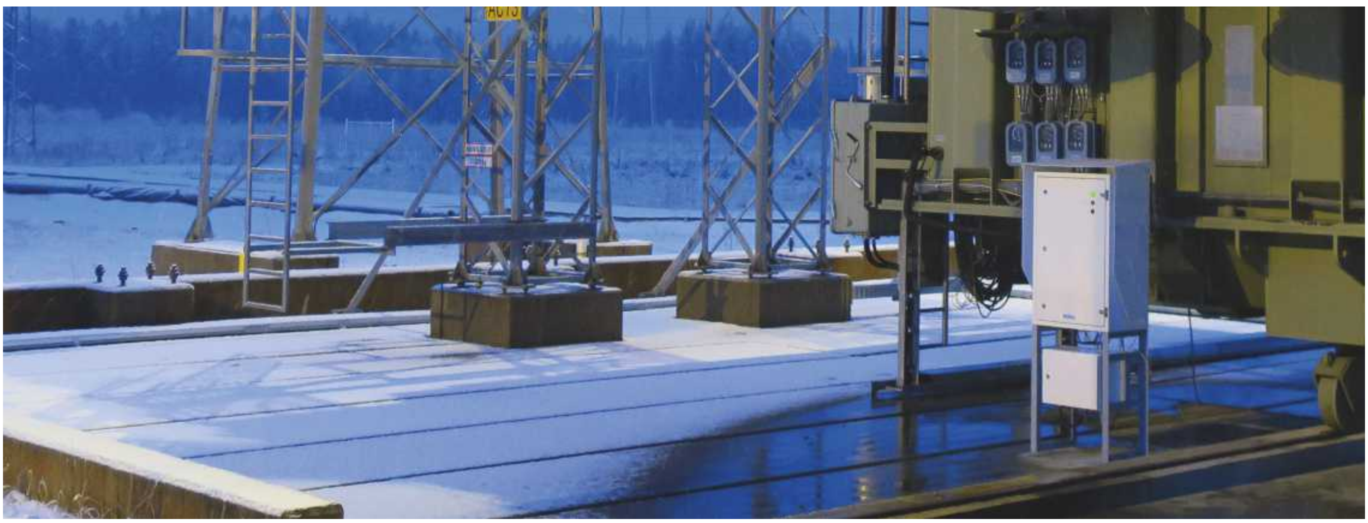
Vaisala Optimus™ DGA monitor OPT100



Power transformers are among a substation's most expensive assets, representing 60% of the total investment. They are also critical in securing reliable electricity supply over the whole power network — from generation to distribution.

To ensure long-term operation of these assets, online monitoring and automatic condition assessment are becoming a crucial part of modern condition-based maintenance strategies for power utilities. Reliable DGA monitors have become essential tools for supplying accurate data on transformer condition. However, with the wide range of DGA monitors available, it may be difficult for users to distinguish between devices from different manufacturers.

This technical note looks at the latest developments in DGA monitors and how they can significantly reduce the uncertainties associated with the measurement technologies used in older-generation monitors, especially gas extraction from oil and cross-sensitivity in infrared-based gas detection.

Gas extraction from oil

With the Vaisala Optimus™ DGA monitor, gases are extracted from transformer oil under a partial vacuum, meaning very low absolute pressure at a controlled temperature. Vacuum extraction results in a more complete gas separation than with traditional headspace or membrane methods; it is therefore significantly less dependent on gas solubility in oil values, also known as Ostwald coefficients, and more reliable across a broad range of oils.

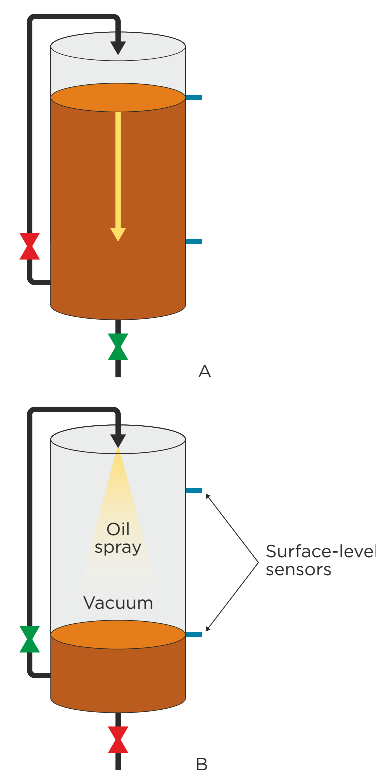


Figure 1. Applying a vacuum above the oil level by pumping the oil out with a closed valve at the top of the cylinder (A). Gas is extracted by spraying oil through the vacuum (B).

