ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

ONLINE MONITORING OF MOISTURE CONTENT IN TRANSFORMER OIL

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KEYWORDS: DP Value, Moisture Content, ppm.

ABSTRACT
Transformer insulation is provided mainly through mineral oil and Kraft paper. The DP (degree of polymerization) value is an indicator of mechanical stability of Kraft paper insulation. The aging process depends on the transformer's operation temperature and is accelerated by presence of moisture and acids in the insulation system. The DP value is a good indication of the aging status of transformer but it cannot be done while transformer is in service, the degradation of solid insulation can be correlate and heavily influenced by temperature and moisture which results cellulose destruction. We can monitor the moisture and temperature with the help of sensors and microcontrollers.

INTRODUCTION
In oil immersed transformers, paper and cellulose material along with oil forms the major insulation. Therefore the insulation must maintain adequate dielectric strength against voltage surges and adequate mechanical strength against short-circuit forces.

Paper and pressboard insulation when heated under oil for long period of time, lose mechanical strength but dielectric strength is hardly affected until the paper is charred to the point where free carbon becomes conducting or too brittle to withstand mechanical shocks. Deterioration to this extent is complicated by free water librated by decomposition, loading to lowering of dielectric strength. Depolymerization of insulation takes place when deterioration sets in.

Long before this occurs, mechanical strength will be reduced considerably. There are several ways of defining mechanical strength of paper, but the most meaningful and easily measured quantity is tensile strength. Although there is no simple relationship between loss of tensile strength and loss of effective transformer life, it seems reasonably logical to use loss of tensile strength as a measure of life.

The combination of factors to which paper insulation is subjected to in service are several, including temperature, time and presence of moisture, Oxygen and various other reaction products in oil. Many studies have been made in the past which give reasonable closeness of relation between tensile strength, temperature and time. However it has been found that very small amounts of moisture accelerate the loss of tensile strength. Presence of Oxygen with moisture can lead to various kinds of reactions depending upon temperature and presence of catalytic materials. Transformer windings are insulated with cellulose and surrounded by oil to ensure proper insulation and cooling. Poor oil quality can lead to a low dielectric strength and even to a system failure. High water content together with dissolved gases in oil may cause bubbling in case the total pressure of gases exceeds the ambient pressure of the transformer.

Knowledge of the transformer's insulation cellulose dryness is needed to avoid a breakdown situation and to optimise the transformer maintenance. As the dryness of the oil correlates well with the dryness of the cellulose, it is a practical and traditional way to monitor the oil moisture level in a transformer. A sudden increase in moisture level indicates e.g. a leak. By keeping the transformer as dry as possible its lifetime will be extended.

MOISTURE DYNAMICS
The insulation cellulose absorbs water from the transformer oil, which can absorb it from the atmosphere via the free breathing conservator or through degraded sealing. The moisture level increases also with water formed as the cellulose insulation slowly degrades i.e. the DP value decreases. With higher water content, the degradation rate is faster, forming more water resulting to an accelerated ageing process. The life span of a transformer is generally defined by the quality of the cellulose insulation.

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It is common practice to monitor the transformer moisture level by a scheduled oil sampling and analysis in a laboratory. The oil sample for moisture analysis should be taken when the system is quite stable i.e. the load and oil temperatures have been relatively constant for a longer period. As this procedure is quite demanding and time consuming several problems might occur, causing a change in the moisture level of the sample and as a result producing misleading information. Moisture in oil levels also vary considerably depending on the operational conditions, which means that a moisture reading from an oil sample at a single point in time may not be typical. Therefore, an on-line moisture monitoring system would be a right solution to overcome possible problems encountered during a traditional oil sampling procedure.

REVERSE WATER ABSORPTION BEHAVIOUR

The cellulose-oil system in a transformer is very complex in regard to moisture distribution, because of the reverse water absorption behavior of oil and cellulose. With increasing temperature, solid cellulose releases water that is absorbed by oil and vice versa when temperature decreases. As there is continuous water transfer between oil and cellulose, equilibrium is difficult to reach. Most water in solid insulation is located in the coolest part, i.e. the bottom. It is important that the relative saturation of oil does not approach high levels at the lowest temperature that the transformer may be exposed to. Due to the load variation of an operating transformer, moisture levels in Cellulose and oil change 24/7as shown in fig.1.

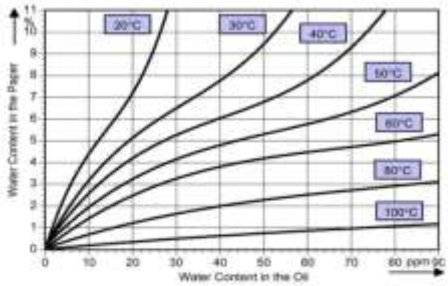

Fig 1. Paper-oil moisture equilibrium curves

OFF-LINE MONITORING OF MOISTURE CONTENT IN TRANSFORMER OIL

The analysis of moisture in oil performed in the laboratory is performed by Karl Fischer titration described in ASTM Test Method D 1533 or IEC method 60814. The test setup is shown in the figure 2. It involves a coulometric titration technique involving the reduction of an iodine- containing reagent. The methods are used to determine the amount of water in an oil sample on a weight-to-weight (mg/kg) basis or what is commonly known as ppm (parts per million). Karl Fischer titration is a method in analytical chemistry that determines trace amounts of water in a sample using volumetric or coulometric titration. KF Titration basically adds a reagent of known concentration (iodine) to an unknown substance until the concentrations are balanced together. However, it is greatly affected by several influences: There is always moisture ingress from the atmosphere during the sampling process, transportation and sample preparation in the laboratory. Sometimes direct injection of sample and heating method lead to different results for water content in insulating oil. It serves as a benchmark for other methods such as moisture equilibrium method & dielectric response methods.

