International Journal of Scientific and Technical Advancements

ISSN: 2454-1532

Maintenance of Power Transformer

Karan Gupta[1], Himani Mahajan[2], Sumeer Khajuria[3]
Associate Professor[1,3], Lecturer[2]
Department of Electrical Engineering[1,2]
Department of Electronics & Communication Engineering[3]
Govt. College of Engineering and Technology, Jammu
karan74_gupta@yahoo.com[1], mhimani90@yahoo.com[2], sameer.kh123@gmail.com[3]

***Abstract*—This paper presents various maintenance process required to achieve high performance and long operating life of power transformer. Maintenance is must for safe and reliable operation of transformers. It detects problems at an early stage and can prevent further deterioration. Scheduled maintenance and testing not only extend the life of transformer but also provide indication of when a transformer is near the end of its service life so that provision for replacement can be made before failure occurs. Therefore, it allows aging process to be quantified and tracked to avoid failure and predict the need for replacement.**

Keywords—power transformer; maintenance.

I. Introduction to Power Transformer Maintenance

Power transformers are generally used in transmission network for stepping up or down the voltage level. It operates mainly during high or peak loads and has maximum efficiency at or near full load. Power transformer is the most important electrical machine with a useful life cycle of about 30 years. It is desired to perform various maintenance process to achieve high performance and long operating life of power transformer. It is the responsibility of the owner to inspect, maintain and keep the power transformer in proper operating condition. Transformer operation is greatly affected by heat, contamination. Excess heat can break down the solid insulation and accelerate the chemical reactions that takes place when the oil is contaminated. The main cause of contamination is moisture ingression through the top bushing seal. Excessive voltage may appear across faulty contacts. Transformer also requires a proper cooling system to ensure excess heat is not produced in the transformer. Proper cooling system for transformer includes cleaning of cooling surfaces, proper ventilation and load monitoring[1].

There are two types of maintenance process one is on routine basis and other is as when required. Routine basis maintenance include daily basis, monthly basis, half-yearly basis and yearly basis. Daily basis maintenance requires reading of magnetic oil gage of main tank and conservator tank, observing color of silica gel in breather and leakage of oil from any point of transformer. In case of unsatisfied level of oil in magnetic oil gage, oil is to be filled in transformer and also the oil leakage is checked and if it is found then action is to be taken to stop the leakage of oil. Color of silica gel is checked and if it becomes pinkish, it needs to be replaced. The breathing holes and oil level in the oil cap of the silica gel breather must be checked on monthly basis and if the oil level is below the specified level then oil is to be top up as per specified level. For oil filled bushing, the oil level inside bushing is checked and if it is below specified level then oil is filled in the bushing under shut-down condition. Condition of cooling system, bushings, relays, alarms, control switches and function of buchholz relays is checked on yearly basis. Oil condition in on line tap changer (OLTC) is checked by taking sample of oil from drain valve of diverter tank for dielectric strength and moisture content and if it is above recommended value then oil is to be replaced and filtered using filtration machine. Insulation resistance and polarization index of transformer is checked with megger once in a year. Dielectric strength, water content, resistivity, sludge content and acidity for transformer oil is to be checked once in 6 months[2].

II. Power Transformer Testing

In addition to scheduled maintenance, power transformer also requires maintenance process for measuring and testing of various parameters of transformer. Testing allows aging process to be quantified and tracked to avoid failure and predict the need for replacement. Following are the tests to be performed for proper maintenance of the power transformer:-

1. Megger Test:-

Insulation resistance test of transformer is essential to ensure the healthiness of overall insulation of an electrical power transformer. There are various factors which affect insulation resistance value of transformer such as surface condition of the terminal bushing, quality of winding insulation, quality and temperature of oil and duration of application and value of test voltage. The test voltages and accepted insulation strength for different electrical components are obtained from ANSI/NETA ATS-2009 standard[3,4].

Table I:- Test voltages and accepted insulation strength as per ANSI/NETA ATS-2009 standard

Rated voltage(V)	Test voltage(dc V)	Insulation strength(M Ω)
0-250	500	25

Karan Gupta, Himani Mahajan, and Sumeer Khajuria, “Maintenance of Power Transformer,” *International Journal of Scientific and Technical Advancements*,Volume 5, Issue 1, pp. 131-136, 2019.

