A Review about Testing of Distribution Transformers

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Abstract

Testing of any electrical equipment indicates the extent to which the equipment is able to comply with a customer's requirements. In this paper testing of distribution transformer is considered. Manufacturers test thousands of distribution transformers at worldwide locations each week. The primary incentive is to make sure the transformers meet manufacturing specifications .Tests are part of a manufacturer's internal quality assurance program .A manufacture's own criteria have to be fulfilled in addition to requirements specified by customers and applicable standards. Differing requirements are generally combined and published in national and international standards. The primary standards organizations are IEC and ANSI. The advancements in double voltage and double frequency testing is done by replacing the bulky and noisy motor generator set with power electronics based frequency generator set, is also discussed. In this paper, I wish to give an overview about the different routine tests conducted in distribution transformers of rating up to 2500KVA and 36KV class.

Keywords: Power electronics, Generator, Distribution Transformer, IEC, ANSI

1. Introduction

In the recent development of the power systems, increase in the power plant capacity has been a major achievement in the power industry. This power is transmitted at a voltage which is much higher than the generated voltage as the power loss at high voltage and low current is lesser than that at low voltage and high current. Hence, it is necessary to step up the voltage level of the generated voltage to a much higher value for transmission purposes in order to avoid extensive power loss. For this purpose, power transformers are widely used in the industry. The purpose of a distribution transformer is to reduce the primary voltage of the electric distribution system to the utilization voltage serving the customer. A distribution transformer is a static device constructed with two or more windings used to transfer alternating current electric power by electromagnetic induction from one circuit to another at the same frequency but with different values of voltage and current. The different tests conducted in a distribution transformer as per the standards are discussed below. The IEC and IEEE standard distinguishes between the following types of tests.

1. Routine tests
2. Type or Design tests
3. Special or Other tests

Routine test are the mandatory tests to be carried out on each individual transformer. Type test are conducted on a transformer which is a representative of other transformers, to demonstrate that these transformers comply with specified requirements not covered by routine tests. Special tests are tests other than type or routine tests agreed to by the manufacturer and the purchaser.

Fig 1: Distribution Transformer

2. The Sequence of the Tests

While there is no specific sequence specified in the standards for performance of these tests, the following sequence is considered healthy for the transformers.

1. Measurement of voltage ratio and check of voltage vector relationship
2. Measurement of winding resistance
3. Applied high voltage tests
4. Induced over-potential tests
5. Measurement of no-load loss and magnetising currents
6. Measurement of impedance voltage (principal tapping), short-circuit impedance and load loss
7. Measurement of insulation resistance (also called the Megger test)

2.1 Measurement of Voltage Ratio and Check of Voltage Vector Relationship

2.1.1 General

This is an important customer specified parameter defining the transformer. As part of the same check, the vector connection is also verified, which is yet another important customer specified parameter.

2.1.2 Purpose

The purpose of the measurement is to ensure that the turns ratio, matches the values as calculated based on the voltage ratio. To ensure that there are no short-circuited turns in the transformer · To ensure whether the vector connection matches specified vector connection ·

2.1.3 Method

Device used for measurement of turns ratio is called "ratio meter”. This is a direct indicating instrument. The high voltage winding of the transformer under test and the high voltage terminals of the ratio meter are connected to a low voltage single phase source. The induced voltage on the low voltage side of the transformer is connected to the low voltage terminals of the ratio meter. Care must be taken to connect correct polarity terminals. The instrument can either directly display the ratio or the ratio can be read off using the indicators on the dials. In the latter case, it will be necessary to balance the ratio meter for the correct ratio using dial switches. Balance, in such cases, is indicated by a null detector. The polarities of the windings determine as to how the windings are interconnected for a given vector connection. Hence, ratio measurement is possible only if the interconnection of windings is correct. Hence there is no need to separately verify the vector connection, when using a ratio-meter.

2.1.4 Equipment Needed

a. Transformer ratio meter accuracy 0.10 % (**or)**
b. Digital voltmeters range 0 to 500 volts for primary side with an accuracy of 1 %
c. Digital voltmeters 0 - 5 - 10- 25- 50 - 100 - 150 - 250 - 400 - 500 volts for secondary side with an accuracy 1 % in all the ranges.

