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Design Of 3-Phase, 1KVA Transformers to Study Effect of Core Deformation

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Abstract— *Now a days it is essential to detect the minor fault of power transformer because these minor faults may develop and lead to major fault and finally irretrievable damage occurs. Sweep frequency response analysis (SFRA) is the method by which we can used for finding out possible reasons for winding displacement or mechanical deterioration inside the transformer, due to large electromechanical forces occurring from the fault current or due to transportation and relocation. Sweep frequency response analysis method is used to evaluate the mechanical integrity of core, winding, clamped structures within power transformers by measuring their electrical transfer function over a wide frequency range. SFRA is proven method for frequency measurement. In this method, the frequency response of a transformer is checked at manufacturing industry and concern site. Both the response is then compared to figure out the fault take place in active part. But in old aged transformer the primary reference response is unavailable. So Cross Correlation Co-efficient (CCF) measurement technique can be a vital process for fault detection in power transformer. These two techniques generally used to identify the core deformation and winding displacement of the transformer.*

This paper briefs about the mechanical core deformation, its causes, how it is harmful to get clear output. Case study on the 1KVA, 3-phase power transformer to evaluate the effects on various parameters. The tests will be performed on both (i.e. healthy and unhealthy) transformer. After calculating the different parameters, the parameters would be evaluated. So the construction of healthy and deformed transformer to analyze the effect of core deformation has been discussed here.

Keywords—*Transformer, core deformation, winding, testing, sweep frequency response analysis.*

I. Introduction

Transformer is one of the most important devices in the grid. For transmission, distribution, step up, step down transformer is used. At normal operating condition of the transformer, its winding suffer from axial as well as radial forces due to the flow of current through the winding. These forces can cause winding deformation in the transformer that may give total discomfort to the operation of the transformer. Distribution transformer is one of the most key elements in the transmission throughout the world. During the short circuit in the power system, active part like core and winding of the transformer experience a strong mechanical movement in the transformer created by electromagnetic forces. There are various types of transformer condition recording measurement in market, but the recording of the mechanical movement in transformer is still lacking. The magnetic core of power transformers is most of the time made of Grain Oriented (GO) steel laminations, which has the best performances in the Rolling Direction (RD). Several studies have shown that this clamping modifies the GO sheet properties such as the permeability or the magnetostrictive behaviour. Magnetostriction phenomenon is one of the causes for core deformation in the transformer. Thus determining the effect of core deformation to avoid major failure of transformer must be taken into consideration. In this paper, a test transformer i.e. 1kVA, 3-phase, 1:1 laboratory fabricated transformer is chosen for the analysis of the performance of transformer due to mechanical deformation.

The transformer core acts as a magnetic path for the flux. The use of highly permeable material (which describes the material‘s ability to carry flux), with better core construction techniques, helps to provide a desired low reluctance flux path and confine flux lines to the core. The core is constructed of numerous thin strips of grain-oriented silicon steel, called laminations, which are electrically isolated (still magnetically coupled), from each other by coatings of thin insulating material. This is significant to reduce the no-load losses in the transformer. The core is a main source to produce heat in the transformer and as a core increases in size, cooling system within the core may become necessary. Problems like short-circuited core laminations results in increased losses and overheating of the core which ultimately results in core deformation.

The core is insulated from the grounded mechanical formation that holds it together and supports it and then intentionally grounded to a single point. Larger transformer cores that have multiple core segments isolated from one another by cooling ducts may implement core jumpers to bond the sections of the core together. The core, which is actually a conductor that is not considered as a current-carrying path, may obtain some potential through a coupling capacitor with the innermost winding when the transformer is energized (resulting in partial discharges that may damage the transformer) and induce potential when transformer carries load unless the core is solidly connected to earth. The core ground also satisfies the protective device operation in the event of a winding to core insulation failure. For such a fault to be recognized by the protective system of the power supply/line (rapidly disconnecting the line), the transformer core must be grounded to provide a (fault) path back to the source.