250-500	1000	100
500-2500	1000	500
2500-5000	2500	1000
5000-8000	2500	2000
8000-25000	5000	10000
25000 & above	15000	10000

Source: ANSI/NETA ATS-2009 standard (Cf. Din, 2015)

In this method, first disconnect all the line and neutral terminals of the transformer. Megger leads to be connected to LV and HV bushing studs to measure IR value in between the LV & HV windings. Megger leads to be connected to HV bushing studs & transformer tank earth point to measure value of Insulation Resistance IR in between the HV windings & earth. Further, Megger leads to be connected to LV bushing studs & transformer tank earth point to measure value of Insulation Resistance IR in between the LV windings and earth.
Firstly, to check the insulation level between HV and LV winding, put one terminal on HV winding and other on LV winding. Apply the correct value of voltage and check the reading of the megger. Megger test equipment will show resistance between the HV and LV winding and this value of resistance will indicate the insulation strength between HV and LV winding. Next step is to find the insulation level between HV and ground. Put one terminal of megger on HV winding and other on the body of the transformer and then repeat the same procedure to check the value of the resistance. The value should be MΩ or GΩ and if not, check the transformer. At Last, check the insulation between LV winding and ground and verify that insulation value lies in the range of MΩ and GΩ. Insulation resistance values are to be recorded at intervals of 15 seconds, 1 minute and 10 minutes. With the duration of application of voltage, value of IR increases. The increase in value of insulation resistance gives an indication of insulation dryness. This test does not verify insulation between consecutive windings.[5]

2. Sweep frequency response analysis test(SFRA):-

SFRA is the most reliable test for monitoring the condition of the winding of transformer and is a pre-commissioning test. This test detects problems such as deformation in winding, displacements between hv and lv windings, collapse in partial winding, shorted or open turns, faulty grounding of core or screens, broken clamping structures and problematic internal connections.
In this test, sinusoidal voltage is applied as input at one end of a winding and output voltage is measured at the other end of the winding while remaining windings are kept open. This provides us with different output voltages at different frequencies depending upon the RLC nature of the winding. This is carried out initially to obtain the signature of the transformer frequency response by injecting various discrete frequencies and is considered as the reference for future comparisons. Any variation from the reference pattern results in change in winding position, degradation in the insulation, tap changer position, configurations of internal leads between bushings and windings. This test also indicate whether the oil is present or not. SFRA is carried out periodically or during short circuits. SFRA test is the identification of changes in frequency response that is the essence of analysis and diagnosis of mechanical integrity[6].

3. Tan δ test:-

Tan delta test is performed on winding and bushings of transformer. In this test, a very low frequency voltage is applied across equipment whose insulation is to be tested. Dissipation factor is given by tan δ ∝ 1/f. So, at low frequency, the tan delta number is high, the measurement becomes easier. Firstly, normal voltage is applied and if the value of tan δ is satisfactory then the value of voltage is raised to 1.5 to 2 times the normal voltage of the equipment.
The controller unit of tan delta measures tan delta value and loss angle analyzer is connected with tan delta measuring unit to compare tan delta value at normal as well as high voltage.

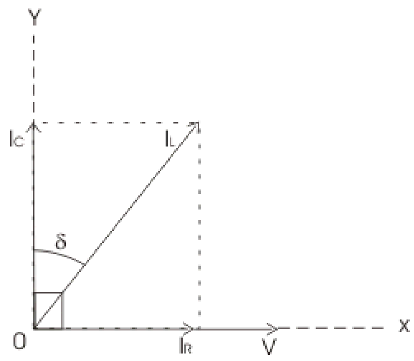

Figure1:-shows dissipation factor

In figure1 shown, I_R is resistive component of leakage current and I_C is capacitive component of leakage electric current. Dissipation factor is obtained by

$$\tan\delta = \frac{I_R}{I_C} \quad (1)$$

This test provides information of the moisture and contamination degree and the behavior and voltage aggressions similar to service ones. It is important to take note of environmental moisture (surface leakage) and transformer temperature.

There are two ways to determine the condition of insulation using tan delta test. One way is the results of previous tests are compared to determine the deterioration of the condition of insulation due to ageing effect. And the other way is to directly compare with the value of tan δ and no need of

Karan Gupta, Himani Mahajan, and Sumeer Khajuria, “Maintenance of Power Transformer,” *International Journal of Scientific and Technical Advancements*,Volume 5, Issue 1, pp. 131-136, 2019.

previous results of tan delta test. If insulation is not perfect, the value of tan delta shows increase in the higher range test voltage and if it is perfect then loss factor will be same for all range of test voltages. Tan delta meters are used for this test.

4. Parts per million(ppm) test:-

Parts per million (ppm) test is performed for checking water content in transformer oil. Moisture or water content in transformer oil affects the dielectric properties, paper insulation of core and winding of the power transformer. From IEEE Std C57.106–2002, the permissible moisture level in paper is obtained from the values of water content in oil by assuming thermal stability and moisture equilibrium between paper and oil[7].

Table II:- Maximum water content in oil and paper for different voltage ratings as per IEEE Std C57.106 – 2002 .

