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Testing Procedure of Three Phase Transformer

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Abstract:- The transformer plays an important role in the electrical generation, transmission, and distribution systems. Therefore, the entire generation, transmission, and distribution systems will be impacted if the transformer is not operating properly. Therefore, we must conduct some tests to determine the transformer's overall health.

Keywords:- *IR test, windings resistance test, Magnetic balance and current test, No load loss and full load loss, Open circuit and short circuit test.*

I. INTRODUCTION

During the design phase of a transformer, we need to follow some international standards for the safety of the transformer itself as well as other related equipment.

We need to do some tests to validate that all the international standards are maintained.

The following are some crucial tests:

- Transformer Insulation Resistance (IR) Test
- Windings Resistance Test
- Transformer Magnetic Balance Test
- Transformer Magnetic Current Test of LV side
- Transformer Magnetic Current Test of HV side
- “No load loss” and “Full load loss” of transformer

II. TECHNIQUES OF DIFFERENT TYPE OF TEST

A. Insulation Resistance (IR) test of transformer.

- **Introduction:**The insulation resistance (IR) test is performed to evaluate the insulation resistance of transformers. Insulation Resistance shows the resistance value of the insulation between copper conductors to earth (zero point). Based on the IR value, we can reveal the degradation of insulation due to contamination, moisture, and severe cracking. The test can be performed through a megger by applying a constant DC voltage of 2500 volts to 5000volts for 10 minutes between HV and LV windings, LV windings to earth, and HV windings to earth. An electrical power transformer's total insulating system must pass this test to be deemed healthy. This test is run between the LV and HV windings, as well as between the HV and LV windings.

- **Procedure of Magnetic Balance Test of Transformer:**
  - ✓ Disconnect all the line and neutral terminals of the transformer from the outgoing and incoming feeders.
  - ✓ Meter leads are connected to LV and HV bushing studs to measure the insulation resistance (IR) value in between the LV and HV windingsas shown in figure # 01.
  - ✓ Megger leads are connected to HV bushing studs and the transformer tank earth point to measure the insulation resistance (IR) value in between the HV windings and earthas shown in figure # 02.
  - ✓ Megger leads are connected to LV bushing studs and the transformer tank earth point to measure the insulation resistance (IR) value in between the LV windings and earthas shown in figure # 03.
  - ✓ The temperature of the insulating oil should be noted at the time of the insulation resistance test of the transformer, since the IR value of the transformer insulating oil may vary with temperature.
  - ✓ IR values are to be recorded at intervals of 1 minute, and 10 minutes.
  - ✓ The IR value increases as the voltage is applied for a longer period of time. The increase in IR is an indication of the dryness of the insulation.
  - ✓ Polarization index (PI) = 10 minutes' value/1 minute's value PI must be greater than 1.5

- **Expected result:** For the 11/0.415kV transformer, IR value on the HV side must be greater than 11 MΩ as well as IR value on the LV side must be greater than 0.415 MΩ.

Insulation resistance shall be at least 1 MΩ for every kV of voltage. A value of IR is considered "Poor" if it is repeated twice; otherwise, it is considered as "Good".

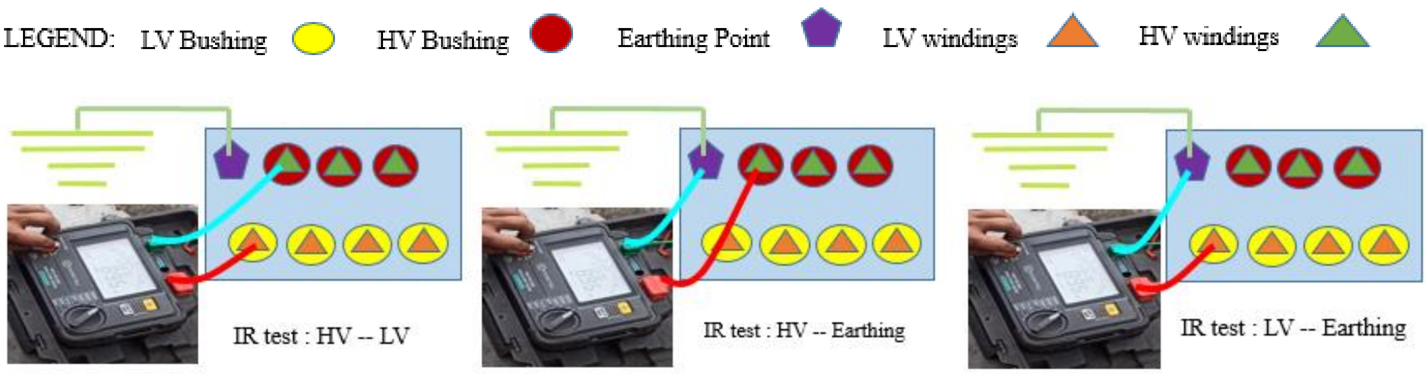

Fig # 01, (Megger connection between HV to LV) Fig # 02, (Megger connection between HV to Earth) Fig # 03, (Megger connection between LV to Earth)

