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Testing of Three Phase Power Transformer

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Abstract: The fault free operation of a power transformer is a factor of major economic importance and safety in power supply utilities. In manual method, lot of time is required to test any type of transformer and risk involved is higher. In this paper, various intelligence techniques are used to test transformer. Such techniques used are Voltage Ratio test, Magnetic Balance test, Winding Resistance test, Polarisation Index test, etc. This study focuses on the temperature of transformer winding, voltage ratio across HV-LV, asymmetrical flux distribution in the core, insulation resistance of paper and oil insulation.

Keywords: Voltage Ratio test, Magnetic Balance test, Winding Resistance test, Insulation Resistance test, Short-Circuit Test, Magnetizing Current test

I. INTRODUCTION

Over the years, a number of methods have been introduced and employed on power transformers to find internal defects within the valuable asset. The electrical energy produced at generating stations is transported over high voltage transmission lines to load center. Power System is divided into many different sections. One which is transmission system, where power is transmitted from generating station and substation via transmission line to consumer Incipient fault detection in transformers can provide early warning of electrical failure and can prevent losses. The life of a transformer depends directly on the life of its insulation. Transformers play an important role in the Power System. They help transfer power to appropriate levels for which other components are designed. They are often in operation for a long time and only stop working during power interruptions and maintenance. Due to the stress they take, it is important to regularly assess their functions to ensure continuous service. Engineers need to ensure that the transformers in operation are in its full capacity. One of the common tests done is Voltage Ratio test. Other tests that should be done on a regular basis are Winding Resistance, Insulation Resistance test, Magnetic Balance test, Short-circuit, Magnetizing current test, etc.

II. VARIOUS TESTING TECHNIQUIES

2.1 Voltage Ratio Test

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. Transformer turns ratio 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).

Test procedure:

This test verifies that the transformer windings have the correct number of turns so as to produce the required voltages. This 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. Soon after turning ON the supply, voltage starts inducing in the secondary winding. 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

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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.

Voltage Applied		
V_{RY}	V_{YR}	V_{BR}
404	405	405
404	405	405
403	403	403

Test Result:

Tap	Secondary Measured Voltage					
	V_{ry}	Vrb	Vbr	Vrn	Vyn	Vbn
1	129.1	129.9	129.9	74.2	74.3	74.3
3	133.9	134.5	134.2	76.6	76.7	77.0
16	175.5	175.5	175.5	100.4	100.3	100.5

2.2 Winding Resistance Test

Winding resistance measurements are used to 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 have 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'.

This test also serves two other important testing functions:

(a) The measured resistance is used for obtaining I^2R, which his used in the 'Load loss' test.

(b) Measurements of cold resistance and hot resistance are used for calculation of temperature rise of windings during the Temperature Rise Test.

The measurement of resistance is done at room temperature but corrected to a reference temperature which is 20 degrees higher than the temperature class of the unit.

For Example: The reference temperature is 75^0C for 55^0C rise oil-filled units, or is 85 ^{0}C for 65 ^{0}C rise units. For dry type transformers, the typical rises are 80^0C, 115^0C and 150^0C in the core. It also indicates healthiness of the inter turn between HV terminal and LV terminal, then between LV terminal and the neutral.

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

Resistance per winding = 1.5 × Measured value

The resistance is measured at ambient temperature and then converted to resistance at 75^oC for all practical purposes of comparison with specified design values, previous results and diagnostics.

The resistance can be measured by simple voltmeter, Ammeter method, Kelvin Bridge meter or automatic winding resistance measurement kit(ohm meter, preferably 25 Amps kit)

Test Procedure:

For star connected winding, the resistance shall be measured between the line and neutral terminal. For star connected auto transformer the resistance of the HV side is measured.

Test Result:

HV Winding Resistance In Milli Ohms			
Tap	**R-Y**	**Y-B**	**B-R**
1	154.7	155.20	155.55
3	148.35	148.35	149.16
16	151.43	152.03	152.27

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LV Winding Resistance In Milli Ohms			
LV Winding	r-n	y-n	b-n
	6.65	6.63	6.64
	r-y	y-b	b-r
	13.2	13.30	13.29

2.3 Magnetic Balance Test

Magnetic balance test is conducted only on three-phase transformers to check the imbalance in the magnetic circuit. Result of this test indicates uniform distribution of flux insulation. This test is carried out by applying 3 phase 400V AC to one winding, measured induced voltages on other two winding on same side. In general magnetic balanced test is carried from HV side.