Transformer rated voltage	Maximum water content in oil			Equivalent water content in paper
	50°C	60°C	70 °C	
Upto 69KV	27	35	55	3%
69KV to 230 KV	12	20	30	2%
230 KV and above	10	12	15	1.25%

Source: IEEE Std C57.106 – 2002

Moisture or water content in transformer oil is obtained by using Coulometric Karl Fischer test. In this test, oil sample is taken at regular interval and oil sample is then submitted in laboratory to process it through Coulometric Karl Fischer instrument[6]. In the titration cell, the reagent and solvent are combined. When a oil sample is introduced into the titration cell and dissolved, reagent is released by the induction of an electrical current. The amount of current required to convert the water is the determinant of the moisture amount. This method of measurement of moisture content in transformer oil is carried out using Coulometric Karl Fischer instrument which is often referred to as a coulometer. This method has the capability to accurately measure small amounts of moisture content in transformer oil. Sensitivity of these instruments is as low as 0.1 microgram (µg) of water and this method is normally used for moisture content below 1% or for samples where the moisture is less than 200 micrograms.

5. Breakdown voltage test:-

The dielectric breakdown voltage test is a measurement of electrical stress that an insulating oil can withstand without failure. Breakdown voltage is affected by several factors, such as moisture, particles, acidity, and pressure[8]. The lower the value of resulting breakdown voltage, the poorer the quality of the transformer oil. The dielectric test measures the voltage at which the oil breaks down, which indicates the amount of contamination (usually moisture) in the oil. In this test, a sample of transformer oil is taken and its breakdown voltage is measured.

For measuring breakdown voltage (BDV) of transformer oil, BDV measuring portable kit is generally available at site. In this kit, the transformer oil is filled in the vessel of the testing device and two standard-compliant test electrodes with a typical clearance of 2.5 mm are surrounded by the dielectric oil. A test voltage is applied to the electrodes and is continuously increased up to the breakdown voltage with a constant, standard-compliant slew rate of e.g. 2 kV/s. At a certain voltage level breakdown occurs in an electric arc, leading to a collapse of the test voltage and at an instant after ignition of the arc, the test voltage is switched off automatically by the testing device. Ultra fast switch off is highly desirable, as the carbonisation due to the electric arc must be limited to keep the additional pollution as low as possible. The transformer oil testing device measures and reports the root mean square value of the breakdown voltage. After the transformer oil test is completed, the insulation oil is stirred automatically and the test sequence is performed repeatedly: typically 5 repetitions, depending on the standard and as a result the breakdown voltage is calculated as mean value of the individual measurements.

For mineral oil, a generally accepted minimum dielectric strength is 30 kV for transformers with a high-voltage rating of 230 kV and above and 27 kV for transformers with a high-voltage rating below 230 kV. New oil should have a minimum dielectric strength of 35 kV by ASTM methods of testing. Oil is not necessarily in good condition even when the dielectric strength is adequate, because this tells nothing about the presence of acids and sludge. Lower value indicates the presence of damp or dirt in the transformer oil[9].

6. Dissolved gas analysis(DGA) of transformer oil:

The identity of the gases being generated can be very useful information in any preventive maintenance program. This method involves testing the oil sample to measure the concentration of the dissolved gases. DGA of the transformer oil be performed is recommended that at least on an annual basis with results compared from year to year. The main causes of gas formation within an operating transformer are electrical disturbances and thermal decomposition.

In DGA, the gases in oil are extracted from oil and analyze the quantity of gasses in a specific amount of oil. The internal condition of transformer can be predicted by observing percentages of different gasses present in the oil. The gasses

Karan Gupta, Himani Mahajan, and Sumeer Khajuria, "Maintenance of Power Transformer," *International Journal of Scientific and Technical Advancements*,Volume 5, Issue 1, pp. 131-136, 2019.

found in the oil in service are hydrogen, methane, ethane, ethylene, acetylene, carbon dioxide, carbon monoxide, nitrogen and oxygen. The most commonly used method to determine the content of these gases in oil is by using a Vacuum Gas Extraction Apparatus and Gas Chronographs.

Firstly, gasses are extracted from oil by stirring it under vacuum using this apparatus and these extracted gasses are then introduced in gas Chronographs for measurement of each component. If internal temperature of power transformer rises up to 150ºC to 300ºC due to abnormal thermal stresses, hydrogen and methane are produced in large quantity and if temperature goes above 300ºC, ethylene are produced in large quantity. If the temperature is higher than 700ºC large amount of hydrogen and ethylene are produced. Production of ethylene gives the indication of very high temperature which results in hot spot inside power transformer. If carbon monoxide and carbon dioxide are found in large quantity it gives indication of decomposition of insulation.

