**Testing of Transformers and Its Significance**

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1. **Introduction:**

 The testing of transformers is aimed at determining their suitability for the

application. The standards, such as ANSI, IEEE, NEMA, etc., give the details of these tests. The objective of this article is to review some of these tests, explaining their purpose and importance with regard to the design, manufacture, and operation of the transformers, without being too technical. Those interested in more technical details are urged to consult standards such as IEEE C 57.12.00, C 57.12.01, C 57.12.90, C 57.12.91, NEMA TR1, etc.

The tests are classified as either "Routine", “Design”, or "Other" tests (previously known as “type” tests). For more detailed explanation, please see C57.12.00.

 The routine tests are considered a minimum requirement and need to be conducted on each and every unit manufactured. The other tests are performed either to prove a design and/or only when specified by the user and usually conducted on one unit of a series.

**1.1. Routine Tests :**

The following tests are routine tests for both dry type and liquid filled transformers :--:

(1) Ratio

(2) Polarity and Vector relation

(3) Excitation Current

(4) No Load Loss

(5) Resistance measurement

(6) Load Loss measurement

(7) Impedance

(8) Dielectric Tests: (a) applied potential test

(b) induced potential test.

 In addition, for certain dry type transformers Partial Discharge test is a routine test. Similarly, Impulse test is a routine test for class II liquid filled transformers.

**1.2 Design & Other Tests**

(1) Impulse Test

(2) Temperature Rise Test

(3) Sound Measurement

(4) Partial Discharge

(5) Insulation Power Factor

(6) Insulation Resistance

We shall now discuss each of these tests.

**2.1 Ratio Test:**

This test verifies that the transformer windings have the correct number of turns so as to produce in them the required voltages. This test is carried out by using a "ratio meter", which applies an AC voltage to the primary windings and measures the voltage induced in the secondary windings and determines the ratio between these two voltages. Since the voltages induced are proportional to the number of turns, this ratio is the same as the turns ratio.

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).

 For a three phase transformer, this test is done for all three phases. For a non-LTC transformer, this test is carried out on all tap positions of the de-energized tapchanger (DETC). For an LTC transformer, ratio test is done at all tap positions of the LTC, with DETC kept at nominal position.

**2.2 Polarity and Vector Relation:**

This test verifies if the internal connections between different phases (both HV and LV) have been done correctly. Vector relation is one of the important factors in determining suitability for parallel operation between two transformers.

The standards require the polarity of single-phase transformers to be either subtractive or additive, depending on its KVA and HV voltage class. Most large size transformers shall have subtractive polarity.

Polarity in a three-phase transformer is the same as in the single-phase transformers. However, depending on the vector relationship to be obtained between the primary and secondary windings, proper connection has to be made between the various phases. For example, the three phases of the primary winding may be conducted in a Delta configuration, whereas the three phases of the secondary windings may be connected in a Wye configuration. By proper connection, it is possible to obtain different vector relation (such as Dyl or Dyll). **Dyl** indicates the vector of the Wye-connected LV winding **lags** Delta-connected HV winding by 30 degrees.). **Dyll** indicates the vector of the Wye-connected LV winding **leads** Delta-connected HV winding by 30 degrees. Dyl is the most common vector relationship.

**2.3 Exciting Current**

Exciting current test is a means of verifying that the core design and manufacture

is satisfactory. This test and the no-load loss test (see below) are done at the same time (using the same circuit) by feeding one of the windings (either HV or LV) with the rated voltage and frequency.

The excitation current is only a few percent of the rated full load current. For

smaller size transformers this percentage is higher, whereas for a larger transformer (and

transformers with low no-load losses) this percentage is quite low (less than one percent).

**2.4 No-Load Loss**

The no-load loss is also known as core-loss. Core loss is generated in the

transformer core when the rated voltage is applied to the transformer and the rated flux

density is induced in the core. The core loss is the total of the hysteresis losses and the eddy-current losses in the core material. As the name suggests, there is no load on the secondary terminals of the transformer during this test (which is achieved by keeping the secondary terminals open circuited). The core loss occurs continuously in the transformer even if the secondary does not deliver any load.

No-load loss is measured by wattmeters. Sometimes, current transformers and

potential transformers are used in conjunction with wattmeters to cover the range of

voltages and currents involved in the test. Ideally this test should be done with a sinusoidal voltage wave. If the voltage is not sinusoidal, correction factor may be applied. If the test is carried out at a frequency other than the rated frequency, correction factor needs to be applied per the standards.