2.1.5 Alternate method of Measuring Ratio with Voltmeters

If voltmeters are used for measurement of ratio (Measurement of applied and transformed voltages) then it is preferable to measure phase by phase voltage. Apply approximately 400 V, 3 phase volts to primary winding. Measure the primary voltages across lines; at the same time, measure the secondary voltages across lines (and also across line and neutral if secondary is in star). The primary line voltages divided by secondary line voltages give the voltage ratio.

2.1.6 Permitted Tolerances

As per IEC and ANSI standards the permitted tolerances are +/- 0.50% of the declared no load voltage ratio or 10% of the impedance, whichever is lower.

2.1.7 Check for Vector Connection

The vector connection forms one of the most important parameters from user's perspective. Hence it is very essential to verify that the inter-winding connections (and clock number) are indeed as per customers' requirements. The ratio meter used for measuring no-load voltage ratio functions only when primary and secondary winding polarities are identical for the connection made. Hence establishment of the polarity of individual windings is a comparatively easy task. For multi-winding transformers, two definite reference points are physically connected so that definite phase relationships of some specific type based on the connection made are established for application of 3 phase voltages (for autotransformers, such a connection already exists, one winding is a tapping from the other).Recourse is usually taken to practically prove the vector connection by applying a low magnitude (normally about 400 volts) 3 phase AC voltage to the high voltage winding of such an arrangement and measuring all the possible voltages.

Example:

We consider the case of a Dyn 11 transformer.

The polarity references phase by phase are:

UV - un ; VW - vn ; WU - wn.

We connect "U" phase of high voltage winding to "u"phase of low voltage winding. We apply - 400 volts, 3 phase voltage at 50 Hz (our supply frequency) to the high voltage delta side. We measure the all possible voltages.

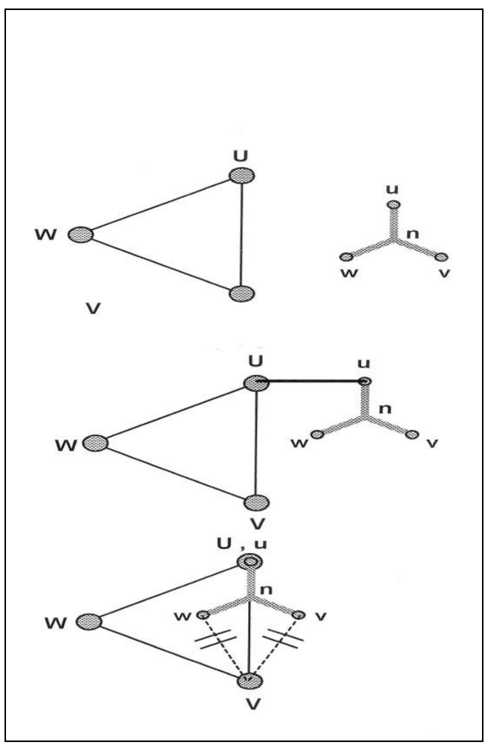

Fig 2.: Vector Group Connections

For connection Dyn 11 ,the following conditions must be satisfied:

Vv=Vw

Wv>Ww

Un + Vn = UV

Wn > Vn

Such a superposition is possible for all types of connections. A voltmeter with a high input impedance has to be used for such measurements (Eg., digital meters)

2.2 Measurement of winding resistance

2.2.1 Purpose

The purpose of the measurement is to ensure that the measured values are indeed the actual values of resistance of the windings and not influenced by loose connections in bus-bars, switch connections, switch contacts and joints made in winding during winding process.

2.2.2 Method

The resistance is measured by using a bridge network (Kelvin double bridge or equivalent) by injecting direct current through the windings. Alternatively, the values of the direct current injected (using high accuracy shunts) and the resulting drop across the winding (using high accuracy mill voltmeters) is measured and from these values, the resistance is calculated. The temperature of the object (transformer) is a very important parameter affecting the values of the measured resistance. This also needs to be recorded along with the resistance values.

2.2.3 Equipment Needed

Kelvin double bridge working on AC mains, range 10 micro-ohms to 500 ohms with built in power supply and transistorised rugged null detector or Stabilised source of DC supply (perhaps a DC power pack or a constant DC current generator or a 12 volts DC battery) Adjustable resistance for controlling the applied DC voltage, Shunts for DC current measurement (10 amperes - 100 mV, 5 amperes - 100 mV, 1 ampere - 100 Mv, 0.50 amperes - 100 mV) accuracy 1 %, DC digital milli-voltmeter 0 to 200 mv accuracy 1 %, DC digital voltmeter 50 mv to 50 volts accuracy 1 %.

