International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || REETA-2K16 ǁ PP. 605-610

MOISTURE MEASUREMENT IN ELECTRICAL EQUIPMENTS

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Abstract: The continuous monitoring of moisture content in power system appliances is necessary as it decides the performance of the system. In this proposed method we monitor the moisture content of transformer oil. The sensor used to measure moisture is resistance type sensor whose resistance varies with the change in moisture. The dielectric strength of transformer oil depends on moisture content in it. Excessive moisture in transformers significantly reduces not only dielectric strength, but also partial discharge inception level. It has been reported that breakdown voltage is affected by several factors, such as moisture, impurities, acidity, and pressure. The objective of this study is to investigate the effect of the moisture on insulating property and breakdown voltage of transformer oil using a set of oil samples. Test setup and procedure for monitoring of transformer oil using the moisture sensor with oil specific solubility parameters is described.

Keywords: moisture content, transformer oil, transmission lines, corona loss, dielectric strength, partial discharge.

1. Introduction:

Power transformers utilize oil as a coolant and an insulator together with cellulose. Breakdown voltage (dielectric strength) is one of the most important specifications of the transformer oil. It is the maximum electrical field that can withstand under ideal conditions without breakdown. It is measured when the transformer is taken into use and normally monitored during its operational duration. It is known that dielectric strength is affected by several factors, such as moisture, impurities, acidity and pressure. The moisture in the paper wrapping of the windings is of interest. Moisture content can be determined for steady-state conditions, by using a family of curves that show moisture content in this paper as a function of relative saturation of oil, with temperature as a parameter. Based on the amount of moisture measurement in the oil, moisture partition curves determine the moisture in the paper. Because these relations can be applied only when the transformer has been at a steady state condition for some time, the utility must use an approximation to evaluate the amount of water in the main insulation. Under fast decreasing temperature conditions moisture in insulating oil may results in free water, which can lead to potential breakdown of insulating oil. Transformer oil with moisture content in it loses its insulating characteristic and due to this its conductivity and dissipation factor increases, which causes reduction in dielectric strength of oil. At higher temperatures water leaves the paper to enter the liquid due to the equilibrium imbalance. Water in the insulating oil initiates from air moisture in the case of open-breather, and due to the thermal decomposition of cellulose based solid insulating materials.

2. Hardware setup:

The hardware setup for monitoring moisture consists of following sections.

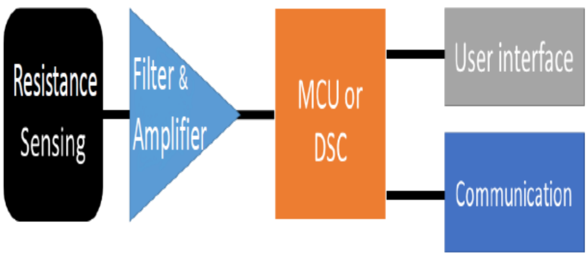

Fig.1 Block diagram of moisture measurement system

2.1 Sensor

In this, resistance type sensors are used whose resistance varies with moisture at its terminals. If any object contains moisture substance its conductance increases than its conductance at dry condition. The sensor circuit here we use is Wheatstone bridge whose arms voltages are fed to differential amplifier. Under balanced operation output voltages of both arms are equal, therefore differential amplifier output is zero. If any object whose moisture to be evaluated is introduced between two nodes of any arm the bridge gets unbalanced due to resistance of object. The resistance of object is inversely proportional to moisture.

2.2 Amplifier

To amplify the output of differential amplifier we use another amplifier in non-inverting operating mode whose voltage gain is given by

$$\frac{Vo}{Vi} = 1 + \frac{Rf}{R2} \qquad (1)$$

The output of amplifier in analogue form fed to ADC which convert it into digital form for processing in microcontroller as shown in fig. 2.

2.3 ADC and Microcontroller

ADC is responsible for conversion of analog output of sensor into digital form which is input to microcontroller. Microcontroller gives corresponding moisture value on LCD using predefined programming code.

