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Testing and Troubleshooting of Transformers

Srilakshmi Inampudi[1], Rajitha T.B.[2], Kavita Sawant[3], Lovely Gaur[4]

Lecturer, Department of Electrical Engineering, Bharati Vidaypeeth Institute of Technology, Navi Mumbai, India[1]

HOD, Department of Electrical Engineering, Bharati Vidaypeeth Institute of Technology, Navi Mumbai, India[2]

Lecturer, Department of Electrical Engineering, Bharati Vidaypeeth Institute of Technology, Navi Mumbai, India[3]

Lecturer, Department of Electrical Engineering, Bharati Vidaypeeth Institute of Technology, Navi Mumbai, India[4]

Abstract: Transformer is an important component in electric power system. The function of the transformer is to adjust the current and voltage values so that it can be used according to usage needs. In the operation of electric power distribution, the transformer is the heart of transmission and distribution. The transformer is expected to operate optimally, so that the continuity and quality of electrical energy can be maintained. The main objective of testing the transformer is to know the quality of the machine, quality of materials used for manufacturing the machine and also to check its behavior and performance as per the design data. In this paper, various techniques are used to test transformer such as Voltage Ratio test, Winding Resistance test, Polarity and Phasing out test, etc. are presented and the troubleshooting of transformers is also covered briefly.

Keywords: Voltage Ratio test, Winding Resistance test, Polarity and Phasing out test, Insulation Resistance test, Short-Circuit Test, Magnetizing Current test.

I. INTRODUCTION

An electrical distribution system's major component is the transformer. Transformer fault will endanger the safe and stable operation of the whole power system. Transformer fault diagnosis can analyze equipment status information to ensure reliable and efficient operation of transformer equipment. Therefore, accurate identification of transformer fault types and timely maintenance can provide an important guarantee for the normal operation of the power system [1, 2].

Failure of the transformer may result from electrical overvoltage conditions, switching surges, partial discharge, static electrification, mechanical deformation of the transformer's windings. It is crucial to put the transformer through a number of testing processes and in this paper, we have presented the results of the tests carried out on the transformer.

II. TRANSFORMER TESTS

After the transformers are manufactured, they are to be tested to check their performance. The performance of the transformers is checked by various routine tests and compared with the designed data. The testing of transformers is generally carried out as per IS 2026. The routine tests conducted on each and every transformer include

1. Measurement of DC resistance winding.
2. Measurement of voltage ratio and check of voltage(polarity and phasing out test)
3. Measurement of no load loss and magnetizing current.
4. Measurement of impedance voltage short circuit impedance and load loss..

A. *DC Resistance of a Two Winding Transformer*

Winding resistance measurements are performed for assessing possible damage in windings or contact problems, such as from the bushings to the windings, the windings to the tap changer, etc. This test is a verification that proper size of conductors has been used and that the joints have been made properly. Since this test is indicative in nature, there is no tolerance applicable to the measured resistances. Resistances of the windings are measured by using resistance bridge.

For delta connected windings, measurement of winding resistance is carried out between pairs of line terminals. As in delta connection, the resistance of individual winding cannot be measured separately, the resistance per winding is calculated using the following formula:

Resistance per winding = 1.5 × Measured value

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The resistance is measured at ambient temperature and then converted to resistance at 75°C for all practical purposes of comparison with specified design values, previous results and diagnostics. The resistance can be measured by simple voltmeter and ammeter, Kelvin Bridge meter or automatic winding resistance measurement kit (ohm meter, preferably 25 Amps kit).

B. *Measurement of Voltage Ratio, Polarity Test and Phasing Out Test*

In substations generally more than one transformer operates in parallel to share the load on substation. Even when any transformer has to be connected in parallel to the existing transformer or a transformer is to be decommissioned after repairs it is necessary to know the polarity, voltage ratio and phase grouping. For fulfillment of these conditions following tests are carried out:

Voltage ratio: Transformer Turn's Ratio (TTR) measurements are performed to verify the fundamental operating principle of a power transformer. By measuring the ratio and phase angle from one winding to the other, open circuits and shorted turns can be detected. The turn's ratio is determined using Factory Acceptance Test (FAT) and needs to be checked routinely once the transformer is in-service. TTR measurements can also be triggered by a trip relay and other diagnostic tests like Dissolved Gas Analysis (DGA) and dissipation factor/power factor measurements. The usual tolerance on the measured ratio should generally be within 0.5 % of the nameplate ratings. However, in some cases where the number of turns in a given winding is very low, the standards allow the ratio to be correct to the nearest turn (rather than 0.5% tolerance).