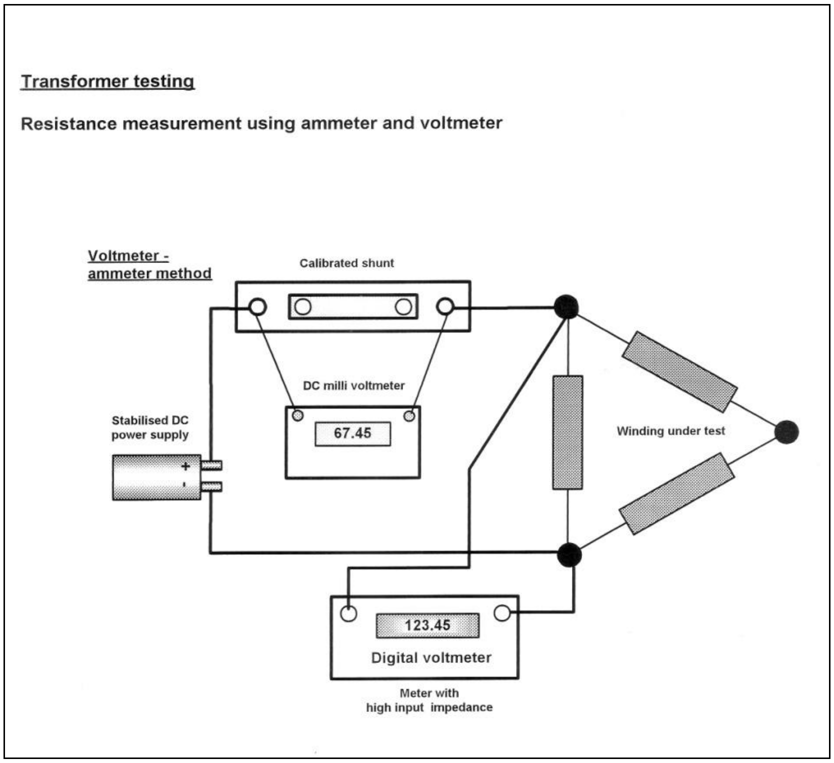

Fig 3.: Resistance Measurement using Voltmeter and Ammeter

2.2.4 Permitted Tolerances

There are no specified tolerances as per the standards

2.3 Applied high voltage tests

2.3.1 General

This test generally is carried at the same frequency at which the equipment is supposed to operate during its life time. This is a single phase test. The power is supplied by a single phase transformer whose line end is connected to the object under test and the neutral of the test transformer is solidly grounded.

2.3.2 Purpose

The purpose is to ensure the electrical healthiness and suitability of the product for the intended voltage application by testing the product with application of test over-voltages as prescribed by the standards. This test verifies the physical clearances between one winding to the other winding in the same phase, Windings to core at top and bottom (end-clearances) , Outer winding to tank sides, Inner winding to core , Bushings to ground, Switch contacts, connections and tapping leads to ground , Air clearances, Bushings of one winding to bushings of the other windings.

2.3.3 Equipment needed

The current drawn is purely capacitive. The source should be capable of feeding the capacitance currents generated by combination of capacitances of the windings of the transformer being tested, at the system frequency (50 Hz).On the object side, all the phases including neutral, if any, of the winding to be tested are connected to the source. All the other available terminals of the other windings not under test are connected to earth. Tank and hence core is also connected to earth. The equipments needed are separate source transformer 8 to 10 KVA, 75000 volts HV /433 volts LV, single phase 50 Hz, Control gear incorporating trip circuit, consisting of voltage regulator 433 /0 to 433 volts, 20 amperes, single phase, 50 Hz , voltmeter 0 to 433 volts calibrated as 0 to 75000 volts (preferably digital or moving coil instrument) , input ammeter 0 to 20 amperes and output ammeter 0 to 250 milliamps. The test shall be commenced with a voltage not greater than one-third of the test value, which shall be increased to the specified value as rapidly as is consistent with its magnitude being indicated by the measuring instrument. Similarly, at the end of the test, voltage shall be reduced rapidly to less than one third of its full value before switching off. The test duration is 60 seconds. The test voltage depends upon the impulse level (or equipment highest voltage).Typical values are given in the standards.