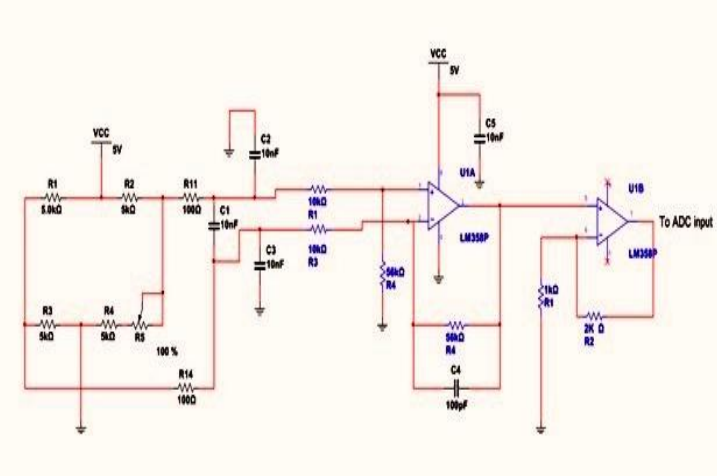

Fig.2 Moisture sensor fed to amplifier

3. Testing Procedure

The sensor measures water in oil in terms of %moisture which indicates the amount of moisture in oil in the scale of 0-100% moisture. In this scale, 0% moisture is an indication of completely water free oil & 100% moisture is an indication of oil fully saturated with wet & may be present in free form. For on-line monitoring of water content in transformer oil, sensor is the main part, and it is used to monitoring of moisture content in oil are able to withstand severe environmental conditions which include the high temperatures between 100℃ to 145℃. During transformer operation, splitting of wet or moisture content between insulating oil and paper insulation in transformer is depending upon the temperature changes that affect the water solubility properties. During laboratory experiment the water content needs to be stay constant, it means that the laboratory test cell should be free from any hydrofoil materials that may adsorb and absorb water to oil because it causes oil temperature changes during test.

3.1 Sensor location:

The moisture sensor should be installed in a location where it is in direct contact with most representative set of the transformer oil. The placement of sensor in the oil cooling circulation line has proven to be significant beneficial for below two reasons. First, the oil is certainly representative and secondly, the oil flow improves the sensor response time significantly, so that the measurement values are representative and real-time. The very bottom of the transformer tank should be avoided if it is not evident that there is true oil exchange present. Without the oil flow at the bottom, the sensor might be measuring just still sludge not the real conditions of the sludge. The very bottom of the transformer tank should be avoided if it is not evident that there is true oil exchange present. Without the oil flow at the bottom, the sensor might be measuring just still sludge not the real conditions of the sludge.

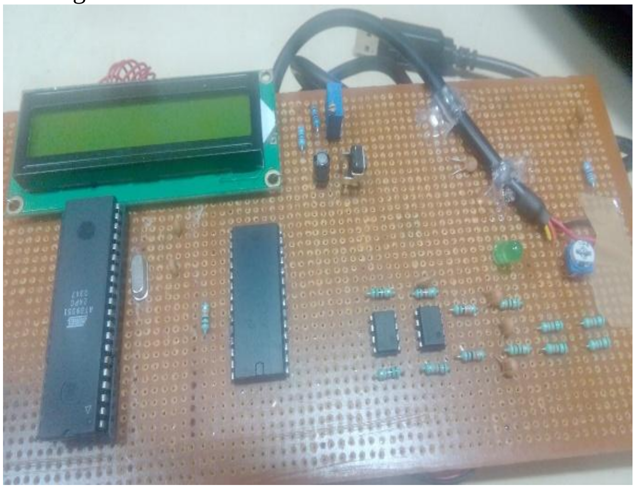

Fig.3 Hardware of Moisture measurement system.

4. Mathematical Evaluation:

Water in transformer exists in four distinctive forms:
(i).Dissolved water is due to hydrogen bonding with the hydrocarbon molecules of oil.
(ii).Emulsified water is supersaturated in solution but not yet totally separated from the oil. It usually causes milky appearance of oil.
(iii).Free water is also supersaturated in solution but if it is high enough concentration, it form water droplets and separate from the oil.
(iv).Water adsorbed in insulating paper.

In most cases, during analysis or discussions regarding the amount of water in oil, one can being referred dissolved water is emulsified, and free water is visually apparent.

A.) Water Solubility

Sometimes the concepts of solubility can be difficult to understand, but it is a very significant concept when trying to analyse the dryness or wetness of a transformer. The water solubility is estimated at a particular temperature as the total amount of water that can be dissolved in the insulating oil at that temperature. The solubility of water is not constant in insulating oil but it changes due to temperature variations. The amount of water that can be dissolved in insulating oil also increases, if the temperature increases. This variation of dissolved water with temperature is not linear but exponential in function.
At 10°C, only 33 ppm of water can be dissolved in the insulating oil. Whereas the almost 663 ppm of water can be dissolved in the insulating oil when the temperature is increase to 90°C.
The Arrhenius Equation used for calculating water solubility of mineral oil is as follows:

$$S = 10^{(-A/T + B)} \qquad (2)$$

Where
S is the solubility of water in mineral oil,
T is the temperature in Kelvin (°C + 273), and
A and B are constants whose values are 1670 & 7.42.