Fig 2. KFT Titration Test Setup

ON-LINE MONITORING OF MOISTURE CONTENT IN TRANSFORMER OIL

Transmitter EE381 as shown ic fig.3 is specially designed for the measurement of water content in oil. EE381 is ideal for online monitoring of moisture in lubrication or insulation oil, which is very important for the long-term performance and preventive maintenance of plant and machinery. For instance, moisture affects dramatically the insulation characteristics of electrical transformer oil and therefore continuous monitoring is extremely important. Similar to the humidity in the air, the water content in oil can be indicated by the absolute value in ppm or by the relative value aw:

- ppm (mass of water / mass of oil)
- aw (actual water content as fraction of the water content in saturated oil)

aw = 0 corresponds to water-free oil, while aw = 1 indicates saturated oil.

Fig 2. EE381 moisture sensor for transformer oil

The measured physical quantities are water activity aw and temperature T. With these quantities EE381 calculates the water content x (ppm) in mineral transformer oils. The EE381 transmitter has two freely selectable and scaleable outputs for water activity, water content or temperature. The EE381 switch with two relay outputs is designed for control and alarm purposes. The status for early warning and main alarm is indicated by LED's. Adjustment of the aw/T/ppm set point and hysteresis can be achieved with the optional configuration software.

BENEFITS OF ON-LINE MONITORING

1. On-line monitoring gives a true and real-time picture on the moisture levels in a transformer oil at all conditions the transformer is exposed.
2. On-line moisture monitoring can provide valuable information on transformers which have previously being identified having moisture problems, and also transformers which may have moisture issues that have not been detected by routine oil sampling. A common observation is that a single heavy overload overtemperature event can rapidly increase moisture in oil levels as moisture is driven from the cellulose. The return of moisture to earlier levels may take a remarkably longer period of time.
3. Installation of the on-line moisture sensor is also beneficial with rather low moisture levels in transformers that have a higher increase rate of the carbons and a low DP value of the cellulose insulation, as these values indicate further possible degradation of the cellulose and therefore a further increase in the water concentration.
4. The moisture sensor will provide the transformer with enough operational safety margins. Moreover, based on the sensor's moisture readings (calculated as ppm) and the equilibrium moisture charts available, it is possible to estimate the water content in the cellulose insulation during the transformer operation. This would often demand an intelligent cooling system in order to maintain the temperature as constant as possible for the time period long enough to reach the moisture equilibrium state.
5. Monitoring alone will not fix anything. It is the action taken based on monitoring which can result to condition improvement in the long run.
6. An online distributed monitoring system will be very reliable and will provide continuous data. It will result in cost saving by increasing the efficiency as well as life expectancy of transformer.

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LOCATION OF SENSOR FOR ACCURATE MEASUREMENT

The results of this study show that the response time is very long in stagnant oil. Furthermore, it is uncertain whether the relative saturation at the sensor level will ever reach the relative saturation of the flowing oil. Therefore, it is clear that the moisture sensor should be placed directly into the oil flow. This provides direct contact with oil that is truly representative of the oil condition within the transformer. The oil cooling circulation line of a transformer provides an installation location where true oil exchange is present and where the oil flow significantly reduces the sensor's response time, meaning that the measured values are representative and provided in real time. Where installation to optimal location is not possible, it is strongly recommended to minimize the distance between the sensor and the oil flow. The sensor should not be located at the bottom of the transformer tank unless it is evident that there is true oil exchange present – the lack of oil flow at the bottom of the tank may mean that the sensor is measuring still sludge and not the actual state of the transformer oil.

CONCLUSION

Oil type, age and flow rate contribute to the measurement and subsequent accuracy of moisture assessment in a paper-oil insulation system. Sensor positioning also contributes to the accuracy of moisture assessment. The parameter of the water solubility of oil is required for the validation of the moisture sensor installed in the transformer. Water-in-paper activity was found to be a factor in determining the state of dryness in a power transformer. A stand-alone software application called "Transformer Moisture Monitor" (TMM) is proposed for the moisture assessment of a transformer. A new classification procedure that aims to identify critical units for further continuous monitoring is suggested for the ranking of power transformers by the level of moisture. Red, yellow and green colors would indicate the 'wet', 'requires attention' and 'dry' states of moisture in transformers. The classification procedure presented is only valid for oil with a water solubility characteristic close to that of new oil. For the accurate ranking of an old transformer, the water solubility characteristic of the transformer's oil would need to be evaluated.

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