Sl No.	Megger (2500V DC)		Result (G Ω)		PI
	(+) Terminal	(-) Terminal	60 sec	600 Sec	
1	R	r	9.5	25.76	2.7
2	Y	y	9.2	25.45	2.8
3	B	b	9.8	24.85	2.5

Table # 01, IR value in GΩ (HV to LV)

Sl No.	Megger (2500V DC)		Result (G Ω)		PI
	(+) Terminal	(-) Terminal	60 sec	600 Sec	
1	R		9.3	23.2	2.5
2	Y	Earthing	9.6	22.8	2.4
3	B		9.9	22.6	2.3

Table # 02, IR value in GΩ (HV to Earth)

Sl No.	Megger (500V DC)		Result (G Ω)		PI
	(+) Terminal	(-) Terminal	60 sec	600 Sec	
1	r		7.8	18.4	2.4
2	y	Earthing	7.9	18.1	2.3
3	b		7.6	18.8	2.5

Table # 03, IR value in GΩ (LV to Earth)

- **Comments on practical test result:** From the result, it is clear that the Insulation Resistance between HV to LV, HV to Earth and LV to Earth is very good.
- **IR test procedure 2:** Insulation Resistance (IR) test can be performed in another smelliest way, figure # 04. Result would be similar as all HV windings are internally connected with each other and LV windings as well. Typical connection diagram as mentioned below:

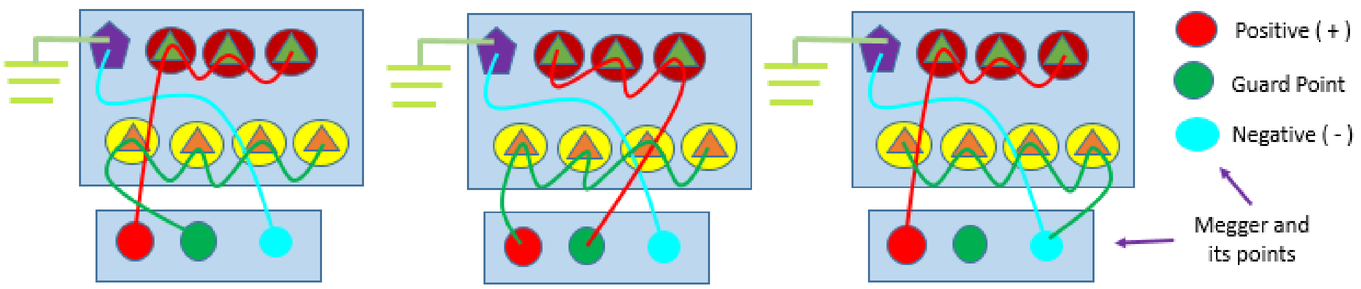

Fig # 04, Typical Megger connection between HV to Earth, LV to Earth and HV to LV. Guard point is used for protection

- ✓ All HV bushing studs are connected through a wire, and then IR values are taken between one HV bushing stud and the earth point.
- ✓ All LV bushing studs are connected through a wire, and then IR values are taken between one LV stud and the earth point.
- ✓ All HV bushing studs are connected by a wire, and all LV bushing studs are connected by a wire as well. The earth point is also connected to the megger's LV point, and IR values are obtained between one HV bushing stud and one LV bushing stud.

- **Impact of Temperature on Insulation Resistance:** Transformer windings are made of copper or aluminium. The resistance of copper or aluminium changes if temperatures change. So we need to adjust the impact of temperature if the test is not performed at the standard winding temperature of 75°C.