In comparison, Ostwald coefficients are necessary when using the traditional headspace extraction method to calculate gas concentrations in oil from only partly extracted gases. The coefficients are different for different gases and dependent on temperature, oil quality, and base oil type – naphthenic or paraffinic, for example. With the partial vacuum extraction of the Vaisala Optimus™ DGA monitor, the measurement uncertainty related to differences in the coefficients can be reduced to one third of that seen with the headspace method.

To create a vacuum the Optimus™ DGA monitor does not use a vacuum pump. Instead, it uses a patented method that utilizes the oil volume as a piston in the cylinder, creating the vacuum above the oil level volume by moving the oil with a magnetic gear pump. The oil sample is then sprayed through the vacuum to extract the gases (Figure 1).

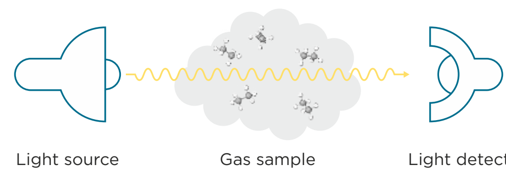


Figure 2. Schematic of IR light absorption caused by molecules shifting into an excited state.

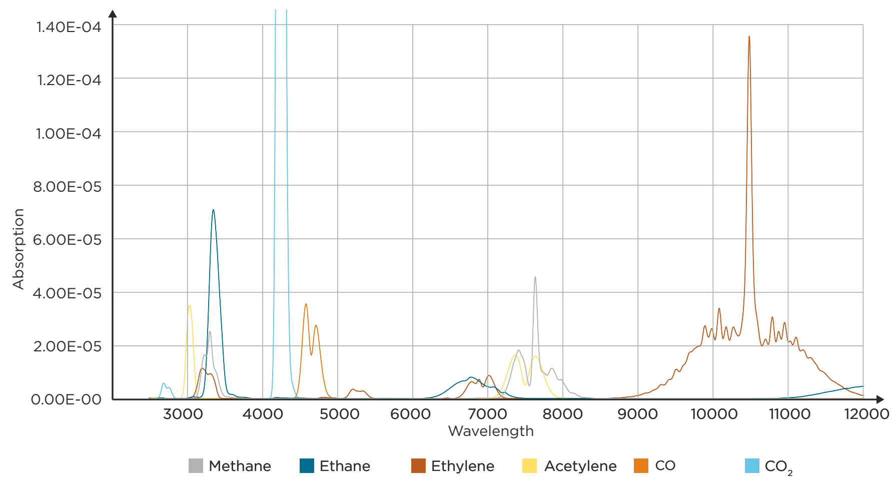


Figure 3. IR light absorption bands of CO_2, CO, acetylene, ethylene, ethane, and methane gases.

Using a vacuum extraction, results in a more complete gas separation, increasing measurement reliability even when the pressure of the total dissolved gases in the transformer oil is very low. This can happen, for example, with sealed transformers or after a transformer degassing process where the total gas pressure may be well below 100 mbar.

Infrared-based gas detection

When extracted gas molecules are exposed to non-dispersive infrared light (NDIR) they absorb energy as they shift into an excited molecular state (Figure 2). Absorbed wavelengths are unique to each gas, forming a gas-specific "fingerprint" that can be used to identify the gas components in the extracted gas mixture (Figure 3). The absorption intensity depends on the gas concentrations, so the amount of each specific gas present can be ascertained by measuring the light intensity.

One of the key benefits of IR measurement is that it is a fundamental gas-analysis method where the gas-specific absorption wavelengths and absorbances of fault gases do not change over time. This enables calibration-free operation over a long period, assuming the other possible drift mechanisms are known and compensated for by the DGA monitor.

The temperature-controlled IR module of the Optimus™ DGA monitor consists of light sources, band-pass filters, the gas cell, a mirror, and detectors (Figure 4). The measured wavelengths are selected with the band-pass filters, which only allow a certain wavelength band to pass through. A key part of this module are the tunable filters, which allow a wider range of IR scanning, revealing the shape of absorption regions and the peak values. Since the module analyses the IR absorption as well as the shape of absorption peaks, it can provide excellent selectivity for the different gases detected and their concentrations. So, the final gas analysis is based on signals gathered using a large wavelength range.

