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Dielectric Failure Analysis of Distribution Transformer

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Abstract

The distribution Transformer acts an important function in the electrical distribution network. Failure of the transformer ends in an outage of power supply to end users. Failure of the distribution transformer usually results in the spare time of some weeks transformer accompanied by commercial misfortunes and the necessity to fix the system at the earliest. The prime reason for the outage of distribution transformers is a short circuit, insulation breakdown, and prolonged overloading. This paper investigates failure analysis of distribution transformers during separate source voltage withstand tests, induced over-voltage withstand tests and short circuit withstand strength tests. In this paper failure cases of three distribution transformers are resolved and the results are analyzed.

Keywords: Distribution Transformer, Testing and Causes of Failure

1. Introduction

Transformers are projected to be extremely reliable parts of the electrical network. It is significant to understand the technical features of the Insulation degradation mechanism and their effects on the service behavior of the transformer. Transformers are complicated products that frequently follow a similar pattern of outage.[1] The transformer does not have a similar life or similar reliability. It states that there are three different stages that a transformer proceeds through in its life. The probabilities of outage are different during each stage, but most assemblies of a lot of component parts reveal these three characteristic stages in their life cycle called infant mortality, useful life, and wear out.

Infant mortality is characterized by a quickly decreasing failure rate. These outages are generally the outcome of recognizable sources such as Errors in manufacture, Acceptance of a feeble lot of raw material, Weaknesses in quality control, and Errors in utilization and application of the product. Some products must be sorted out by overstressing in a scheme of testing or burn-in. Other products are "serviced-in" during the first months of their life by replacing feeble elements under a warranty procedure.

The useful life stage in a product's life stage starts following the rate of the outage has dropped to some essential and stable value for those manufactured goods. During this stage, outages are approximately rare and accidental in the incident. They are the results of limits inbuilt into the design, manufacturing limits, and refining abilities, then misfortunes created by usage or insufficient maintenance. The transformer is appropriately functioned, utilized, and maintained during its useful life; outages will be as occasional as feasible for that design. The only habit to decrease outages further will be to redesign the device. For this reason, it is this stage of the life cycle and, expressly, the breakdown rate along this stage, that is of interest to those attempting to evaluate the dependability of an exact device.

The wear-out stage distinguishes the last part of a device's life stage. Here, the outage rate starts to enhance. Outages are created by embrittlement of metals, wear, ageing of insulation, etc. Reliability enhancement at this cycle demands preventative substitute of these expiry parts before the end result in a destructive outage. Complicated

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occurrences such as shock waves in transformer oil, shakings, and shocks are usually not contemplated in calculation methods.

2. Separate Source Voltage Withstand Test

This test is used to verify the dielectric strength between winding and main insulation to the earth. AC voltage withstands the strength of the line, and their connected windings to the earth, core, neutral terminals, tank, frame, and rest of the windings are confirmed by utilizing this test.

In a transformer bearing significant electrostatic capacitance, the peak value of the test voltage is measured by an appropriate voltage divider or an electrostatic voltmeter. The magnitude of test voltage decides on several factors that contain whether the transformer windings are

(a) Uniformly or non-uniformly insulated.
(b) Air or oil insulated.

The test is fulfilled if no failure in the dielectric of the insulation appears all along the test[2]. Figure 1 shows the circuit schematic for separate source voltage withstands testing the HV windings of a transformer. Figure 1 is drawn according to the separate source voltage withstand test procedure mentioned in IS 2026 part 3 standard.

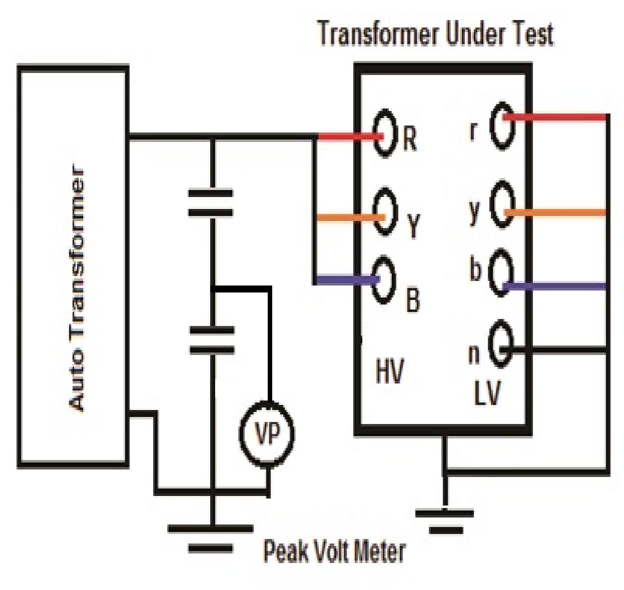

Figure 1. Circuit of separate source voltage withstand the test.

3. Induced over Voltage Withstand Test

This test is used to verify the dielectric strength of the main insulation along the winding and between phases. AC voltage withstands the strength of the line, their connected windings to earth, and the rest of the windings is confirmed by utilizing this test. This test is accomplished by providing the particularized test voltage to the LV windings from an HV testing transformer at a frequency more than the rated value to prevent over fluxing core throughout the test.