This test verifies that the transformer windings have the correct number of turns so as to produce the required voltages. The test is carried out by using a "ratio meter", which applies an AC voltage to the primary windings. The primary windings are connected to the 3 phase 400V ac supply. The voltage applied across primary turns is presented in Table 1. Soon after turning ON the supply, voltage starts inducing in the secondary winding.

The induced voltage in the secondary windings is shown in Table 2. The ratio meter, a potential divider on which tapping are provided so that voltage across tapping and voltage applied to the ratio meter bears a constant ratio. By suitably adjusting the voltage ratio of ratio meter the current flowing through the ammeter is made zero, which indicates that secondary voltage of ratio meter and transformer under test are equal in magnitude but act in opposite direction. Their primary voltages being equal, voltage ratio of transformer under test is equal to voltage ratio of ratio meter.

Table 1 : Voltage applied across primary turns

Voltage Applied		
V_{RY}	V_{YB}	V_{BR}
402	403	403
402	403	403
403	403	403

Table 2 : Voltage induced across secondary turns

Tap	**Secondary Measured Voltage**					
	Vry	**Vyb**	**Vbr**	**Vrn**	**Vyn**	**Vbn**
1	126.4	126.8	126.8	72.4	72.6	72.6
3	132.5	133.5	133.2	75.5	75.7	75.2
16	173.7	173.5	173.5	98.5	98.8	98.8

Polarity test: It is essential to know the relative polarity of primary and secondary terminals of the transformer, at any instant for making correct connections, when the two transformers are to be connected in parallel to share the load on the system. Figs. 1 & 2 indicates subtractive and additive polarity respectively. Table 3 presents the results of subtractive and additive polarity of the single phase transformer.

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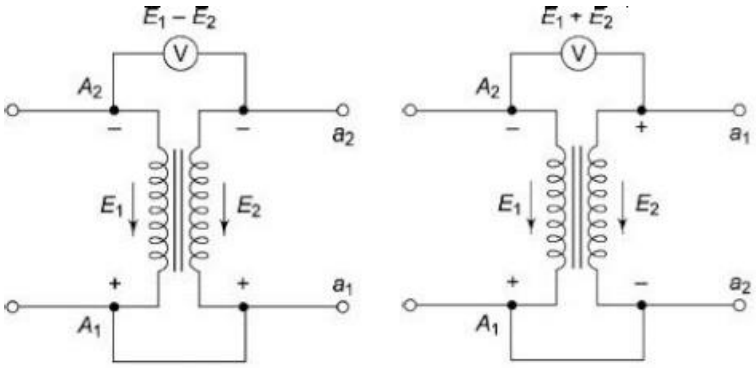

Fig.1 & 2 : Subtractive and additive polarity of single phase transformer

Table 3 : Subtractive and additive polarity test results

Fig.No.	Primary Induced EMF E_1 Volts	Secondary Induced EMF E_2 Volts	Measured voltage(V)	Calculated voltage V = (E_1- E_2) or V = (E_1+ E_2)	Type of Polarity
1	60	30	30	30	Subtractive
2	50	25	75	75	Additive

Phasing out: This test is carried out to identify primary & secondary windings belonging to same phase. Fig.3 shows the connections for phasing out test of three phase transformer. Table 4 presents the results obtained by conducting phasing out test on three phase transformer.

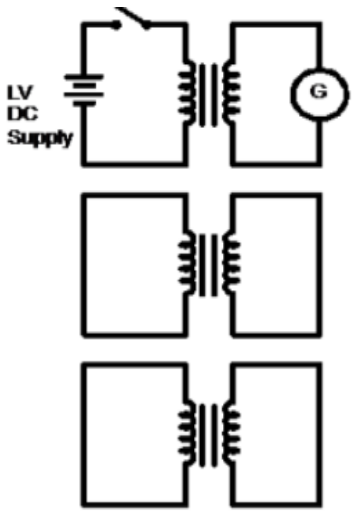

Fig.3 : Phasing out test of three phase transformer

Table 4 : Phasing out test results of three phase transformer

DC supply given to Primary winding	Deflection of Galvanometer observed between secondary terminals		
	Deflection across first secondary	Deflection across second secondary	Deflection across third secondary
Primary 1	Positive	Negative	Negative
Primary 2	Negative	Positive	Negative
Primary 3	Negative	Negative	Positive

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C. *Measurement of No-load loss and Magnetizing Current*

Pre-determining the regulation and efficiency of a transformer at any load condition (at any power factor) is of utmost importance in electrical power system. Open circuit test and short circuit test are very economical and convenient methods to predetermine the regulation and efficiency of high capacity transformer as they are done without actually loading the transformer.

