VAISALA / APPLICATION NOTE

TRANSFORMER MONITORING

Online Moisture Monitoring for Power Transformers

Power transformers represent 60% of the asset value in a high voltage substation, making them among the most expensive assets in electricity transmission and distribution. Knowing the condition of power transformers is key to ensuring reliable grid operation, improving risk assessment, and implementing more effective maintenance strategies.

Moisture is one of the dominant factors that limit the lifetime of a power transformer. For effective transformer lifetime management, the moisture content of the insulation system, cellulose, and oil should be kept at a low level.

After initial factory drying, the moisture content in solid insulation is typically between 0.5 and 1% depending on requirements, and starts to increase gradually over the operating lifetime of the transformer. The main moisture sources are residual moisture in thick structural cellulose components, ingress from the atmosphere, and small amounts of moisture generated as a by-product of cellulose decomposition.

Issues Caused by Moisture

In a power transformer, the majority of water is found in the solid paper insulation. Higher water content leads to accelerated deterioration of the paper, reducing its degree of polymerization (DP). Moisture and heat provide an optimal environment for various compounds in the oil – such as acids and metal ions – to react with the cellulose molecules and break them down. This is important as when the water content in the paper doubles, it can cut the remaining life of the transformer in half.

Poor oil quality and high moisture levels can lead to low dielectric strength and eventual system failure. It has been reported that when relative moisture saturation goes above 20%, the relative saturation (RS) dielectric strength of oil starts to decrease rapidly (Vaisala White Paper The Effect of Moisture on the Breakdown Voltage of Transformer Oil B211282EN-A).

When the temperature rises, high water content in the insulation, combined with dissolved gases in the oil, may cause bubble formation if the total pressure of gases and water vapor exceeds the oil pressure of the transformer. If bubbles form or travel into energized parts of the transformer like the windings, there is a severe risk of system failure due to sudden local collapse of the dielectric-medium.

In a wet transformer, exceptional high-loading events can drive excess moisture from the paper into the oil, creating relative moisture saturation of 100% RS and the formation of free water. The same may happen if a heavily loaded wet transformer cools down quickly. Free water may cause corrosion and rust particles in oil circulation pipes and radiators. In the worst case, free water can form around active parts, resulting in discharge that damages the transformer.

Evaluating Moisture Dynamics

A scheduled oil sample and KF titration in a laboratory is the common practice for estimating the moisture level of transformer paper based on the moisture-in-oil reading. The oil sample for analysis should be taken when the insulation system is in equilibrium and thermally stable – in other words, when winding and oil temperatures have been relatively constant for a longer period of time.

But is this really practical? In general, most water is found in the solid insulation paper and other cellulosic materials. The cellulose-oil insulation system in a transformer is complex in regard to moisture distribution as the oil and cellulose exhibit reverse moisture absorption behavior – at increasing temperatures, moisture is released from the paper surface and dissolved in the oil, and absorbed back from the oil to the paper as temperatures decrease. There may be considerable short-term variation in the oil moisture driven by changes in transformer loading and the ambient temperature. The higher the water content in the paper insulation, the bigger the variation in oil moisture during temperature fluctuation.

The moisture absorption back to paper is a significantly slower process than desorption. This can be seen as clear hysteresis in online moisture monitoring data measured as a function of transformer temperature (Figure 1). With such strong moisture dynamics, it may be difficult or even impossible to determine the correct moment to take a representative oil sample for laboratory analysis. For example, if the oil sample is taken from the above-mentioned transformer at 35°C, the laboratory result may give 30 ppm or 50 ppm depending on whether the transformer is in the cooling or loading phase at the point of sampling. Such a large variation may lead to significantly erroneous conclusions about the condition of the transformer.

The lower the operating temperature of a transformer, the less water is found in the oil. This is an important fact to take into account when assessing the moisture content in solid insulation and evaluating its effect on safe operation. A transformer that operates normally at a relatively low temperature and with low oil moisture can have rapidly increasing moisture in oil levels during a single heavy overload event due to temperature-induced moisture migration from the paper surface. The return of moisture to the previous "normal" level may take days or even weeks, meaning that during a cooling period, relative moisture saturation can become dangerously high.

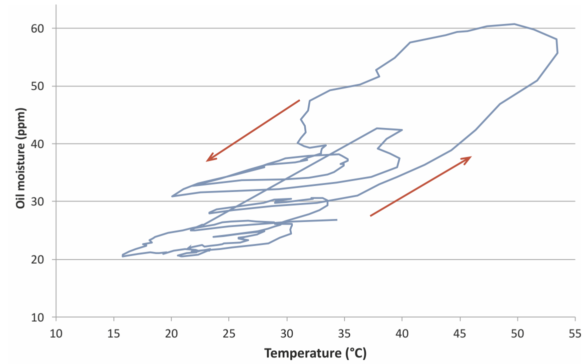

Figure 1. Online moisture monitoring data in ppm during temperature fluctuation in a 10 MVA (ONAN) transformer

Benefits of Online Moisture Monitoring

Online monitoring gives a true and real-time picture of the moisture levels in transformer oil in all operating conditions.

The moisture dynamics of a transformer during normal operating conditions can be significant. Online monitoring provides the operator with valuable information on oil moisture, enabling further analysis such as evaluation of the risk of moisture saturation and decreased dielectric strength, as well as input data for paper moisture evaluation. Online monitoring allows the operator to detect evolving moisture-related risks and other early signs of faults – and react appropriately. For example, a transformer with high moisture levels may not be permitted to run at full load until dry-out has occurred. This can be considered an operational limit, and may differ from the nominal limit, which in general assumes serviceable and dry oil.

Online moisture monitoring can provide valuable information on transformers that have previously been identified as having moisture problems. It is also valuable for relatively lightly loaded transformers that may have moisture issues that have not been detected by routine oil sampling.

A moisture sensor provides the transformer with a proper operational safety margin. Moreover, by using moisture sensor readings in ppm and published equilibrium moisture charts, it is possible to estimate the water content in the cellulose insulation during transformer operation. This would typically demand an intelligent cooling system in order to maintain the temperature as constant as possible during the time period needed to reach the moisture equilibrium state.

Alternatively, moisture and temperature readings can be taken as an average from a longer period, which represents moisture equilibrium better than a single point oil sample during dynamic loading. Recently published literature also evaluates cellulose moisture directly from the measured relative moisture saturation and temperature of oil (CIGRE TB349).

Finally, it's important to remember that monitoring alone will not fix anything – only taking action based on monitoring information will result in condition improvement in the long run.

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