Transformer is connected in either two fashion.

- Star
- Delta

Star Fashion:

In case of failure of two phases in transformer (either RY, YB or BR) only one limb of transformer will produce flux by using neutral point. The main aim of this test is hence proved, that flux produced by one limb is the sum of fluxes of other two limbs. From the results, we can say that core is in healthy condition.

Delta Fashion:

In case of failure of one phase in transformer (either R, Y, or B) then only one limb of transformer will produce flux and in remaining two limbs will provide return path for that flux, the main aim of this test is to prove, flux produced by one limb is the sum of fluxes of other two limbs so that we can say core don't have any problem for path of flux.

Test procedure:

Apply 3 phase 415V voltage to primary winding of transformer and remove any one phase for delta fashion winding and remove any two winding for star fashion winding. Note down the voltages in three phases by using multi meter in primary winding and secondary windings.

- line to line voltage in case of delta fashion
- line to neutral voltage in case of star fashion

Repeat the same procedure for remaining two cases.

Test Result:

Tap No	Voltage Applied Across	Voltage Measured		
		R-Y	Y-B	B-R
1	R-Y	400	284.4	114.5
	Y-B	188.4	401	211.4
	B-R	104.3	297	402
3	R-Y	401.6	289.7	110
	Y-B	190.8	401.6	209.6
	B-R	103.3	297.5	402.3
16	R-Y	401.1	286.7	112.7
	Y-B	188.6	402.2	211.5
	B-R	98.3	302.6	402.5

2.4 Insulation Resistance test

Polarisation index test on a transformer is carried out to check the service condition of the insulation of the material. This test is normally conducted to check the dryness and healthiness of the insulation. Because each transformer is unique is some ways, it is difficult to prescribe an acceptable value of IR. It is measured in Mega-ohms. IR is dependent upon the temperature.

In Insulation Resistance test, high DC voltage is applied across the insulator. This applied voltage is then divided by current through the electrical insulator to obtain resistive value of the insulator. Since as per Ohm's law,

Insulation resistance between HV-LV, HV-E, and LV-E windings are measured with the help of 5000V/1000V insulation resistance tester (megger). Use 1000V megger for measurement of LV-E resistance.

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Megger gives required direct (DC) voltage across the insulator, and it also shows the resistive value of insulation directly in M – Ω and G – Ω range. We generally use 500 V, 2.5 KV and 5 KV megger depending upon the dielectric strength of the insulation. For example, we use 500V megger for measuring up to 1.1 KV rated insulation. For high voltage transformer, we use 2.5 or 5 KV megger depending up on the insulation level.
When we apply voltage across an insulator, there will be a corresponding current through it. Although this current is small and it is in milliampere or sometimes in microampere range, it has mainly four components.

1. Capacitive component
2. Conductive component
3. Surface leakage component
4. Polarisation component

The significance of **polarisation index test** is,
Let I be the total initial current during polarisation index test or PI test
I_C is the capacitive current
I_R is resistive or conductive current
I_S is surface leakage current
I_P is polarization current of the insulator

$$Hence,\ \ I\ =\ I_C\ +\ I_R\ +\ I_S\ +\ I_P$$

Value of insulation resistance test or IR value test, i.e. megger reading just after 1 minute of the test is

$$R_1\ =\ \frac{V}{I_R\ +\ I_S\ +I_P}$$

Megger value of 10-minute test, is

$$R_{10}\ =\ \frac{V}{I_R\ +I_S}$$

Therefore, result of **Polarisation Index**, is

$$\frac{R_{10}}{R_1}\ =\ \frac{\frac{V}{I_R+I_S}}{\frac{V}{IR+IS+IP}}\ =\ \frac{I_R\ +I_S\ +I_P}{I_R\ +I_S}\ =\ 1\ +\ \frac{I_P}{I_R\ +I_S}$$

Test Procedure
Before measuring the resistance, you should remove all connections to the transformer and discharge the windings (of electric wire) to the grounded transformer frame. Using a direct-indicating, power-driven megohmmeter (an electrical test instrument producing a DC voltage), an electrical current of either 500 volts or 1,000 volts DC should be applied between the winding and ground. The amount of current you use depends on the rating of the transformer.