2.3.4 Typical failures

Typical failures are due to creepage, tracking on insulating materials and flash over in oil.

2.3.5 Test voltages

The test voltage depends upon the impulse level (or equipment highest voltage).

Typical values as per the standards are given below:

Table 1: Test Voltages

Equipment Highest Voltage KVrms	Impulse Level KVp	Power Frequency Voltage KVrms
≤ 1.1	-------	3
3.6	20 or 40	10
7.2	40 or 60	20
12	60 or 75	28
17.5	75 or 95	38
24	95 or 125	50
36	145 or 170	70

2.4 Induced Over-Potential Tests

2.4.1 General

This test is carried out at a frequency which is at least 2 times the frequency at which the equipment is supposed to operate during its life time. With one application, all windings are tested as all windings get the voltages by induction. This is a poly-phase test for 3 phase transformers and single phase test for single phase transformers.

2.4.2 Purpose

This test verifies the inter-turn insulation (insulation between adjacent turns in the form of enamel on copper, paper covering and interlayer insulation in case of foil winding) ,the interlayer insulation (paper layers between adjacent layers) ,Clearances between phases of outside winding on the active-part (inter-phase · clearances) , external clearances between bushings of same phase and to bushings of other windings.

2.4.3 Equipment needed

A 100 Hz generator set comprising of a Prime mover induction motor 433 volts, 3 phase, 50 Hz and 10 Kwatts , Separately excited generator, 50 Kva, 3 phase, 100 Hz , with control of output from near 0 to 1000 volts , Control gear for above incorporating trip circuit , 3 digital voltmeters (or analog), range 0 to 1000 volts AC , 3 digital ammeters (or analog) 0 to 20 amperes AC.

Fig 4.: Induced Over Potential Test Control Panel

The source should be capable of feeding the no-load loss at the increased frequency of the transformer under test (and also of the intermediate transformer, if any) at a low power factor. The frequency should be at least twice nominal frequency. The current requirement is a combination of magnetizing currents at the higher frequency and the charging currents, which increase due to increase in frequency. The current drawn depends on many factors including the amount of insulation, voltage class, frequency, flux-density, rating of the transformer (size of core) etc. The output of the high frequency generator is connected to one winding of the transformer under test. It may be necessary to use intermediate transformers and potential transformers of suitable ratio depending upon the test voltage. All the other windings are kept open. Tank and hence core is tied down to earth potential. The test duration in seconds is given by (6000 / test frequency in Hz).

2.4.4 Advancement Done

The motor-generator sets need large starters and breakers for operation and time to spin up or spin down. An induced motor-generator set is also prone to self-excitation. The self-excitation phenomenon can cause an overvoltage in the generator and transformer under test. In high voltage systems, conventional method of generating a wave with a frequency over 50 Hz that has high power is interconnecting a motor and a generator with nominal frequency over 50 Hz, like 100 Hz or 150 Hz; but for routine test of distribution transformers, it is not economical to construct a experimental setup with a motor and generator. Nowadays with power electronics instruments some cheap solutions are available, like power frequency inverters. Nowadays static frequency inverters are state of the art for nearly all drive applications. High dynamic inverters advance in the area of middle and high power.

2.4.5 Typical failures

Typical failures are due to breakdown of inter turn insulation or interlayer insulation. This test can also cause creepage, tracking on insulating materials and flash over in oil.

2.5 Measurement of No-load Loss and Magnetising Currents

2.5.1 General

This is one of the more important parameters either specified by customer or guaranteed by the organization. There is a definite need to establish that the actual tested figures are indeed within the specified tolerances. This is an important parameter, which if exceeded results in quite high penalties and even in rejection of the unit.

2.5.2 Purpose

The purpose is to carry out the measurement of no-load loss of the transformer at specified no-load conditions and establish that the measured no-load loss conforms to the designed and guaranteed figures within the specified tolerances. The average magnetizing current of the transformer, which may form of part of guaranteed parameters in special cases

2.5.3 Equipment Needed

The method consists of applying the specified no-load voltage at the principal tapping or the appropriate voltage at the specified tapping, if the test is performed at another tapping, with all other windings on open-circuit. Any open delta winding shall have the delta closed.