Relation between phase-to-phase resistance and phase-to-neutral resistance

R ph—ph = 2 x R ph for star or Y-connected windings,
R ph—ph = 2/3 x R ph for delta-connected windings

Here,
R ph—ph is phase-to-phase or line-to-line resistance.
R ph is the resistance between phase and neutral

Formula for temperature correction: R ref = R test x (T ref + C const) / (T test + C const)
R ref. = Resistance of windings at Standard temperature of 75°C
R test = Resistance of windings at testing temperature of 30°C
T ref. = Standard temperature which is 75°C
T test = Temperature at the time of testing
C const = Constant, which is 234.5°C for copper and 225°C for aluminium

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B. WINDINGS RESISTANCE TEST OF TRANSFORMER

- **Introduction:** The resistance of transformer windings is very important for the performance of the transformer.

This test is performed to check:

- ✓ Copper loss of windings
- ✓ Quality and healthiness of windings
- ✓ A loose joint or a poor winding connection
- ✓ Any open winding turns

➢ **Procedure of Magnetic Balance Test of Transformer:**

- The tap position is kept at the ordinary or normal operating position
- Disconnect the transformer connections (HV and LV) from incoming and outgoing feeders
- Disconnect the transformer neutral point from ground or earth
- The transformer shall be kept in an off condition without excitation for at least 3 to 4 hours. During this time, the winding temperature will reach the same level as the oil temperature
- Now, DC current is injected between two phases (R and Y) of HV windings, as shown in figure #01 (red cables).
- During our test, we injected a DC current of 10 A and 1 A for the HV and LV windings respectively
- Now, voltage is measured between R and Y windings through the winding's resistance tester, as shown in figure # 02 (green cables).
- Voltage measurement leads shall be independent of the current injection leads to protect them from high voltages that may occur during switching on and off the current circuit. (Figures # 03 and 04 are for the LV side test.)
- The readings shall be recorded after the current and voltage have reached steady-state values. This may take a few minutes.
- Windings' resistance is measured directly on the Y or star side. Phase-to-neutral resistance is half of line-to-line resistance.
- We cannot directly measure the phase winding resistance on the delta side. So, we need to measure line-to-line resistance and then multiply the measured value by 0.67 to get actual phase winding resistance.
- Repeat the test for each of the three phases

Typical connection diagram for windings resistance test:

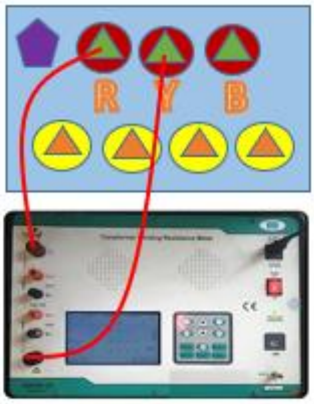


Figure # 01

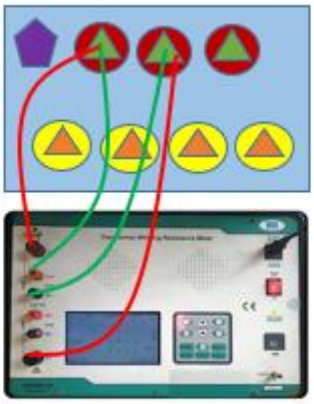


Figure # 02

Windings Resistance measure for HV Side (delta)

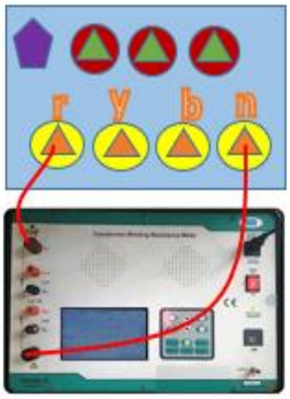


Figure # 03

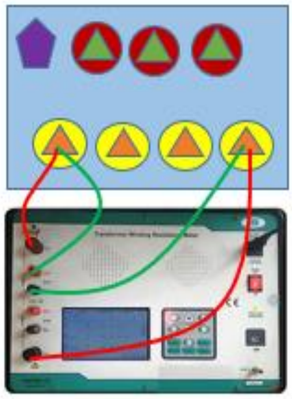


Figure # 04

Windings Resistance measure for LV Side (Star)

Practical test result for winding resistance test:

11/0.415kV 2000kVA delta-- star			
HV side test: 10A and 2 Ω range			
tap	R-Y mΩ	Y---B mΩ	B---R mΩ
1	219.4	218.8	219.1
2	214.3	214.5	213.9
3	207.1	206.8	207.3
4	201.6	201.2	201.4

Table # 01 (Winding resistance in mΩ for HV side)

11/0.415kV 2000kVA delta-- star			
LV side test: 1A and 20 mΩ range			
tap	r--n mΩ	y--n mΩ	b--n mΩ
1			
2	0.453	0.438	0.447
3			
4			

Table # 02 (Winding resistance in mΩ for LV side)

- **Expected result:**For a given tap position, resistance value between R—Y to Y—B to B—R as well as r—n to y—n to b--n shall be very close to each other.
- **Comments on test result:** The resistance of windings is as per expectation and windings are good
- **Precaution:**The windings resistance test shall be performed at the end of all tests, as this test will charge both the windings and core. So, the results of other tests may be affected.