Test Result:

Time	IR(Mega Ohms)		
	HV-E	HV-LV	LV-E
0:00:15	5.4962	4.6042	3.4542
0:01:00	8.2342	6.59	4.82
0:03:00	10.4	9.34	6.34
0:05:00	11.5	10.6	7.28
0:10:00	12.9	12.2	8.83

2.5 Magnetizing Current Test
Magnetizing Current test on transformer is performed to locate defects in the magnetic core structure, shifting of windings, failure in between turn insulation or problem in tap changers. These conditions change the effective reluctance of the magnetic circuit, thus affecting the current required to establish flux in the core.
Magnetizing Current is the term used to denote the total current that flows into the primary of a transformer when the transformer is energized at a specific voltage and frequency, with the secondaries open circuited.
Although known as magnetizing current, it is actually the combination of the current required to magnetize the core (I_1) and the current required to supply the losses in the core (I_2).

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In case of a transformer with a split primary, the test can be conducted equally well by energizing just one of the primary windings, as opposed to the two in series. The expected current will be greater for the single winding, rising in proportion to the turns ratio: -

$I_A = I_{AB} \times (N_{AB} / N_A)$

Where

I_A = The current to be specified when testing with winding A

I_{AB} = The current for windings A and B in series

N_A = The number of turns on winding A

N_{AB} = The number of turns on A and B in series

(As an alternative, the formula above can be written using the voltage ratio between the two windings, rather than the turns ratio.

Test Procedure:

Keep the tap changer in the lowest position and open all HV and LV terminals Then apply three phase 415 V supply on the line terminals for three-phase transformers and single phase 230 V supply on single phase transformers. Measure the supply voltage and current in each phase. Now repeat the magnetizing current test of transformer test with keeping tap changer in normal position. Repeat the test while keeping the tap at highest position. Normally, there are two similar higher readings on two outer limb phases on transformer core and one lower reading on the center limb phase, in the case of three phase transformers.

Test Result:

Tap No		**I_R(mA)**	**I_Y(mA)**	**I_B(mA)**
1	1	31.1	24.9	23.65
3	3	32.9	26.02	24.56
16	16	49.4	39.2	36.5

2.6 Short Circuit Test:

The test is conducted on the high-voltage (HV) side of the transformer where the low-voltage (LV) side or the secondary is short circuited. A wattmeter is connected to the primary. An ammeter is connected in series with the primary winding. A voltmeter is optional since the applied voltage is the same as the voltmeter reading. The LV side of the transformer is short circuited. Now with the help of variac applied voltage is slowly increased until the ammeter gives reading equal to the rated current of the HV side. After reaching at rated current of HV side, all three instruments reading (Voltmeter, Ammeter and Watt-meter readings) are recorded. The ammeter reading gives the primary equivalent of full load current IL. As the voltage applied for full load current in short circuit test on transformer is quite small compared to the rated primary voltage of the transformer, the iron losses in transformer can be taken as negligible here.

Test Procedure:

Isolate the power transformer from service. Remove HV/LV jumps and disconnect neutral from earth/ground. Short LV phases and connect these short circuited terminals to neutral. Energize HV side by LV supply. Measure current in neutral, HV voltage and HV line currents. Wattmeter indicates total cu loss of the transformer.

Test Result:

Tap	**I_R**	**I_Y**	**I_B**	**I_r**	**I_y**	**I_b**	**Voltage applied**
1	31.3	31.3	30.9	98.5	97.7	98.4	397
3	34.1	33.7	33.7	103.3	102.5	102.7	
16	62.3	62.1	61.8	142.3	142.4	142.7	

CONCLUSION

This paper is giving us the correct result of different test parameters. This technique is simple than other techniques. The goal of testing is to confirm the transformers ability to continue functioning properly and reduce the chance of failure. From this test result, we came to know the quality of product and to prevent from accident. Therefore, it is essential to test the transformer.

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