Fig 5 : No Load Loss Control Panel

The test shall be commenced with a voltage not greater than one-third of the test value, which shall be increased to the specified value as rapidly as is consistent with its magnitude being indicated by the measuring instrument. Similarly, at the end of the test, voltage shall be reduced rapidly to less than one third of its full value before switching off. The equipments required are : Power analyser or 3 ammeters (0.5% accuracy range 0 to 5 amperes) , 3 voltmeters with extension range (0.5% accuracy, range 0 - 75 - 150 - 300 - 450 - 600 volts), 3 dynamometers watt meters (pf 0.20 lag, 0 to 5 amperes, 0 - 75 - 150 - 300 - 450 - 600 volts) , Voltage regulator 433/0 to 480 volts , 40 amperes, Current transformers 0.5 - 1 - 2 - 2.5 - 5 - 10 - 15 - 20 - 25 - 40 - 50 amperes primary /5 amps secondary, Accuracy class 0.20 %.

2.6 Measurement of Load Loss and Short-Circuit Impedance

2.6.1 General

The load loss and impedance are two of the more important parameters either specified by customer or guaranteed by the organization. There is a definite need to establish that the actual tested figures (derived figures) are indeed within the specified tolerances. This is important parameters, which if out of tolerance may result in quite high penalties, de-rating and even in rejection of the unit.

2.6.2 Purpose

The purpose is to carry out the measurement of load loss and impedance of the transformer at specified load conditions and establish that the derived load loss and impedance figures conform to the designed and guaranteed figures within the specified tolerances. The goals achieved at the end of the test are, the impedance voltage corresponding to the applied currents at the temperature of measurement · The total load loss at the temperature of measurement.

2.6.3 Equipment needed

The test applies to pair of windings. For a selected pair of windings , the method consists of supplying one of the windings with a current not less than 50 % of the rated current of the winding (or appropriate current corresponding to the selected tapping) with the other winding short-circuited. Any other windings, if existing shall be left on open-circuit. The short-circuiting bar or arrangement shall be such that it does not create significant additional losses (more than 1 % to 1. 50 % is considered significant). The equipments required, is the same as that of the no load loss measurement equipments.

2.6.4 Permitted Tolerances

As per the standards, the tolerances are as under

- No Load Loss -- +15% of guaranteed values
- Load Loss at 75°C -- +15% of guaranteed values
- Total Losses -- +10% of (sum of no load losses and load losses)

2.7 Measurement of insulation resistance

2.7.1 General

Insulation resistance is the ratio of the applied voltage to the resulting current at some specified time after the voltage is applied. Direct, rather than alternating voltages are used for measuring IR value. The principal currents affecting insulation resistance after a specified time (1 minute or 10 minutes) are , Leakage current over the surface of bushing terminations · Conduction through insulation material ,Absorption currents in the insulation. The first two are essentially steady with time, but the last current decays approximately exponentially from an initial high value. The measurements are affected by the degree of cleanliness of the bushing surfaces, temperature of the measurement and the moisture within the insulating material.

2.7.2 Purpose

The purpose of the measurement is to ensure that the Processing (drying of active-part and oil filling under vacuum) is satisfactory · There are no physical connections between different windings and also between windings and ground (tank body or core)

2.7.3 Equipment needed

Device used is called megger, a DC voltage generator with display for direct indication of insulation resistance values. The test is carried out by applying direct current voltage of compatible magnitude (about 2500 volts for systems up to 36 Kv). To each of the windings (with all terminals connected together) to all other windings (terminals connected together) and to earth (tank).

Fig 6: Megger Test

Between one of the windings (with all terminals connected together) to the other windings (terminals connected together) with tank connected to ground. Generally the readings are recorded at the end of one minute (or 10 minutes) after application of voltage. It is also common practice to record readings at the end of 10 seconds (or 60 seconds) and at the end of 60 seconds (or 600 seconds). The ratio of reading at the end of 60 seconds to reading at the end of 10 seconds (or 600 seconds to reading at the end of 60 seconds) is referred to as " Polarization index" If this value is less than 1.5, it may indicate that the processing may not have been good.

3. Conclusion

In this paper, I have discussed in detail about the various routine tests which each individual transformer has to undergo, along with the purpose of the tests and the various electrical equipments required conducting the test. This paper did evolve with my practical and theoretical experiences gained during my days in Transformer manufacturing, MNC companies.

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