C. MAGNETIC BALANCE TEST OF TRANSFORMER

- **Introduction:** The magnetic balance test of a transformer is a widely used test that is performed only on three-phase transformers and on the Y, or star, side of the transformer, though the magnetic balance test can also be performed on the delta side. The results of this test indicate the uniform distribution of flux in the core.

  This test is performed to check:
  - ✓ The imbalance in the magnetic circuit
  - ✓ Any fault or defect in the magnetic core
  - ✓ To identify inter-turn faults in the transformer

- **Procedure of Magnetic Balance Test of Transformer:**
  - ✓ The tap changer of the transformer shall be placed in an ordinary position
  - ✓ Disconnect the transformer connection from incoming and outgoing feeders
  - ✓ Disconnect the transformer neutral point from ground or earth
  - ✓ Supply a single phase 230 V AC supply across the one phase winding and neutral terminal, as shown in figure # 01, 02 and 03
  - ✓ Now, measure the voltage that is induced between the other two phases with respect to the neutral terminal
  - ✓ Repeat the test for each of the three phases

- **Typical connection diagram for the magnetic balance test:**

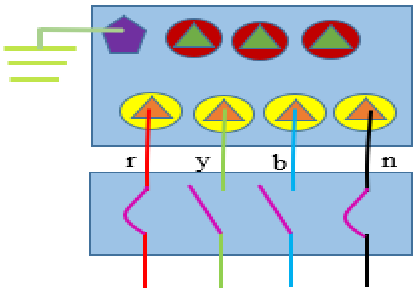


Figure # 01

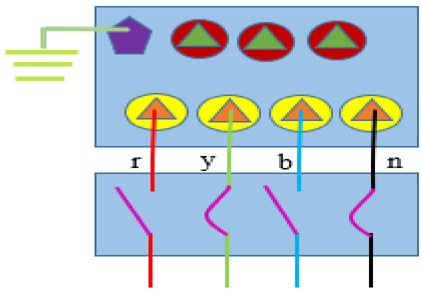


Figure # 02

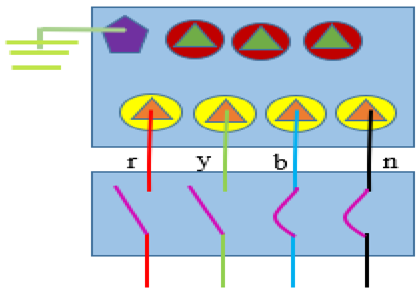


Figure # 03

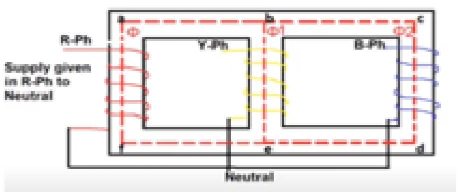


Fig # 04, AC supply between r and n

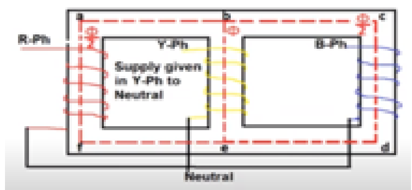


Fig # 05, AC supply between y and n

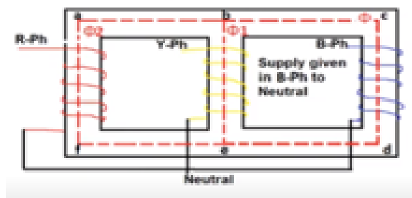


Fig # 06, AC supply between b and n

If we apply 230V between r (the windings of the core's left limb) and n (the windings' neutral point), the flux induced in the core's other two limbs (the middle and right limbs) are different due to the different reluctance paths. As a result, the induce voltages between y and n, as well as b and n, is different from each other.