**2.5 Resistance Measurement:**

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 I2 R, which is 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 0C for 65 0C rise units. For dry type transformers the typical rises are 800C, 115 0C and 150 0C.

**2.7 Load Loss and Impedance Measurement:**

 Load losses are those losses that are incident to carrying the load current. The load loss is comprised of I2 R losses occurring in the windings and the eddy and stray losses occurring in the windings, as well as in the tank and other metallic structures.

The Load Loss and Impedance are generally measured by short circuit method. The secondary of the transformer is shorted and sufficient voltage is applied to the primary terminals to circulate rated current in the windings.

**(a) Load Loss**

The load loss is measured by watt-meter method. The measured losses need to be

corrected to the reference temperature. The two components of the load loss (namely I2 R and the eddy and stray losses) need to be separately corrected to the reference temperature. The I2 R component increases with temperature, and the eddy and stray losses decrease with temperature. These are then combined to obtain the corrected load I2 R loss at the reference temperature.

The load losses are proportional to the square of the load current. In other words,

the load losses are only one-fourth when the load is 50% of the full load.

**(b) Impedance**

Impedance is the short name for Leakage Impedance. Higher impedance would cause the short-circuit currents to be lower in magnitude (and hence less harmful to the transformer) and vice-versa. On the other hand, higher impedance would produce more regulation voltage drop at the secondary terminals, which may be disadvantageous for applications like motor starting. Impedance is also an important parameter for deciding suitability for parallel operation of two transformers, because unequal impedances will result in unequal load sharing.

The impedance voltage is that voltage which is required to circulate the rated

current in the primary winding when the secondary is shorted. Usually this is expressed

as percentage of the rated voltage. For example, it requires only 5.75% of the rated

primary voltage to circulate the full rated current in the windings of a transformer with 5.75% impedance. The impedance comprises of two parts, namely the reactance (the predominant factor) and the resistance. The reactance does not change with temperature, whereas the resistance does. The resistance part is corrected to the reference temperature and added back vectorialy to the reactance.

The impedance is directly related to the KVA and hence should be referred to that particular KVA base.

**2.8 Dielectric Tests:**

Dielectric tests verify the dielectric strength of the insulation by demonstrating its

suitability to withstand the test levels defined in the standards. Dielectric tests are very critical because if the insulation is inadequate, it may lead to failure of the transformer.

There are three dielectric withstand tests that can be performed on a

transformer: (a) applied potential test, (b) induced potential test and (c) Impulse

Test.

 **The Concept of BIL**

 The test levels of a transformer are governed by the BIL (Basic Impulse Level) of the respective windings - for different voltage classes of transformers and the windings (such as HV or LV); whether power transformer or distribution transformer; and whether dry type or liquid filled. BIL is the level at which the lightning impulse test needs to be conducted. The test levels for the other dielectric tests are determined according to their BILs. For example, for a class I transformer of 350 BIL (for HV of 69 kV class), the Hipot level is 140 kV rms for 1 minute.

In the following paragraphs we shall see the purpose of each of these tests.

**(a) Applied Potential Test,**

The purpose of this test is to check the adequacy of the major insulation of the

winding under test to ground and to all other windings. This test is sometimes

referred to as Hipot. For conducting this test, all the terminals of all the three phases of the winding under test (say, HV) are shorted together and brought out as one point: all the terminals of all other windings are tied to a single point and connected to tank and then to ground. The required test voltage (Hipot level corresponding to its BIL) is applied between these two points. Usually this test is done at 60 Hz for the duration of one minute.

 In a similar fashion, the other winding(s) is tested to its own Hipot level.

**(b) Induced Potential test :**

 The purpose of this test is to check the inter-layer insulation, turn-to-turn insulation and section-to-section insulation, etc., within the windings. Since this test is done by inducing the voltage, this test checks all windings simultaneously.

 For fully insulated class I transformers, the induced test voltage is twice the rated voltage. To avoid saturation of the core at twice the rated voltage, the frequency of this test is at least twice the normal frequency, i.e., 120 Hz, or higher.

 For class II transformers, this test is done differently. The PD test is combined during this test for class II transformers. The transformer is first induced to a given level (called enhancement level) for a short duration (typically 1 minute), which is followed by a long duration (one hour) induction during which the PD is measured.

**(3) DESIGN & OTHER TESTS (“TYPE TESTS”)**

**3.1 Impulse Test**

Impulse tests are done to prove the capability of the insulation to withstand the lightning and switching surges. The impulse levels corresponding to the different voltage classes have been established and are known as Basic Impulse Level, or BIL, mentioned earlier. The impulse voltages have special wave shapes that are defined in the standards, and these wave shapes simulate the actual impulses a transformer may experience in service. The two most important wave shapes are full wave and chopped wave.