The HV windings are maintained open circuit, and the test voltage supplies to the LV windings. The test voltage shall be monitored on the LV side of the transformer during the test, whether directly or utilizing a voltage transformer in the HV winding shall be measured using an acceptable voltage divider. The tests are accomplished with the transformer connected for service. Throughout the test the supply frequency is raised, generally to a minimum of two times the rated frequency.[4] Figure 2 shows the circuit schematic for induced overvoltage withstands testing the LV windings of a transformer. Figure 2 is drawn according to the Induced over-voltage withstand test procedure mentioned in IS 2026 part 3 standard.

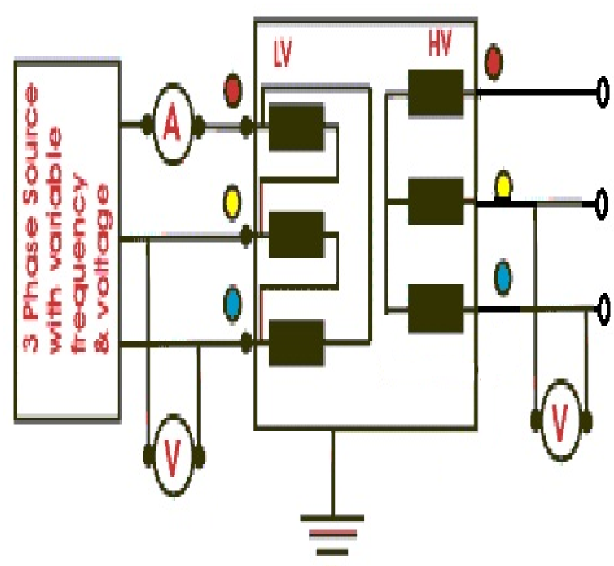

Figure 2. Circuit of induced over-voltage withstand the test.

4. Design Considerations for SC Test

The short circuit current gives rise to mechanical forces that can go up to hundreds of newtons within milliseconds on the transformer. The current peaks and the corresponding forces depend on many factors. In high voltage systems, the most possible type of short circuit is a single line-to-earth flashover, normally due to environmental conditions like a lightning strike on the line, product failure at the station, pollution of insulation strings, and similar reasons. Sometimes, short circuit faults will progress into other more extensive faults, such as single-phase to-earth faults developing into a double phase to earth and ultimately three-phase faults[3]. The relative severity of the different types of faults depends on the features of the system. The severity of a short circuit and the peak current and forces depend to a significant extent on the condition of the installation, and in particular on the short circuit impedance magnitude of the transformer. The fault configuration that normally provides the highest through currents in any winding of the transformer is the symmetrical three-phase fault. Hence, it is meaningful to use this fault mode as a basic design principle for the transformer.

The short circuit currents develop considerable thermal and mechanical stresses in electrical equipment. Electromagnetic forces tend to deform the windings to decrease the magnetic energy density. The generation of an electromagnetic field inside the transformer is therefore intrinsic to the transformer function.

This electromagnetic field will lead to the generation of forces inside the transformer windings specified by the Faradays law of induction and Lenz law[5]. Forces and related withstand are divided into 2 components given below:

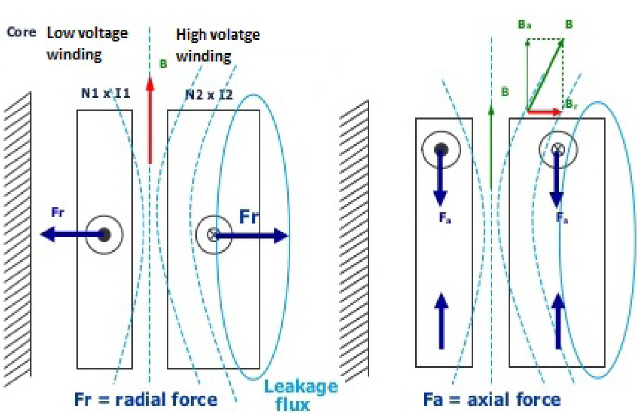

Figure 3. Radial and axial force on transformer[5].

4.1 Radial Forces

For transformers having circular windings, the axial part of leakage flux density interconnects with the winding current, which develops a radial force. Forces performing on the inside windings result in compressive stress whereas on the outer winding, this leads to a tensile stress acting to elongate the winding stress[3]. Forces perpendicular to the winding circumference cause tangential stresses. These forces result in forced buckling, free buckling, and hoop forces.

Failures due to radial forces are:

a. Squeezing of inner winding.
b. Augment in diameter of outer winding.
c. Spiraling of end turns in the circular winding.

Compression of the inner winding issue is avoided by the self-supporting structure of the winding. Spiraling is avoided with the help of helical windings[5]. The spacers are assembled to give essential strength to the winding. The winding dynamic response is also considered. Figure 3 is drawn based on the generation of radial and axial force in the transformer winding and Figure 4 is drawn based on failure cases of the transformer due to Tilting.