All IR sensor elements, including the micro glow light sources, filters, and detectors, are micro-

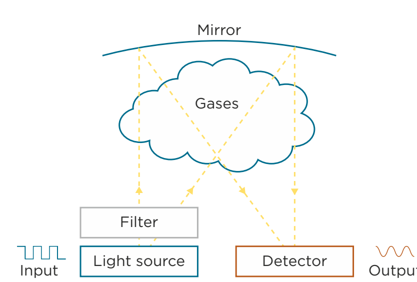


Figure 4. Schematic of the Optimus™ DGA monitor IR module.

electromechanical systems (MEMS) fabricated on single-crystal silicon wafers. These elements are designed and optimized for the Optimus™ DGA monitor and manufactured in our own cleanrooms. To further maximize reliability, there are no moving parts in the optical measurement module.

Eliminating drift

Although the absorption characteristics of fault gases do not change over time when using IR-based analysis, measurement signals may still be affected by other factors. Therefore, a DGA monitor should compensate or eliminate such drifting effects.

Typical drift mechanisms in IR technologies include contamination or aging of sensor components such as light sources and detectors. DGA systems should have ways to compensate for these mechanisms to achieve long-term stable measurements. This is crucial as gas trends are one of the most important sources of information for revealing a transformer's condition.

Vaisala has developed and patented multiple unique methods to overcome drift and ensure stable measurements without recalibration. With the Optimus™ DGA monitor, internal gas extraction and oil handling mechanisms are built and controlled in such a way that contaminating compounds from the oil cannot gather on the optical surfaces and cause long-term drift. Additionally, any external contamination is avoided by using a fully hermetic mechanical structure, which means that any compounds from the ambient air cannot reach the optics and affect the measurement.

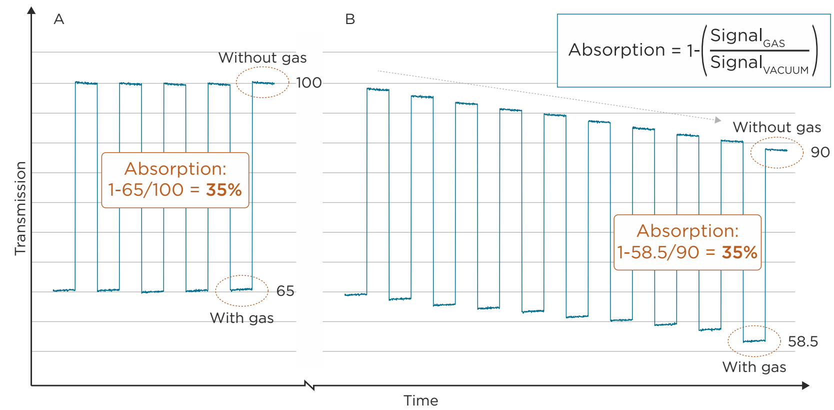


Figure 5. Operating principle of IR reference signal during vacuum phase in optics. A) Stable measurement, B) 10% drift in light source intensity.

Providing a reference measurement

The Optimus™ DGA monitor creates a reference measurement for internal calibration using a patented system during each oil sampling cycle. The scanning and measuring of predefined wavelength ranges is done both with the extracted gases present and then under vacuum after the gases have been removed from the optical module. The latter measurement then acts as the reference. The ratio of these two scanning signals defines the actual absorptions and thus the gas concentrations.

This enables the system to compensate for possible drift in the optical components, whether due to aging or contamination. Figure 5 shows an example of IR transmission signals when gas is present and under vacuum (no gas) both during stable measurement and if a drift of 10% occurred in the light source intensity.

Autocalibration on oil – long-term performance & eliminating drift

Transformer oils in service have a very complex chemical composition, including the key fault gases used for transformer diagnostics as well as heavier hydrocarbon gases and other volatile organic compounds (VOCs). The IR absorption bands of the hydrocarbon gases and the VOCs – the interfering gases – may overlap with the fault gases and interfere with the absorption signal and thus the gas analysis, unless identified and compensated for.

However, these compounds have different physical characteristics compared to the key fault gases. The Optimus™ DGA monitor uses this physical difference between the VOCs and the key fault gases to compensate for the VOCs. When gases are extracted under different conditions, a significantly lower amount of the heavier hydrocarbon gases are extracted. The reduction in interfering gases is detected at each extraction step with the IR absorption measurements (Figure 6). With this method, the relative proportion of the interfering gases can be calculated and subtracted from the actual measurement signals.

