© 2015 IJCRT | Volume 3, Issue 2 May 2015 | ISSN: 2320-2882

Transformer Testing Techniques: In-Depth Review Of Open Circuit And Short Circuit Testing

Er. Vikas Mathur , Er. Asad Zai

Jodhpur.

Abstract

The open circuit and short circuit tests are fundamental experiments conducted on transformers to determine their performance characteristics and to assess their efficiency in electrical power transmission and distribution systems. These tests provide crucial information about a transformer's parameters, such as core losses, winding resistance, and voltage regulation, enabling engineers and operators to make informed decisions regarding their operation and maintenance.

Transformers

The transformer is a device that transfers electrical energy from one electrical circuit to another electrical circuit. The two circuits may be operating at different voltage levels but always work at the same frequency. Basically transformer is an electro-magnetic energy conversion device. It is commonly used in electrical power system and distribution systems.

Principle of Working

In its simplest form a single-phase transformer consists of two windings, wound on an iron core one of the windings is connected to an ac source of supply f. The source supplies a current to this winding (called primary winding) which in turn produces a flux in the iron core. This flux is alternating in nature (Refer Figure 1.1). If the supplied voltage has a frequency f, the flux in the core also alternates at a frequency f. the alternating flux linking with the second winding, induces a voltage E2 in the second winding (called secondary winding). [Note that this alternating flux linking with primary winding will also induce a voltage in the primary winding, denoted as E1. Applied voltage V1 is very nearly equal to E1]. If the number of turns in the primary and secondary windings is N1 and N2 respectively, we shall see later in this unit that . The load is connected across the secondary winding, between the terminals a1, a2. Thus, the load can be supplied at a voltage higher or lower than the supply voltage, depending upon the ratio N1/N2

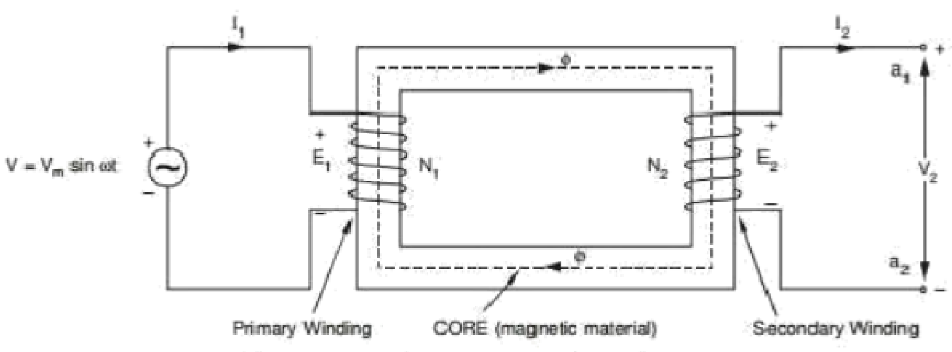

Figure 1.1 Basic Arrangement of Transformer

When a load is connected across the secondary winding it carries a current I2, called load current. The primary current correspondingly increases to provide for the load current, in addition to the small no load current. The transfer of power from the primary side (or source) to the secondary side (or load) is through the mutual flux and core. There is no direct electrical connection between the primary and secondary sides. In an actual transformer, when the iron core carries alternating flux, there is a power loss in the core called core loss, iron loss or no load loss. Further, the primary and secondary windings have a resistance, and the currents in primary and secondary windings give rise to I 2 R losses in transformer windings, also called copper losses. The losses lead to production of heat in the transformers, and a consequent temperature rise. Therefore, in transformer, cooling methods are adopted to ensure that the temperature remains within limit so that no damage is done to windings' insulation and material. In the Figure 1.1 of a single-phase transformer, the primary winding has been shown connected to a source of constant sinusoidal voltage of frequency f Hz and the secondary terminals are kept open. The primary winding of N1 turns draws a small amount of alternating current of instantaneous value i0, called the exciting current. This current establishes flux φ in the core (+ve direction marked on diagram). The strong coupling enables all of the flux φ to be confined to the core (i.e. there is no leakage of flux).