A core is grounded typically at a single point only, as several core grounds may result in circulating currents and overheating in the core. The magnetic health of a transformer is of paramount importance to a transformer‘s proper operation. Most common problems in core encountered in the field like ground problems, bad core construction, shorted lamination, overheating, etc. The following electrical field tests used in place with our range of transformer test equipment gives information about the integrity of the transformer core.

II. Method To Identify Core Deformation

There are different causes of core deformation and various methods available to detect the core deformation of transformer which are follows.

A. Exciting Current

Detects core problems in transformer including shorted laminations and other problems that affects the reluctance of flux in the core, such as a slightly shifted or open core joint, sensitive to core magnetization.

B. DC insulation resistance

Checks for unintentional core grounds and problems involved are the core ground insulation. Low insulation resistance values between the core and ground can be produced by shifting the core laminations and by conductive contamination or foreign objects that bridge core-to ground insulation

C. Capacitance/power factor/dissipation factor method

Capacitance of the low voltage winding is measured during a power factor/dissipation factor test which is sensitive to the deterioration or complete loss of core ground connection

D. Cross Correlation Method.

Distribution transformers are exposed to thermal and electrical stresses. Those stresses are affecting the main mechanical active parts in transformer such as core and winding. In field, lightning strokes and faults in cable may cause problem due to transformer core and winding. SFRA detection is made which is based on the comparison between two SFRA responses and any significant difference in low, middle or high frequency sub-bands region would potentially indicate mechanical/ electrical problem because to core and windings of transformer. Instead of comparing graphically, using statistical techniques such as Cross-correlation Coefficient Function (CCF), Standard Deviation (SD), and absolute Sum of Logarithmic Error (ASLE) are used to interpret the SFRA results in a proper way. The aim of this paper is to evaluate the condition of distribution transformer by using SFRA method in line with the clarification from statistical techniques. For the analysis of a measured response, the response in compared with one of the following:

- The same phase tested with the same tap changer position.
- If earlier result is not available then another phase of the same transformer, tested at the same occasion.
- The same phase and same tap changer position but on a unit believed to be of the same design group and made at the same factory. It is found that Cross Correlation coefficient (CCF) is the most reliable statistical indicator to take data from comparison method.

E. Sweep Frequency Response Analysis

(SFRA) is a solid method to calculate the mechanical integrity of core, windings and clamping structures of power transformers by measuring their electrical transfer functions over a wide range of frequency. SFRA is a method used for frequency measurements. The SFRA is a relative method i.e., evaluation of the transformer condition is done by comparing an actual set of SFRA results to the reference results. Three methods which are commonly used to assess the measured traces:

- Time-based – current SFRA results will be compared with previous results of the same unit.
- Type-based – SFRA of one transformer will be compared with an equal type of transformer.
- Phase comparison – SFRA results of one phase will be compared with the results of the other phases of the same transformer.

F. Discussion On Natures Of SFRA Plots Of Various Types Of Connection:

The end to end SFRA connection is one of the most frequently used connection in the SFRA test. It has two end-to-end open circuit (secondary winding open-circuited) and end-to-end short circuit (secondary winding short-circuited). The purpose of the end-to-end open circuit connection is particularly to check core health in addition to health of windings.

III. Methodology

We design two transformers with same rating where one is healthy and other is with deformed core. We make the core like deform what actually being while harmonic, assembly structure, vibration or any other activity of transformer. With these two transformers we go for different test independently, like inductance test, resistance test, voltage ratio test, open circuit test and short circuit test. With these all test we get data of this both healthy and core deform transformer and identify the difference of these both transformer results.