This functionality is called autocalibration on oil. The Optimus™ DGA runs it on the first measurement cycles after installation, so that the monitor can identify and "learn" the mixture of hydrocarbon gases and VOCs present in the oil. In normal operation the autocalibration on oil function runs on a regular, roughly monthly schedule. It reruns the calculations to ensure it can effectively compensate for changes in oil composition, thus ensuring long-term performance.

Total gas pressure

As the OPT100 online DGA monitor uses partial vacuum to extract gases from transformer oil, it can measure the total pressure of all dissolved gases with its integrated pressure sensor. Total gas pressure (TGP) is the sum of the partial pressures of all gases dissolved in the oil.

Increasing pressure is an early indication of an air leak into sealed transformer tank. In case of an air leak into the transformer tank, the largest portion of gases measured would be nitrogen and oxygen. Both can be completely extracted from oil, because of their poor solubility. Furthermore, the proportion of fault gases in the total pressure value is negligible.

Even if all oxygen had been consumed, the pressure value would give a reliable indication of a leak. A leak can be identified because the nitrogen value will both dominate and increase over time as it is neither formed nor consumed in the transformer.

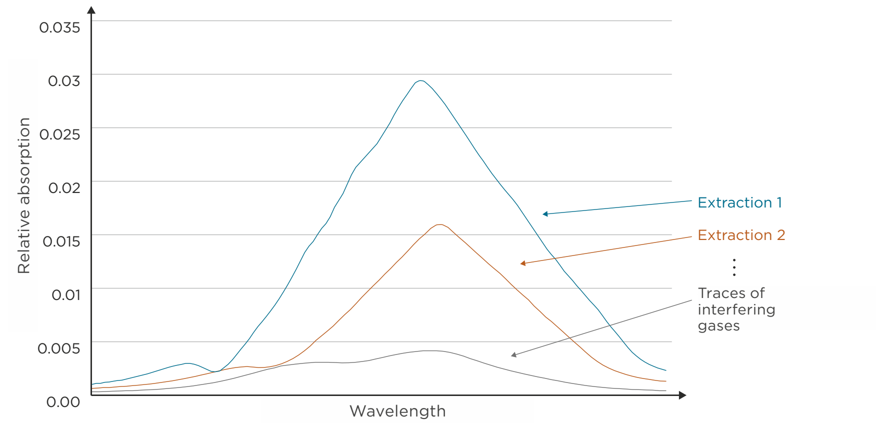


Figure 6. Gas extraction under different conditions reduces the proportion of interfering gases in the absorption scan.

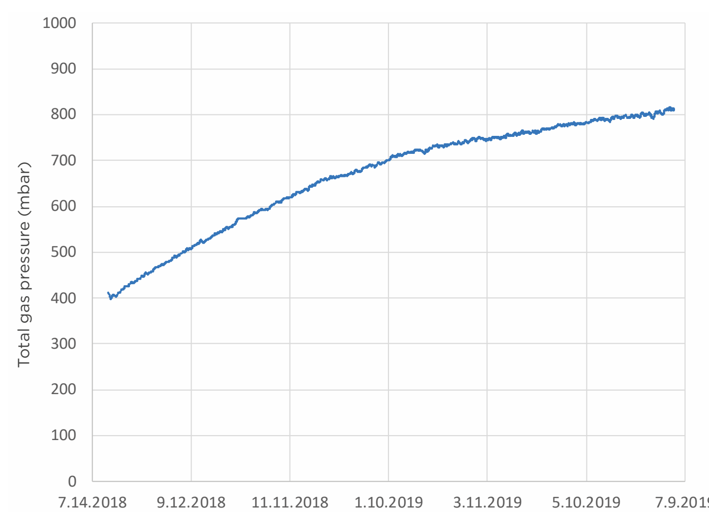


Figure 7. Total pressure of dissolved gases in a power transformer's insulation oil as measured with a Vaisala OPT100 online DGA monitor.

The Vaisala Optimus™ DGA monitor is unique on the market in that it can create vacuum conditions in a very simple way, using just an oil pump and magnetic valves. This brings two major advantages for measurement accuracy and stability:

- The gas extraction efficiency is far superior to typical monitors based on headspace or membrane sampling, and the powerful vacuum reference measurement method can be used to compensate for all the major drift mechanisms seen in IR measurement technologies.
- The oil and gas processing mechanisms are fully closed, so the risk of an oil leak is negligible and any oil contamination by ambient moisture and oxygen is prevented.

These advantages, combined with the autocalibration on oil functionality, mean the Optimus™ DGA monitor can ensure many years of accurate, reliable, and maintenance-free operation.

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