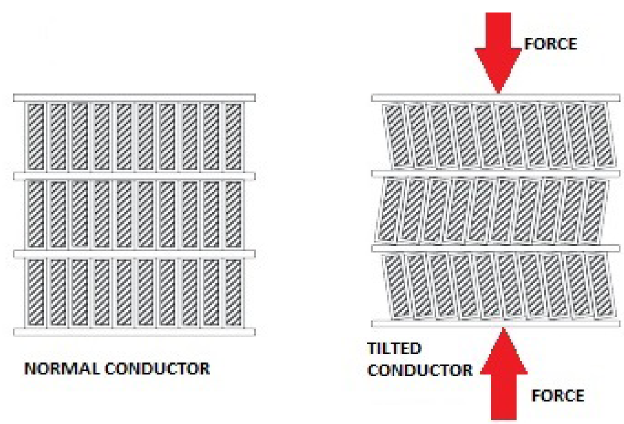

Figure 4. Tilting of the conductors on the transformer[5].

4.2 Axial Forces

The radial flux component interacts with the winding currents and develops an axial force that acts in a way to produce an axial compression or enlargement of the winding coils[5].

The types of failures due to axial forces are:

a. Mechanical collapse of yoke insulation, press plates, press rings, and core clamps.
b. Conductor tilting.
c. Conductor axial bending between spacers.
d. Possible initial dielectric failure inside windings followed by mechanical collapse.

Clamping of the windings provides mechanical strength to the individual conductors to avoid conductor tilting. The force magnitude follows a sinusoidal pattern and therefore compressive tension stored in the winding is released as the force approaches zero. This force will perform against the core yokes and end insulation structure. Still, the most important measure is that all windings need the capability to avoid any displacement between windings. Figure 3 shows the radial and axial force on transformer winding. Figure 4 shows the tilting of the conductors on the transformer.

5. Test Results

The influence of the radial and axial force on the transformer is analyzed here. Some significant cases of separate source voltage withstand test, induced over voltage withstand test and short circuit withstand strength tests performed in CPRI are demonstrated.

Case study 1: Routine Test carried out on 500 kVA, 11/0.433 kV transformer. During a separate source voltage that withstands the test, the leakage current rising from 12mA at 14kV to 89mA at 15kV was noticed. During untanking, it was noticed that insulation was degraded between the body and the live part hence high leakage current was observed on the transformer throughout the test.

Case Study 2: Testing of 200 kVA, 11 kV transformers for dynamic short circuit withstand test. After the forth Shot, Percentage in percentage reactance of the transformer is 0.43%. During the fifth Shot, oil started coming out from a hole formed in the tank and heavy arcing was observed. During the fifth shot, the voltage and current oscillogram distorted after 60 ms as shown in Figure 5. During untanking, it was observed that the winding has deformed and the low voltage winding was touching the tank. High thermal and dielectric stresses evolved during the test cause such failure.

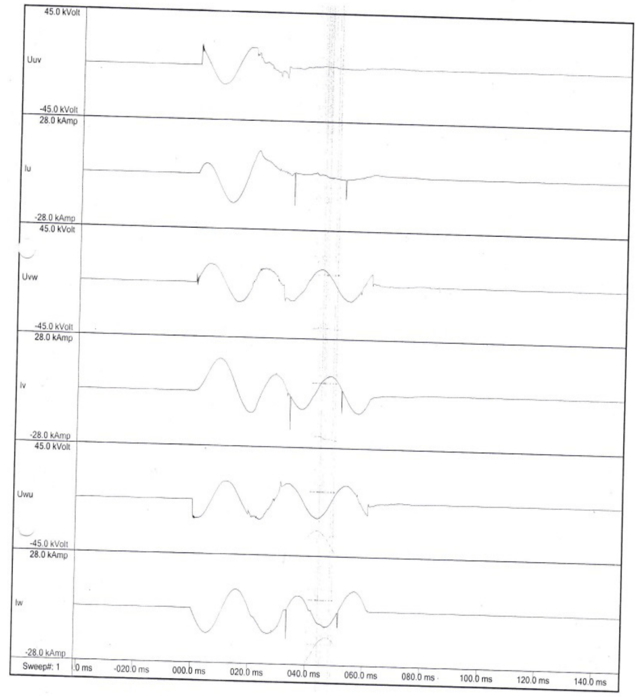

Figure 5. Oscillogram of 200kVA transformer.

Case Study 3: Dynamic short circuit withstand strength carried out on 315 kVA, 11/0.433 kV transformers. No load current was noticed to be 92A at 48V, which was greater than the value stated in the standard throughout post routine test.

No load current was noticed to be 1.8 A at 433V, which was within the value stated in the standard during the pre-routine test. After the ninth shot, the Percentage in percentage reactance of the transformer is 0.81%. During inspection insulation was found damaged. High stress evolved due to short circuit current causes such failure which leads to insulation deterioration and due to this no-load current increases.

6. Conclusions

Routine and Type tests are essential methods to enhance the quality of transformers. The condition of the material used in the production of transformers must be very extreme and its selection must be carefully done as this and magnificent workmanship will be key factors towards high-quality transformers. High-standard transformers' ability to withstand routine and type tests in the electrical distribution network will reduce outages and supply breakdowns.

7. Acknowledgements

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