A full wave impulse represents a voltage wave which reaches its peak value in

1.2 microseconds and decays to half the peak value in 50 microseconds. A chopped wave

represents a traveling wave caused by a disturbances such as a flash over after reaching its crest. The amplitude and the wave shapes of full wave and chopped wave are described in detail in the standards. They are somewhat different for dry types as compared to oil filled transformers.

This test is conducted using an impulse generator which generates the required

wave shapes. Oscillograms of the voltage and the current wave shapes are used to

determine the ability of the transformer to have passed this test.

**3.2 Temperature Rise Test:**

Transformers are designed to meet the temperature rise limits as specified in the

standards. This test verifies that these limits have been met. This test is conducted by

generating the heat corresponding to the full load condition (including core loss) of the transformer, often at the maximum loss position. This is done by short-circuiting one of the windings and circulating sufficient current through the windings to produce the required losses. This test is continued till thermally stable condition is achieved. Then the unit is shut down and the hot resistance measurement is taken. The winding rises are determined from the hot and cold resistances, using the law of variation of resistance with temperature. Transformers with more than one level of cooling (such as ONAN/ ONAF) are sometimes tested consecutively.

For dry type transformers, this test is a two-part test. In the first part only the

winding rises are measured, and in the second part the rises due to the no-load excitation

are measured. These two rises are combined according to the method prescribed in the

standards to obtain the final rises of the winding.

**3.3 Sound level Measurement:**

Purpose of this test is to measure the sound level generated by the transformer when energized. Sound is generated in a transformer core due to 'Magnetostriction' phenomena, which is a very small mechanical vibration of the laminations occurring at frequencies of 120 Hz and higher harmonics.

 This test is performed by energizing the transformer at rated voltage and frequency. The measured value is the average sound level taken around the transformer. The sound level is measured in decibels (dB). The acceptable level of sound is governed by the original NEMA standards, which are more or less adopted by IEEE. Here again, the acceptable limits are different for dry types and liquid filled.

**3.4. Partial Discharge :**

 Partial discharges are minute discharges within the insulation system of a transformer, which do not result in breakdown of the insulation, but cause slow damage to the insulation life.

 In an ideal homogenous insulation, there are no imperfections. But in the real world, all insulation items have micro-porosities (voids) in them. If these voids are not impregnated by oil (or varnish in the case of dry type transformers), the air inside the void will get ionized under the electric field which is created when the transformer is excited electrically (such as induced voltage test). Therefore, it is very important to properly dry out and process the transformer to insure removal of the voids and proper impregnation.

 Another reason for discharges is high stress areas on various conductors, such as sharp edges facing other objects or a ground plane. The remedy to this type of problem is to insure proper clearances and avoiding of sharp edges.

 Apart from reducing the life of the insulation, the discharges also produce radio-frequency voltages, which can interfere with radio communications.

 This test is conducted by creating an elevated level of electrical stress between various parts of the transformer winding and insulation and then measuring the discharge voltages electronically. These discharges are measured either in terms of Radio Influence Voltage (RIV in micro-volts)) or in terms of Charge (Pico-Coulomb pC). Commonly this test is combined with the induced voltage test.

**3.5. Insulation Power Factor :**

 This test helps in determining the condition of the insulation of a transformer. This test treats the insulation as capacitor. Every practical (imperfect) capacitor has some amount of lossy resistive component. Using a capacitance bridge, both the capacitance and the resistive components are measured. The insulation power factor is the loss-angle of the capacitance.

 Mainly there are three Capacitances in a transformer : HV to LV, HV to Ground and LV to Ground. All three Capacitances and their power factors are measured.

 The typical acceptable values for the insulation power factor lie in the range of 0.5% to about 1.0%. The value measured during factory tests serves as benchmark for later field measurements.

 The power factor is also dependent upon the temperature. There are some rules for converting the power factor from one temperature to another.

**3.6. Insulation Resistance (IR) :**

 This test is a simple indicator of dryness of 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. There are some rules for converting the power factor from one temperature to another. The values measured during factory tests serve as a benchmark for later field measurements.

 Here again, there are three main IR : HV to LV, HV to Ground and LV to Ground. All three Insulation Resistances are measured. While measuring IR, all other objects not being measured are grounded. This test is popularly known as Meggar Test.

 In summation, all transformer test procedures are governed by established industry standards, and are designed to determine the reliability and functional performance of the transformer, as well as its suitability for the particular application in which it will be utilized.

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