Outcome: If we apply 230V between the r and n phases, the sum of the induce voltages between y and n as well as b and n must equal the supply voltages as shown below:

Voltage applied	r -- n	y -- n	b -- n
r -- n	100%	70 – 75 %	30 – 25 %
y -- n	50%	100%	50%
b -- n	30 – 25 %	70 – 75 %	100%

Table # 01, supply voltage to one ph to n and induced voltage range between another ph to n

Practical Test result:

Voltage applied	r -- n volt	y – n volt	b – n volt
230V (r – n)	**230** (100%)	**179** (77 %)	**53** (23) %
231V (y – n)	**115** (50%)	**231** (100%)	**115** (50%)
230V (b – n)	**54** (23) %	**178** (77 %)	**230** (100%)

Table # 02, supply voltage to one ph to n and induced voltage between another ph to n in practical test

- **Comments on result:** In the practical test, it is clear that there is a negligible difference between the supply voltage and the sum of induce voltages of the other two phases with respect to neutral.

  On the other hand, the percentage of induced voltages is very close to expected values.

  This indicates that the transformer is magnetically balanced.

D. Magnetic Current Test of Transformer in LV side:

- **Introduction:** The magnetic current test of a transformer is a widely used test that is performed only on three-phase transformers. A magnetic current test can be performed on both the star and delta sides. This test is performed to detect the magnetic core structure, shifting of windings, failure in between turn insulation, or problems in tap changers. These conditions change the effective reluctance of the magnetic circuit, thus affecting the current required to establish flux in the core.

- **Procedure of Magnetic Current Test LV side --01:**
  - ✓ Keep the tap changer in normal position
  - ✓ Disconnect all HV and LV terminals from incoming and outgoing feeders
  - ✓ Disconnect the transformer neutral point from ground
  - ✓ Supply a three-phase 415 V supply on the line terminals for three-phase transformers and keep the neutral open as shown in figure # 01
  - ✓ Measure the supply voltage between r—y, y—b, and b—r, as well as the current through r, y, and b.

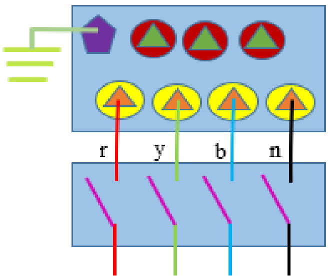


Figure # 01

11/0.415kV 2000kVA delta-- star						
415 Volt on LV side and HV side is open						
tap	r--y volt	y--b volt	b--r volt	r mA	y mA	b mA
1						
2	415	416	414	62	49	58
3						
4						

Table # 01 (Magnetic Current test result)

- **Expected result:** Normally, there are two similar higher readings on two outer limb (r and b) phases on transformer core and one lower reading on the center limb (y) phase, in the case of three phase transformers.

- **Comments of test result:** Current through r and b is higher than the current of phase y which indicate that transformer core is good.

- **Procedure of Magnetic Current Test LV side --02:**
  - ✓ Disconnect all HV and LV terminals from incoming and outgoing feeders
  - ✓ Disconnect the transformer's neutral point from ground
  - ✓ Supply the three-phase, 415-volt supply on the line terminals for three-phase transformers and the neutral wire to the neutral point of the transformer
  - ✓ As shown in figure #02, keep the circuit breaker (CB) switch on for the r and n terminals and turn it off for the y and b terminals
  - ✓ Measure the voltage between r—n, y—n, and b—n, as well as the current flowing through the r terminal
  - ✓ As shown in figure # 03, keep the circuit breaker (CB) switch on for the y and n terminals and turn it off for the r and b terminals
  - ✓ Measure the voltage between r—n, y—n, and b—n, as well as the current flowing through the y terminal
  - ✓ As shown in figure # 04, keep the circuit breaker (CB) switch on for the b and n terminals and turn it off for the r and y terminals
  - ✓ Measure the voltage between r—n, y—n, and b—n, as well as the current flowing through the b terminal