Open Circuit test (O.C. Test) : It is used to estimate iron losses, transformation ratio and parameters of magnetizing branch of equivalent circuit. It is determined by applying rated voltage to the low voltage winding and keeping the high voltage winding open. This test is carried out on the transformer to assess the performance characteristics of the transformer without actually loading it. The data so obtained i.e. no-load current, no-load loss is used to determine constants Ro, Xo of the equivalent circuit of the transformer. Figure 4 shows the setup used for the Open Circuit Test and table 5 presents the results of open circuit test performed on the single phase transformer.

The Purpose of this test is to determine no load loss or core loss. A wattmeter, voltmeter, ammeter are connected in the low voltage winding (primary side). Voltage across primary is adjusted to its rated value through variac. The reading of the various instruments is then recorded.

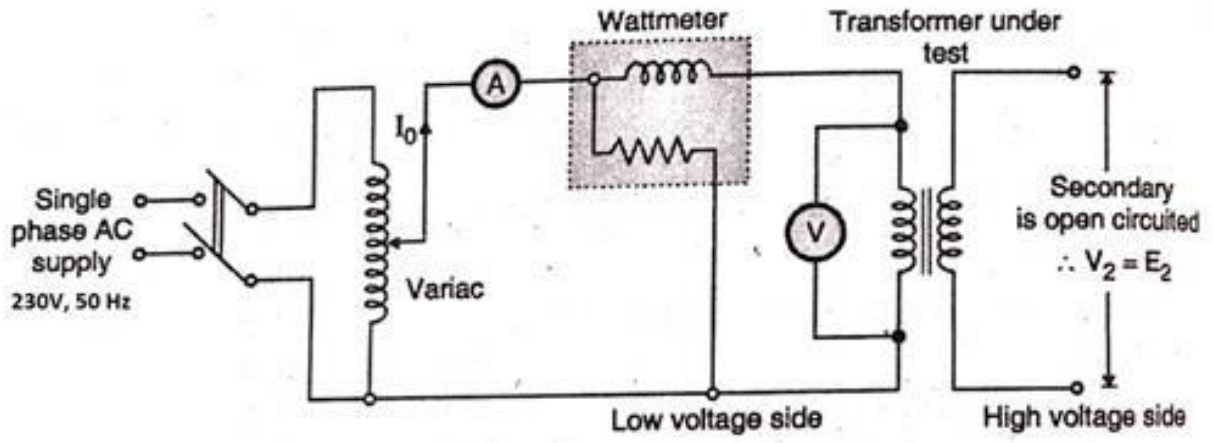

Fig.4 : Setup for the Open Circuit Test

Table 5 : Oper Circuit Test Results

Applied voltage V_0 volt	**No load current I_0 amp**	**No load Power W_0 watt**	**Secondary voltage V_2 volt**	**Transformation Ratio $K=V_2/V_1$**
115V	0.38	39	230V	2

Calculation for R0 and X0

Wattmeter reading indicates the input power

$W0=V1\ I0 \cos \phi$

Power factor $\cos \phi = W_0 / (V_1 I_0) = 0.892$

$I_c = I_0 \cos \phi_0 = 0.338$ A

$I_m = I_0 \sin \phi_0 = 0.171$ A

$R_0 = V_1/I_c\ \Omega = 340.23\ \Omega$

$X_0 = V_1 / I_m\ \Omega = 672.51\ \Omega$

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D. *Measurement of Impedance Voltage Short Circuit Impedance and Load Loss*

Short Circuit test (S.C. Test) : It is used to estimate copper losses and parameters of equivalent circuit of a transformer by applying low voltage to primary winding, just sufficient to circulate rated full load current or the required load current in the secondary winding, keeping low voltage winding short circuited. Figure 5 shows the setup used for the Short Circuit Test and table 6 presents the results of short circuit test performed on the single phase transformer.