B.) Relative Saturation (% Moisture content)

Relative Saturation (RS) is defined as the amount of water content measured in the insulating oil respect to the solubility of water in oil level at that temperature. Relative saturation is expressed in units of percent & it is the concentration of water (W) in the insulating oil relation to the solubility (S) or concentration of water that the insulating oil can hold at the measurement temperature, as

$$\%RS = (W / S) * (100) \qquad (3)$$

Where: W is in ppm ,
S is in ppm

C.) Water Concentration in Paper Insulation System

The equilibrium curves showing relationship between water content in paper and water content in oil for different temperatures are obtained by analysing the equilibrium between water content in paper and oil insulation. So it is possible to decide the value of one of these variables once knowing the other one. It takes long time to reach equilibrium condition which can be estimated as follows:

$$t = \frac{4d^2}{\pi^2 D} \qquad (4)$$

Where
d is the thickness of insulating paper
D is the moisture diffusion coefficient and
t is the diffusion time constant.

It is the time required for moisture diffusing from one side of solid insulation.

5. Results

5.1 Effects of Relative Saturation on Dielectric Strength

To suitably maintain and operate transformers, an understanding of the effects of moisture on the dielectric breakdown strength of the electrical insulating liquids is necessary. Increasing moisture content reduces the dielectric breakdown voltage of insulating liquids. Of course, the dielectric breakdown voltage is also a function of the number and type of particles and their conductivity, not just the water content. Taking the same dielectric breakdown voltage data and converting it to RS provides a much straighter curve except at the extremes. It is evident that there is a better correlation between RS and dielectric breakdown voltage than with moisture concentration and dielectric breakdown voltage.

Table 1: Effect of % moisture on Dielectric strength

S.No.	%Relative Saturation	Dielectric strength(kV)
1	10	39
2	20	36
3	30	33
4	40	31
5	50	28
6	60	23.5
7	70	19

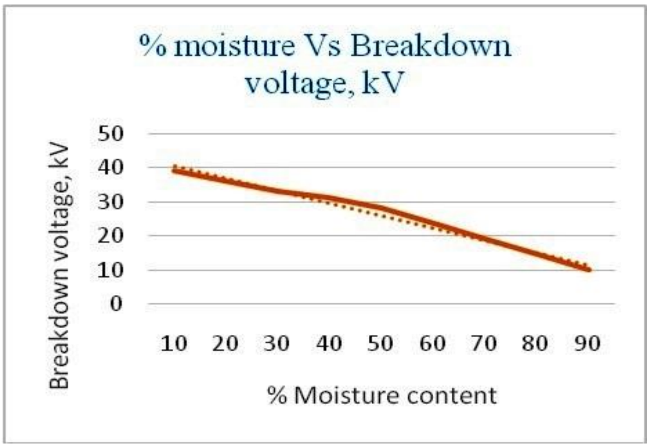

Fig:4. % Moisture Vs Break down Voltage

5.2 Water content in ppm

Water content in ppm present in transformer oil is given by,

ppm=RS*(A-B/T) (5)

Where

T is the temperature in Kelvin (°C + 273)
A & B are constants are 1670 & 7.42

Table 2: Water content (ppm) Vs Breakdown Voltage (kV)

S.No.	Water content, ppm	Dielectric strength, kV
1	12	36
2	16	35
3	20	33
4	24	31
5	28	28
6	32	24
7	36	21
8	40	17

If the wet content in oil increases so that its amount is greater than or equal to the oil occurs even if actual water content (ppm) in oil becomes higher than the maximum value specified at this new temperature.

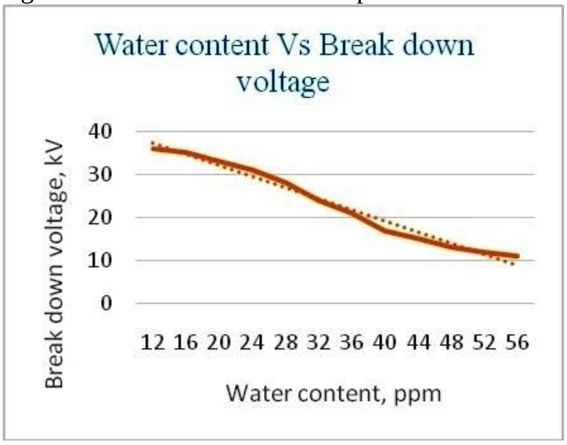

Fig:5. Water content Vs Break down Voltage

6. Conclusion:

As the dielectric strength of insulation oil is affected by higher relative moisture saturation, also the dielectric strength of oil may fluctuate during the transformer operation. Estimation of the moisture-induced transitory change in the breakdown voltage could be useful regarding the transformer operation and maintenance. Short-term variation in the moisture of the transformer oil driven by the changes in the transformer loading and ambient temperature. By monitoring relative moisture saturation of oil, an operator can get a warning if moisture increases to a level where there will be a intense drop in the dielectric strength of oil, which increases the risk of dielectric faults. The monitoring offers the operator with actual data to detect early signs of faults and correct them.

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