- **Typical connection diagram for test procedure—02**

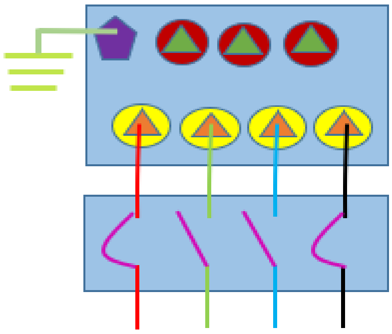


Figure # 02

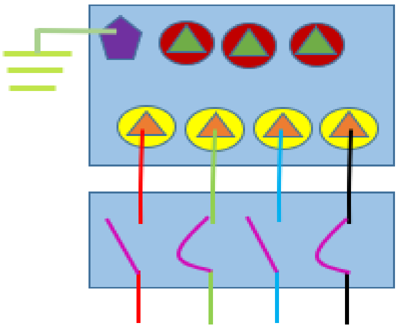


Figure # 03

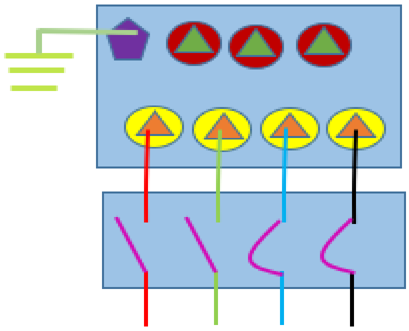


Figure # 04

Test result:

11/0.415kV 2000kVA delta-- star				
LV side test: 1A and 20 mΩ range				
Supply	r--n volt	y--n volt	b--n volt	I mA
r--n	235	165.5	72.3	63
y--n	116.8	230	114.5	52
b--n	68.9	165.3	232	59

Table # 02 (Magnetic Current test result)

- **Comments of test result:** Applied voltage to one phase to neutral is almost equal to the sum of another two phases with respect of neutral. So, the core of transformer is good.

E. Magnetic Current Test of Transformer in HV side:

- **Introduction:**The magnetic current test of a transformer is a widely used test that is performed only on three-phase transformers. A magnetic current test can be performed on both the star and delta sides. This test is performed to detect the magnetic core structure, shifting of windings, failure in between turn insulation, or problems in tap changers. These conditions change the effective reluctance of the magnetic circuit, thus affecting the current required to establish flux in the core.

- **Procedure of Magnetic Current Test for HV side:**
  - ✓ Keep the tap changer in the lowest position
  - ✓ Disconnect all HV and LV terminals from incoming and outgoing feeders
  - ✓ Disconnect the transformer neutral point from ground
  - ✓ As shown in figure #05, supply a three-phase 415 V supply to the line terminals of three-phase transformers
  - ✓ Determine the supply voltage between R—Y, Y—B, and B—R, as well as the current flowing through R, Y, and B.
  - ✓ Repeat the test as described above, but this time leave the tap changer in the normal or ordinary position, and keep the record
  - ✓ Repeat the test as above while keeping the tap in the highest position and keeping the record.

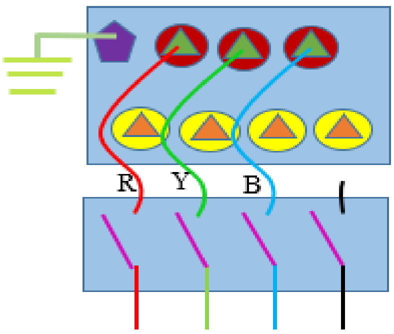


Figure # 05

11/0.415kV 2000kVA delta-- star						
415 Volt on HV side and LV side is open						
tap	R-Y volt	Y---B volt	B---R volt	R mA	Y mA	B mA
1	415	414	416	4.5	2.8	4.2
2	415	416	414	4.7	3.3	4.4
3	416	413	415	4.9	3.8	4.7
4	413	415	416	4.12	4.1	4.9

Table # 03 (Magnetic Current test result HV Side)

- **Comments of test result:** Current through r and b is higher than the current of phase y which indicate that transformer core is good.

- **Caution:** This magnetizing current test and balance test of a transformer shall be carried out before DC resistance measurement test.

F. No Load test (open circuit test) of Transformer:

- **Introduction:** When a transformer's one side (the HV side) is open and not connected to any loads, it is called the "no load" condition of the transformer. Now, if we apply any voltage to the LV side, then a very small amount of current (usually 2% to 5% of the full load current) will flow through the LV windings. This current is known as the "no load current" of a transformer. So, the copper loss due to this "no load current" is very small and can be ignored, and hence the input power is almost similar to the core loss of the transformer. This core loss of the transformer is referred to as the "no load loss" of the transformer. So, the "no-load loss" of a transformer does not depend on the load of the transformer. This happens for 24 hours a day and 265 days a year.