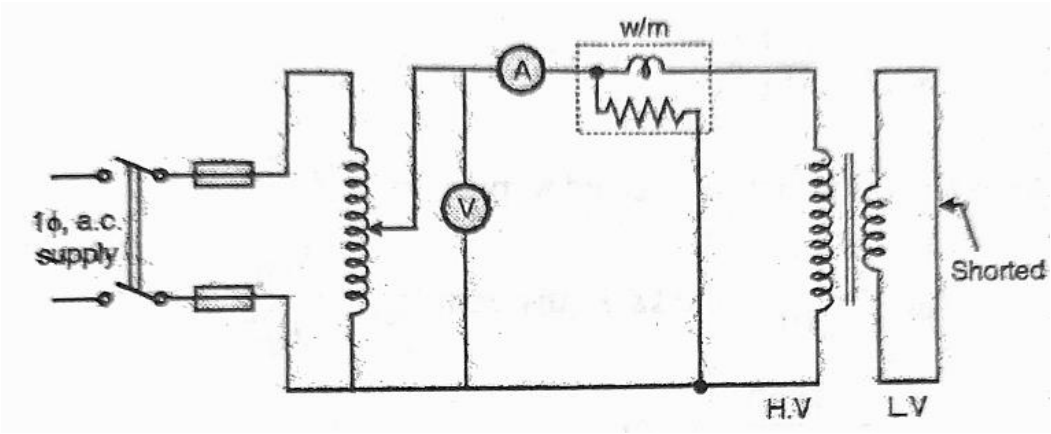

Fig.5 : Setup for Short Circuit Test

Generally, meter is connected on HV side and LV side is shorted. Only about 5 to 8% of the rated voltage is required. Voltage applied to HV side gradually increased with a variac till the full load current is circulated in the windings. The wattmeter gives the full load losses i.e., copper loss plus iron loss, iron loss is neglected.

Table 6 : Oper Circuit Test Results

Voltage applied V_{sc} volt	**Current circulated I_{sc} amp**	**Short circuit power W_{sc} watt**
25	4.3	93

Calculations for SC test: (primary side) ie High voltage side

$\cos \phi_{sc} = 0.865$

$R_{sc}=W_{sc}/I_{sc}^2 = 5.02\ \Omega$

$Z_{o1}=V_{sc}/I_{sc} = 5.81\ \Omega$

$X_{01} = \sqrt{Z2_{01} - R2_{01}} = 2.92\ \Omega$

III. CAUSES OF FAILURE IN TRANSFORMERS

The main reasons that causes failures in transformers are the improper repair, poor maintenance, corrosion, manufacturing deficiencies, vibration and mechanical movement within the transformer. Deterioration of oil may occur due to the result of prolonged overloading of the transformer [3, 4, 5, 6].

A. *Types of Faults*

Mechanical faults:

- It is due to vibrations in stampings of core.
- Cracks developed in bushings due to atmospheric conditions.
- Sometimes tap-changes are mechanically damage due to damages due to developments of arc due to repeated operations.

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Electrical faults :

- These is due to dry soldering, improper/loose soldering, melting of contacts, break due to opening of solders.
- Insulation damaging due to long time over loading.
- Overload stresses, entry of moisture.

Magnetic faults :

- Due to mechanical injuries
- It is due to increase gaps in the stampings of T/F core, core insulation damage, over heating of insulation due to frequent overloading due to over voltages.
- Due to non-uniform flux distribution.
- Due to dented core and burns

IV. TROUBLE SHOOTING

Maintenance is a process which includes regular / periodical checking, testing and replacing defective parts. Regular maintenance increases the life of a machine. Troubleshooting chart helps locating the fault in a machine and rectifying it. It helps in reducing downtime of the machine. Maintenance is classified as routine maintenance, preventive maintenance, and breakdown maintenance. The main aim of maintenance is to maintain machine in a good running condition. Maintenance of three phase transformer is carried out as per IS 10028 (Part III)-1981.Troubleshooting chart is essential for successful breakdown and preventive maintenance.

V. CONCLUSION

Transformer is an important component in electric power system. The transformers require number of periodic tests to be performed for trouble free and uninterrupted operation. The routine test results carried out on single phase transformer and three phase transformer indicated the satisfactory working of the transformers.

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