O.C. and S.C. Tests of Transformer

The efficiency and regulation of a transformer on any load condition and at any power factor condition can be predetermined by indirect loading method. In this method, the actual load is not used on transformer. But the equivalent circuit parameters of a transformer are determined by conducting two tests on a transformer which are,

1. Open circuit test (O.C Test)
2. Short circuit test (S.C.Test)

The parameters calculated from these test results are effective in determining the regulation and efficiency of a transformer at any load and power factor condition, without actually loading the transformer. The advantage of this method is that without much power loss the tests can be performed and results can be obtained. Let us discuss in detail how to perform these tests and how to use the results to calculate equivalent circuit parameters. Open Circuit Test (O.C. Test) The experimental circuit to conduct O.C test is shown in the Fig. 1.2

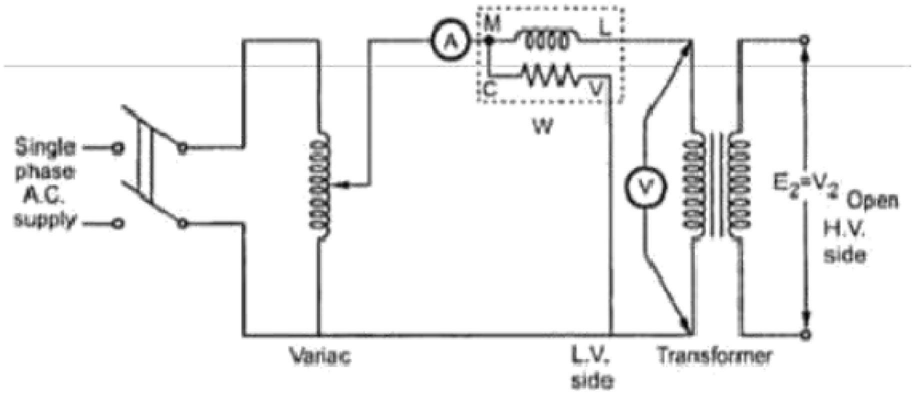

Figure :1.2 . Experimental circuit for O.C. test

The transformer primary is connected to a.c. supply through ammeter, wattmeter and variac. The secondary of transformer is kept open. Usually low voltage side is used as primary and high voltage side as secondary to conduct O.C test. The primary is excited by rated voltage, which is adjusted precisely with the help of a variac. The wattmeter measures input power. The ammeter measures input current. The voltemeter gives the value of rated primary voltage applied at rated frequency. Sometimes a voltmeter may be connected across secondary to measure secondary voltage which is V2 = E2 when primary is supplied with rated voltage. As voltmeter resistance is very high, though voltmeter is connected, secondary is treated to be open circuit as voltmeter current is always negligibly small. When the primary voltage is adjusted to its rated value with the help of variac, readings of ammeter and wattmeter are to be recorded. Let, Vo = Rated voltage Wo = Input power Io = Input current = no load current As transformer secondary is open, it is on no load. So current drawn by the primary is no load current Io. The two components of this no load current are,

$$Im = Io \sin \Phi o$$

$$Ic = Io \cos \Phi_0$$

where cos Φo = No load power factor And hence power input can be written as, Wo = Vo Io cos Φo The phasor diagram is shown in the Fig.1.3

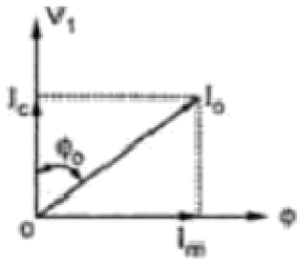

Figure 1.3 Phasor Diagram

As secondary is open, I2 = 0. Thus its reflected current on primary is also zero. So we have primary current I1 =Io.

The transformer no load current is always very small, hardly 2 to 4 % of its full load value. As I2 = 0, secondary copper losses are zero. And I1 = Io is very low hence copper losses on primary are also very very low. Thus the total copper losses in O.C. test are negligibly small.