- **Description:** When measuring a transformer's no-load loss and current, one of the windings (often the HV winding) is kept open while the other windings (LV windings) are powered at the specified voltage and frequency. Then a very small amount of "no load current" will flow through the LV windings. In three-phase transformers, the no-load currents are neither symmetrical nor equal in amplitude. For each of the three phases, the phase angles between the voltages and currents may change. The wattmeter readings on each of the three phases may not be equal because of this. One of the wattmeter results may occasionally be zero or negative (-). The fundamental test requirement is that voltage and frequency (50 Hz or 60 Hz) must both fall within tolerances of 1% and 3%, respectively.

  If the frequency of the supply source is less or higher than the standard frequency, then we need to adjust the supply voltage and output power.

➢ **Procedure of "No load loss" Test:**

- Disconnect all HV and LV terminals from incoming and outgoing feeder
- Disconnect the neutral of Transformer from the grounding/Earthing
- Keep the HV windings openas shown in figure # 01
- Connect watt meter (W), voltmeter (V) and ammeter (A) as shown in figure # 01
- Supply a three phase 415 V on LV side (Y or Star side) of three-phase transformers
- Now, supply voltage is gradually increase, by variac, from zero to rated voltage (415volt).
- If supply voltage reach to rated value then reading of all instruments are recorded.

The reading of an ammeter is known as the no-load current, which is very small. So, the copper loss is so small that it can be neglected. Hence, the wattmeter readings give the core losses of the transformer. Total core loss is the sum of three wattmeter's readings. After getting wattmeter, voltmeter, and ammeter readings, we may need to adjust the supply voltage as well as the output power as per the below-mentioned procedure.

- **Procedure 1 (test-01): When the frequency is less (49 Hz) than the standard frequency of 50 Hz,**

If the supply voltage is 415 volts and the frequency is 49 Hz, the supply voltage must be multiplied by 50/49 = 1.02 times. As a result, the final supply voltage must be 415 x 1.02 = 423 volts.

Similarly, output power means no load loss and shall be multiplied by (50/49) + (50/49) * (50/49)/2 = 1.03.

Because the total "no load loss" of three phases in our first test for a 2000 kVA transformer was 1760 watts, the final "no load loss" must be 2760 x 1.03 = 1812.80 watts.

- **Procedure 2 (Test 02): When the frequency is higher (51 Hz) than the standard frequency of 50 Hz,**

If the supply voltage is 415 volts and the frequency is 51 Hz, the supply voltage must be reduced by 50/51 = 0.98 times. As a result, the final supply voltage must be 415 times 0.98, or 406 volts.

Similarly, output power means no load loss and shall be multiplied by (50/51) + (50/51) * (50/51)/2 = 0.97.

The total "No load loss" of three phases in our second test for a 2000 kVA transformer was 1990 watts, so the final "No load loss" shall be 1992 x 0.97 = 1932.24 watts.

- **Procedure 3 (Test 3): When the frequency is equal to the standard frequency of 50 Hz,**

If the supply voltage is 415 volts and the frequency is 50 Hz, then the supply voltage shall not be multiplied by any factor. Because the testing condition is similar to the standard condition, no factor must be applied to the output power. In our third test for a 2000 kVA transformer, the total "No load loss" of three phases was 1870 watts, so the final "No load loss" shall be 1870 watts.

- **Comments on the result:** After adjustment of lower and higher frequency impacts, "no load loss" of a three-phase, 2000 kVA transformer is almost similar for all the test conditions.

- **Expected result:** "No load loss" of 2000kVA transformer shall be around 1500wattas per IEC. So, our test result can be accepted.

G. Full Load test (short circuit test) of Transformer:

- **Introduction:** Transformer's "full load test" is also known as a "short circuit test," as one side (the LV side) of the transformer is short circuited. Now, if we apply any voltage to the HV side, then current will flow through the HV windings. This current is known as the "full load current" of a transformer. So, the copper loss due to this "full load current" is very large, and hence the input power is almost similar to the copper loss of the transformer. This copper loss of the transformer is referred to as the "full load loss" of the transformer.

- **Description:** When measuring a transformer's full-load loss and current, one of the windings (often the LV winding) is kept short while the other (the HV windings) is powered at the specified voltage and frequency. The input voltage is increased from zero until the ammeter in the HV windings indicates normal full-load primary current. When this occurs, the normal full-load secondary current is circulating in the secondary winding. Because the secondary terminals are short-circuited, the input voltage required to produce full-load primary and secondary currents is around 3% to 10% of the normal input voltage level. With such a low input voltage level, the core losses are so small that they can be neglected. However, the windings are carrying normal full-load current, and so the input is supplying the normal full-load copper losses.