Table III:- Suggested action levels for key gas concentrations obtained from ANSI/IEEE C57.104

Gas description	Key gas concentration (ppm)		
	Normal limits	Action limits	Potential fault type
Hydrogen	150	1000	Corona, Arcing
Methane	25	80	Sparking
Acetylene	15	70	Arcing
Ethylene	20	150	Severe overheating
Ethane	10	35	Local overheating
Carbon monoxide	500	1000	Severe overheating
Carbon dioxide	10000	15000	Severe overheating
Total Combustibles	720	4630	-

Source:ANSI/IEEE C57.104

An increase in key gas concentration is the indication of a potential problem within the transformer. If the values are above normal limits, sample frequency should be increased with consideration given to planned outage in near term for further evaluation and if values exceeds action limits, there is a need for removal of transformer from service[9]. Suggested action plans are obtained from information provided with ANSI/IEEE C57.104.[10]

7. Voltage ratio test:-

Voltage ratio test is done to check the transformer voltage ratio and tap changer. This test is done with the help of turns ratio meter considering the principle that voltage ratio is equal to turns ratio in a transformer. Turns ratio between hv and lv windings at various tap positions is measured and recorded with TTR meter and moreover, if it is found correct then voltage ratio is assumed to be correct. TTR meter has in built power supply having voltages commonly used being very low such as 8-10 V and 50 hz. The hv and lv windings of one phase of a transformer are connected to the instrument and the internal bridge elements are varied to produce a null detection on the detector. A phase voltage is applied to the one of the windings by means of a bridge circuit and the ratio of induced voltage is measured at the bridge. The accuracy of measuring instrument is <0.1%.

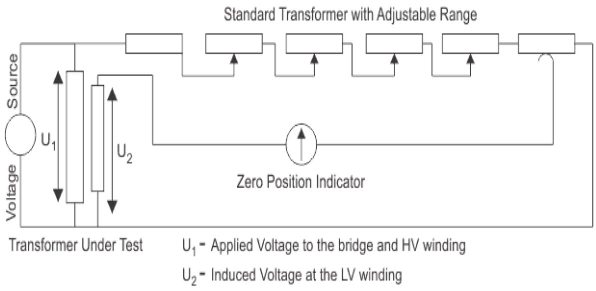

Figure 2:- Bridge connection to measure turns ratio[11]

This turn ratio is adjusted on the TTR tested by the adjustable transformer shown in figure 2 and is to be changed till a balance occurs in percentage error indicator. This indicator gives deviation of measured turn ratio from expected turn ratio in percentage.

Deviation in percentage

$$= \frac{\text{Measured turn in ratio- expected turn ratio}}{\text{Expected turns ratio}}$$

Short turns indicate high exciting current and open turns in hv winding indicate very low exciting current and no output voltage. But open turns in lv winding causes low level of unstable output voltage and normal excitation current. The turns ratio of transformer also detect high resistance in the lead circuitry or high contact resistance in tap changers by higher excitation current and a difficulty in balancing the bridge.[11]

Conclusion

This paper presented a scheduled maintenance and testing methods required to achieve high performance and long operating life of power transformer. Scheduled maintenance and testing not only extend the life of transformer but also provide indication of when a transformer is near the end of its service life so that provision for replacement can be made before failure occurs. Proper maintenance and testing should be done at

regular intervals aging process to be quantified and tracked to avoid failure and predict the need for replacement. Thus, it should be ensured that oil must be kept as free as possible from moisture and oxygen, dissolved combustible gases, and particulates, proper cleaning of cooling surfaces, proper ventilation and load monitoring.

REFERENCES

[1] "Transformers:Basics, Maintenance, and Diagnostics," U.S. Department of the Interior Bureau of Reclamation, April 2005.
[2] https://www.electrical4u.com/maintenance-of-transformer/ [Accessed on 20-11-2018].
[3] http://www.iemworldwide.com/pdf/ansi-neta-ats-2009[Accessed on 20-11-2018].
[4] Syed Noman Ud Din, "Megger test procedure explained with Transformer Example," help2educate, May 2, 2015.
[5] https://electricalstudy.sarutech.com [Accessed on 02-12-2018]
[6] G M Kennedy, A J McGrail and J A Lapworth, Doble Engineering, "Transformer sweep frequency response analysis (SFRA)," energize - October 2007.
[7] Brian Sparling, Jacques Aubin , "Assessing Water Content in Insulating Paper of Power Transformer," GE Energy, Canada.
[8] "The Effect of Moisture on the Breakdown Voltage of Transformer Oil,"Vaisala,whitepaper,2013.
[9] Lynn Hamrick, "Dissolved Gas Analysis for Transformers," NETA WORLD, winter 2009-2010.
[10] "IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers," IEEE Power & Energy Society IEEE Std C57.104™, February 2009.
[11] Jignesh Parmar,"Various Routine Test of Power Transformer,"Electrical India, Dec 5, 2014.

Karan Gupta, Himani Mahajan, and Sumeer Khajuria, "Maintenance of Power Transformer," *International Journal of Scientific and Technical Advancements*,Volume 5, Issue 1, pp. 131-136, 2019.