How Wet Is My Transformer, and What Should I Do About It?

by **Brian Sparling**

The most important piece of information needed (and often ignored at the time of sampling) is the temperature of the oil sample when it is taken. Without this temperature being noted, the value of the moisture-in-oil test is meaningless.

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Moisture assessment in transformers is often determined using equilibrium diagrams, where the moisture content in the solid insulation (paper, pressboard) is derived from the moisture content in oil (ppm). This method fails for several reasons, a primary one being that aging of oil has a major impact on the moisture titration assay. Furthermore, the Karl Fischer Titration (KFT) method suffers from moisture ingress into the sample during transportation to the laboratory, and different processes utilized during transportation and improperly sealed sample containers can also lead to the release of water from the sample leading to unsatisfactory results. The most important piece of information needed (and often ignored at the time of sampling) is the temperature of the oil sample when it is taken. Without this temperature being noted, the value of the moisture-in-oil test is meaningless.

To illustrate this point, the graph shown in Figure 1 reveals the situation for a hypothetical Karl Fischer test result of 50ppm. The curves at different temperatures represent the saturation curves up to 100%. Assuming the oil temperature of the sample was 30℃ then the RS is 60%. This result indicates the transformer unit needs to be dried. If the sample temperature was instead 63℃, then the RS would be 20%, which is considered acceptable for service. If the sample temperature was 20℃. the RS is 100%, which suggests a high moisture content symbolic of "raining" inside the transformer. In this case, the unit should be removed from service, and consideration for a complete and effective dry out of both solid and liquid insulation should be mandated.

Research has demonstrated that the key to understanding the moisture condition is to gain knowledge of the % RS (relative saturation) of moisture dissolved in the oil. The Karl Fischer test measures the absolute water content in oil, which is composed of:

(1) free water,

(2) bound water (to particles and other polar compounds) and

(3) dissolved water in the oil known as % RS.

The previously published equilibrium curves used with the PPM measurement of moisture in oil therefore neglects to consider the following:

- Sampling process and (in many cases) lack of temperature of the sample
- Uncertainty of the KFT testing
- Equilibrium conditions in the transformer
- Absorption capacity of the oil
- Aging of oil and paper

The relative saturation of moisture in oil can be measured with a sensor permanently installed on the transformer, in an area with good oil circulation. It measures directly and continuously the % RS and temperature of the oil at the sensor location.

The question then becomes at what point should I seriously consider drying my transformer?

Answer:

1) When the % RS moisture in oil consistently exceeds 18%. At this point, the dielectric breakdown strength of the oil has decreased by 20 to 30%.[2]

2) When the moisture content in paper consistently exceeds 2% wt./wt. for units < 69 kV class.[3]

3) For EHV transformers the limit for moisture in paper may be lower at 2% wt./wt.

The moisture in power transformers using dielectric response methods and equilibrium diagrams can provide the user with information on the condition such as:

- Dielectric diagnostic methods deduce moisture in the solid insulation from dielectric properties like polarization/depolarization currents and dissipation factor as a function of frequency of applied voltage.
- Improved technology for de-energized testing combines time-domain (PDC) and frequency-domain (FDS) measurements and thus substantially shortens the measurement duration.
- The analysis algorithm compensates for the influence of conductive aging by-products.
- The updated software has been successfully utilized[1] for onsite measurements that compare favorably to other measurement and analysis methods.
- The conventional application of equilibrium diagrams to derive moisture in cellulose (%) from moisture in oil (ppm) are affected by substantial errors.

Figure 1.

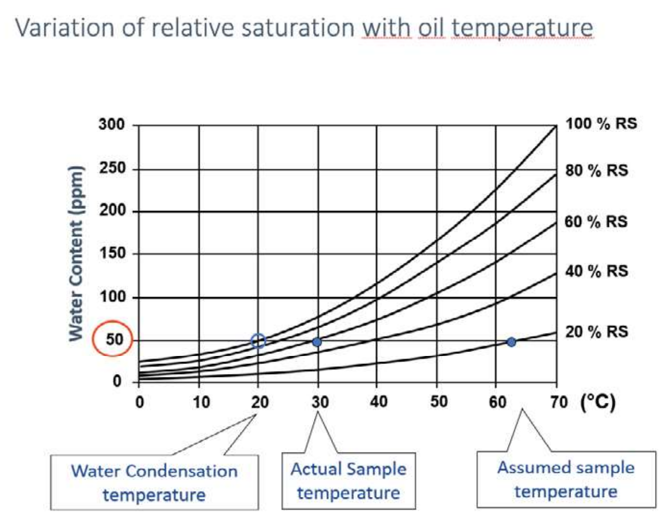

Figure 2. A Single Phase GSU with excessive moisture in the paper, and puncture from HV to LV through the barrier [4]

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- To exclude the interference due to oil aging, the moisture in oil relative to saturation level is more appropriate than moisture in oil in ppm.
- Updated equilibrium curves using % RS of dissolved moisture in oil have been produced, and when used provide a realistic view of the overall moisture condition of the transformer.
- One step forward constitutes the use of moisture relative saturation in oil sensors. This measurement is easy to perform on a continual basis, with accurate and repeatable measurements. These data points should be then integrated into an on-line monitoring system, where the values can be computed, and alarms set accordingly.

Where does all this water come from?

A primary source for this accumulation of moisture inside the tank is via leaks due to deteriorated gaskets. When oil leaks out from gasketed joints, it is possible for moisture and ambient air to enter. Another major source of moisture is from the paper itself as it naturally ages due to the chemical reactions induced by heat, moisture in the paper and acids found in the oil. The byproducts of this continuous chemical reaction are water, carbon monoxide and carbon dioxide, as well as Furanic compounds. All these chemicals dissolve into the oil. The oil gives up the water, and the paper absorbs it, and feeds the chemical reaction.

Why should I be concerned about this?

Excessive moisture in the oil and paper insulation can lead to the following:

- Dielectric breakdown of the oil and paper leading to partial discharges and dielectric breakdown.
- Accelerated aging of the winding insulation, reducing its tensile strength and its useful remaining life.
- The risk of 'bubble formation' between turns and sections of the winding insulation under heavy loading leading to sudden failure.

When oil leaks out from gasketed joints, it is possible for moisture and ambient air to enter. Another major source of moisture is from the paper itself as it naturally ages due to the chemical reactions induced by heat, moisture in the paper and acids found in the oil.

References

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