A. Design Of Transformer

- A transformer is a device which transfers electrical power between two or more circuits through electromagnetic induction. Electromagnetic induction produces an electromotive force around a conductor which is exposed to time varying magnetic fields. Transformers are used to increase or decrease the AC voltages in electric power applications. A current varying in the primary winding of transformer creates a magnetic flux in varying nature in the transformer core and a varying field impinging on the transformer's secondary winding. This secondary of varying magnetic field induces a varying electromotive force (EMF) or voltage in the secondary winding due to faraday's law of electromagnetic induction. Making use of Faraday's Law (discovered in 1831) in conjunction with high magnetic permeability core properties, transformers are designed so that it can be used to change AC voltages from any voltage level to another efficiently within power networks. Transformers have become crucial for transmission, distribution, and utilization of alternating electrical energy. A wide range of transformer designs is generally preferred in electronic and electric power applications. Transformers range in size from RF transformers less than a cubic centimeter in volume to hundreds of tons interconnecting the power grid.
- Core: core is the very important part of the transformer. Main core consist of different shape of CRGO (cold rolled gross oriented) strips, which shape is like I, E and U shape. They are arranged in such way that make strong core.

Transformers which are used at power or audio frequencies have cores made silicon steel with high permeability. The steel has a permeability many times to that of free space and the core thus greatly serves to reduce the magnetizing current and intern the flux to a path which closely couples the windings. Transformer developers realized that cores constructed from solid iron results in prohibited to eddy current losses, and their designs modified this effect with core bundles of insulated iron wires. Later, designs were constructed the core by stacking layers of thin steel laminations, a principle that has remained in use. Each lamination is insulated by its neighboring thin non-conducting layer of insulation. The universal transformer equation indicates a minimum cross-sectional area for the core to avoid saturation problem. Transformers used at power or audio frequencies have cores made of silicon steel with high permeability. Permeability of steel is many times that of space free region and hence core serves greatly to reduce the magnetizing current and intern the path of flux which closely couples the windings. Effect of laminations encloses eddy currents to highly elliptical paths that enclose little flux, thereby reducing their magnitude. Thinner laminations reduce losses, but are more difficult and expensive for construction. Thin laminations are generally preferred for high-frequency transformers, with some laminations of very thin steel able to operate up to 10 kHz.

- Windings: The conducting material which is used for the windings depends upon the application, but in all the cases, the individual turns must be insulated electrically from each other to assure that the current flows throughout every turn. For small power transformers in which currents are low and the potential difference between adjacent turns is small, the coils are often wound with enameled magnetic wire, such as forever wire.

Rectangular strip of copper conductors are insulated by oil-impregnated paper. Pressboard blocks are generally wound on large power transformers which are operated at high voltages.

B. Calculation and Design

Transformer Design

Output Equation: -It gives the relationship between electrical rating and physical dimensions of the machines. Let

V1 = Primary voltage LV
V2 = Secondary voltage HV
I1 = Primary current
I2 = Secondary current
N1= Primary no of turns
N2= Secondary no of turns
a1 = Sectional area of LV conductors (m^2)

$$= \frac{I_1}{\delta}$$

a2 = Sectional area of HV conductors (m^2)

$$= \frac{I_2}{\delta}$$

δ = Permissible current density (A/m2) Q = Rating in KVA

For 3-phase core type transformer

$$Q = 3 \times V_1 I_1 \times 10^{-3} \text{ kVA}$$

$$= 3 \times (4.44\, f\phi_m N_1) I_1 \times 10^{-3} \text{kVA} \qquad (V_1 = 4.44 f\phi_m N_1)$$

$$= 3 \times (4.44\, f A_i B_m N_1) I_1 \times 10^{-3} \text{kVA} \text{ ---(1)}$$

Window Space Factor

$$K_w = \frac{\text{Actual Cu Section Area of Windings in Window}}{\text{Window Area } (A_w)}$$

$$= \frac{2(a_1 N_1 + a_2 N_2)}{A_w}$$

$$= \frac{2 \times [(I_1/\delta) N_1 + (I_2/\delta) N_2]}{A_w} \qquad (a_1 = I_1/\delta \,\&\, a_2 = I_2/\delta)$$

$$= \frac{2(I_1 N_1 + I_2 N_2)}{\delta A_w}$$

$$= \frac{2 \times 2 I_1 N_1}{\delta A_w} \qquad (\text{For Ideal Transformer } I_1 N_1 = I_2 N_2)$$