As against this the input voltage is rated at rated frequency hence flux density in the core is at its maximum value. Hence iron losses are at rated voltage. As output power is zero and copper losses are very low, the total input power is used to supply iron losses. This power is measured by the wattmeter i.e. Wo. Hence the wattmeter in O.C. test gives iron losses which remain constant for all the loads. ... Wo = Pi = Iron losses

Calculations : We know that,

Wo = Vo Io cos Φ cos Φo = Wo /(Vo Io) = no load power factor Once cos Φo is known

we can obtain, Ic = Io cos Φo and Im = Io sin Φo

Once Ic and Im are known we can determine exciting circuit parameters as,

Ro = Vo /Ic Ω

and

Xo = Vo /Im Ω

Key Point : The no load power factor cos Φo is very low hence wattmeter used must be low power factor type otherwise there might be error in the results.

If the meters are connected on secondary and primary is kept open then from O.C. test

we get Ro'and Xo' with which we can obtain Ro and Xo knowing the transformation ratio K.

Short Circuit Test (S.C. Test)

In this test, primary is connected to a.c. supply through variac, ammeter and voltmeter as shown in the Fig. 1.4

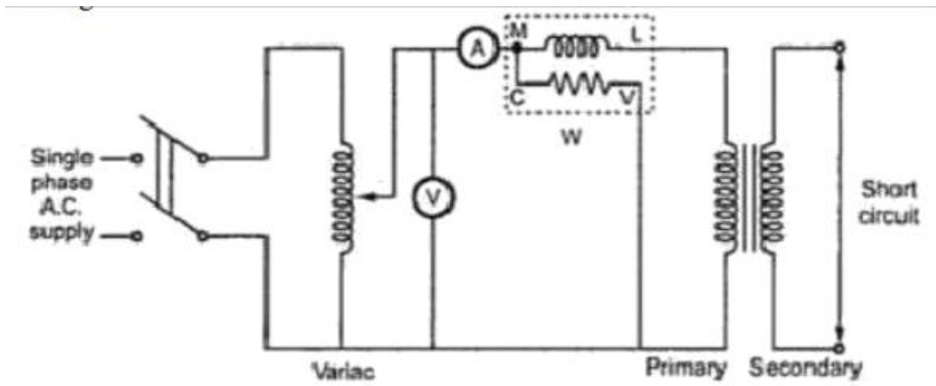

Figure 1.4Experimental circuit for O.C. test

The secondary is short circuited with the help of thick copper wire or solid link. As high voltage side is always low current side, it is convenient to connect high voltage side to supply and shorting the low voltage side. As secondary is shorted, its resistance is very very small and on rated voltage it may draw very large current. Such large current can cause overheating and burning of the transformer. To limit this short circuit current, primary is supplied with low voltage which is just enough to cause rated current to flow through primary which can be observed on an ammeter. The low voltage can be adjusted with the help of variac. Hence this test is also called low voltage test or reduced voltage test. The wattmeter reading as well as voltmeter, ammeter readings are recorded. Now the current flowing through the windings are rated current hence the total copper loss is full load copper loss. Now the voltage supplied is low which is a small fraction of the rated voltage. The iron losses are function of applied voltage. So the iron losses in reduced voltage test are very small. Hence the wattmeter reading is the power loss which is equal to full load copper losses as iron losses are very low

∴ $W_{sc} = (P_{cu})$ F.L. = Full load copper loss Calculations :

From S.C. test readings we can write,

$$W_{sc} = V_{sc} I_{sc} \cos \Phi_{sc}$$

∴ $$\cos \Phi sc = V_{sc} I_{sc} / W_{sc} = \text{short circuit power factor}$$

$$W_{sc} = I_{sc}^2 R_{1e} = \text{copper loss}$$

∴ $$R_{1e} = W_{sc} / I_{sc}^2$$

while $$Z_{1e} = V_{sc} / I_{sc} = \sqrt{(R_{1e}^2 + X_{1e}^2)}$$

∴ $$X_{1e} = \sqrt{(Z_{1e}^2 - R_{1e}^2)}$$

Thus we get the equivalent circuit parameters R1e, X1e and Z1e. Knowing the transformation ratio K, the equivalent circuit parameters referred to secondary also can be obtained.