  Due to these two factors, the short-circuit test is always conducted on the HV side.

  - Rated current must flow through the windings during short circuit testing, and the rated current of the HV side is less than the rated current of the LV side.As a result, achieving the rated current on the HV side is easier than on the LV side.
  - If we short the HV windings and supply a voltage to the LV side, then the current flow through the HV side is very high (because the VA rating is constant) compared to the LV side, causing the transformer to burn.

➢ **Procedure of "Full load loss" Test:**

- Disconnect all HV and LV terminals from incoming and outgoing feeder
- Disconnect the neutral of Transformer from the grounding/Earthing
- LV side windings is short circuited as shown in figure # 02
- Connect watt meter (W), voltmeter (V) and ammeter (A) as shown in figure # 02
- Now voltage is applied to HV side (delta) and gradually increase, by variac, from zero to until the ammeter reading reach to rated value.
- If ammeter reading reach at rated current value then reading of all instruments are recorded.

In comparison to the rated voltage, the voltage applied for full load current is very low. So, the core loss is so small that it can be neglected. Thus, the wattmeter reading can be taken as the copper loss of the transformer. Total copper loss is the sum of two wattmeter's readings.

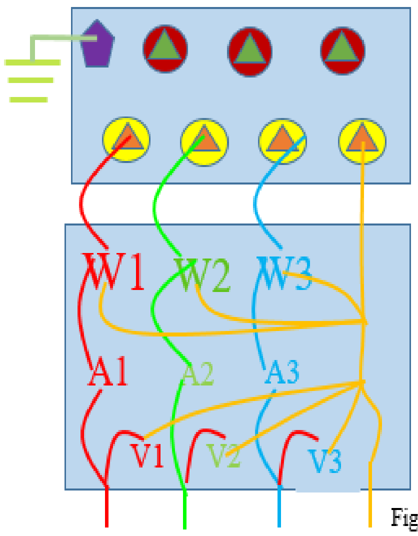
Outcome of test: Total full load loss of a 2000 kVA transformer is the sum of two wattmeter readings, which is around 14546 watts, so the overall loss of the transformer is the sum of "no load loss" and total full load loss. Therefore, the total loss of a 2000 kVA transformer is around 16416 watts.

Now, we need to adjust this value to standard temperature of 75°C.

Formula for temperature correction: R ref = R test x (T ref + C const) / (T test + C const)

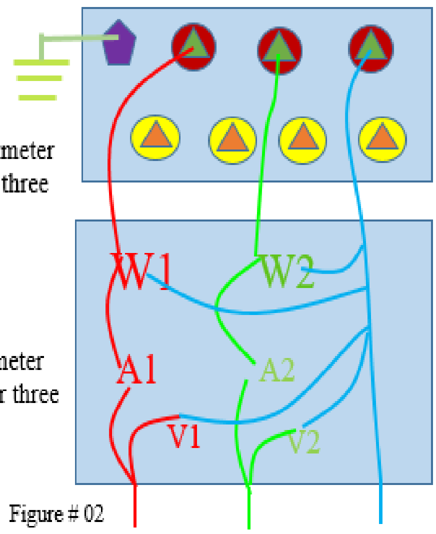
R ref. = Resistance of windings at Standard temperature of 75°C
R test = Resistance of windings at testing temperature of 30°C
T ref. = Standard temperature which is 75°C
T test = Temperature at the time of testing
C const = Constant, which is 234.5°C for copper and 225°C for aluminium

So the final value of total loss is: 16416 x (75 + 234.5) / (30 + 234.5) = 16416 x 309.5 / 264.5 = 19208.89 watts, which is very close to the IEC reference value of 18000 watts (maximum). IEC TS 60076-20:2017 IEC 2017 (table 04).



Typical Connection diagram of three wattmeter method for "No load loss" (Fig # 01), for three phase transformer

Figure # 01



Typical Connection diagram of two wattmeter method for "Full load loss" (Fig # 02), for three phase transformer

Figure # 02

III. CONCLUSION

One of the most important components of electrical power systems is a transformer, especially a three-phase transformer. If a transformer fails, then the whole transmission and distribution network will go offline. If there is any issue with an oil leak or fire, this will be dangerous to people's safety and the environment. As a result, before the transformer is installed, some cost-effective and dependable testing activities must be carried out to ensure its health. This will increase the operating life of a transformer as well. Routine tests must be performed every year after installation to ensure the transformer's health.

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