Calculation of Efficiency from O.C. and S.C. Tests

We know that,

From O.C. test,

Wo = Pi

From S.C. test,

Wsc = (Pcu) F.L.

$$\therefore \quad \% \eta \text{ on full load} = \frac{V_2 (I_2) \text{F.L.} \cos\phi}{V_2 (I_2) \text{F.L.} \cos + W_o + W_{sc}} \times 100$$

Thus for any p.f. cos Φ2 the efficiency can be predetermined. Similarly at any load which is fraction of full load then also efficiency can be predetermined as,

$$\% \eta \text{ at any load} = \frac{n \times (\text{VA rating}) \times \cos\phi}{n \times (\text{VA rating}) \times \cos\phi + W_o + n^2 W_{sc}} \times 100$$

where n = fraction of full load

$$\text{or} \qquad \% \eta = \frac{n V_2 I_2 \cos\phi}{n V_2 I_2 \cos\phi + W_o + n^2 W_{sc}} \times 100$$

where I2= n (I2) F.L.

Calculation of Regulation

From S.C. test we get the equivalent circuit parameters referred to primary or secondary. The rated voltages V1, V2 and rated currents (I1) F.L. and (I2) F.L. are known for the given transformer. Hence the regulation can be determined as

$$\% R = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$$

$$= \frac{I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi}{V_1} \times 100$$

where I1, I2 are rated currents for full load regulation

For any other load the currents I1, I2 must be changed by fraction n.

.

.

. I1, I2 at any other load = n (I1) F.L., n (I2) F.L

Conclusion:

In conclusion, the open circuit and short circuit tests are essential procedures to evaluate the performance and efficiency of transformers in electrical power systems. By conducting these tests, engineers can assess core losses, winding resistances, and leakage reactance, which are crucial for proper transformer design and maintenance. This information ensures that transformers function optimally, reduce energy losses, and maintain the reliability of electrical networks, ultimately contributing to efficient power transmission and distribution.

References

1. Mohan, N.; Undeland, R.M.; Robbins, W.P. *Power Electronics, Converters, Applications and Design*, 2nd ed.; John Wiley & Sons: Hobroken, NJ, USA, 1995.
2. She, X.; Huang, A.Q.; Burgos, R. Review of Solid-State Transformer Technologies and Their Application in Power Distribution Systems. *IEEE J. Emerg. Sel. Top. Power Electron.* 2013**.**
3. Pires, V.F.; Cabral, A.; Guerreiro, M. Transformer differential protection based on the 3D current trajectory mass center. In Proceedings of the 4th International Conference on Power Engineering, Energy and Electrical Drives, Istanbul, Turkey, 13–17 May 2013.
4. Moscoso, M.; Lloyd, G.J.; Liu, K.; Wang, Z. Improvements to transformer differential protection-Design and test experience. In Proceedings of the 47th International Universities Power Engineering Conference (UPEC), London, UK, 4 September 2012.
5. *IEC 60076-7*; Power Transformers—Part 7: Loading Guide for Mineral-Oil-Immersed Power Transformers. IEEE Power and Energy Society: New York, NY, USA, 2005
6. *IEC 60076-11*; Power Transformers—Part 11: Dry-Type. IEEE Power and Energy Society: New York, NY, USA, 2004.
7. Pezeshki, H.; Wolfs, P.J.; Ledwich, G. Impact of High PV Penetration on Distribution Transformer Insulation Life. *IEEE Trans. Power Deliv.* 2014.
8. *IEEE std 519*; IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. IEEE Power and Energy Society: New York, NY, USA, 1992.
9. *IEEE C.57.110*; IEEE Recommended Practice for Establishing Transformer Capability When Supplying Non-Sinusoidal Load Currents. IEEE Power and Energy Society: New York, NY, USA, 1998.
10. Jordi-Roger Riba Ruiz, Antonio Garcia Espinosa, Luis Romeral. A Computer Model for Teaching the Dynamic Behavior of AC Contactors. J IEEE Transactions on Education ,2010.