So

$$N_1 I_1 = \frac{\delta K_w A_w}{4} \text{ - - - - - - - - - - - - - (2)}$$

Put equation value of N1I1 form equation (2) to equation (1)

$$Q = 3 \times 4.44\ f A_i B_m \frac{\delta K_w A_w}{4} \times 10^{-3} \quad KVA$$

$$Q = 3.33\ f A_i B_m \delta K_w A_w \times 10^{-3} \quad KVA - - - - - (3)$$

ESTIM[redacted]

We kn[redacted]

$$E_t = K_t \sqrt{Q} \quad - - - - - - - - (1)$$

$$E_t = 4.44 f \phi_m$$

Or $$E_t = 4.44\ f A_i B_m \quad - - - - - - - - - - (2)$$

So $$A_i = \frac{E_t}{4.44 f B_m} \quad - - - - - - - - - - (3)$$

d = Di[redacted]

Gross Area $= \frac{d}{\sqrt{2}} \times \frac{d}{\sqrt{2}} = 0.5\ d^2$

Actual Iron Area

$$A_i = K d^2$$ **Or**

$$d = \sqrt{\frac{A_i}{K}}$$

ESTIMATION OF MAIN DIMENSIONS:

We know output equation

$$Q = 3.33 f A_i B_m \delta K_w A_w \times 10^{-3} \quad KVA$$

So, Window area

$$A_w = \frac{Q}{3.33 f A_i B_m \delta K_w \times 10^{-3}} \quad m^2$$

Where, K_w=Window space factor

$$K_w = \frac{8}{30 + Higher KV} \quad for\ upto\ 10\ KVA$$

Width of the window W_w = D-d

Height of the window

$$L = \frac{A_w}{width\ of\ window(W_w)}$$

$$(L \times W_w = A_w)$$

Generally $$\frac{L}{W_w} = 2\ to\ 4$$

[redacted]

loss in[redacted]

windings and so more cost through we are reducing the iron loss in the core. Further length of the winding will Increase resulting higher resistance so more cu loss.

Ay = (1.10 to 1.15) Ai

Depth of yoke	$D_y = a$
Height of the yoke	$h_y = A_y/D_y$
Width of the core	$W = 2*D + d$
Height of the core	$H = L + 2*h_y$
Flux density in yoke	$B_y = \frac{A_i}{A_y} B_m$

Steps for 3 phase 1 KVA transformer design:

A) Steps for determination of main dimensions for Core, Window & Yoke

Step1: Calculation of voltage per turn

$Et = K\sqrt{Q}$ Volts

Step 2:Net cross sectional area of the core Ai

We know,

Et = 4.44 f Φm

= 4.45 f Bm Ai

Step 3: Determination of diameter of circumscribing circle using

$Ai = K d^2$

$$\text{Where } d = \sqrt{\frac{Ai}{K}}$$

Step 4: Width of window

Ww = D-d

Step 5: Calculation of window area

We know that for 3 phase transformer

$$Q = 3.33 f A_i B_m \delta K_w A_w \times 10^{-3} \ KVA$$

$$A_w = \frac{Q}{3.33 f B_m \delta K_w Ai} \times 10^3$$

Step 6: Now we calculate height of the window

$$Hw = \frac{Aw}{Ww}$$

Step7: Obtaining depth & height of the yoke Dy = Hy = a

Now, a is width of largest stamping

Step8: Calculation of overall height & length of 3 phase 1

KVA transformer

H = Hw + 2Hy

W = 2D + a

B) Calculation of ampere turn AT & conductor area

We know that, ampere turn AT $= \frac{KwAw\delta}{2}$

Window space factor Kw $= \frac{Ac}{Aw}$

C. Test to be perform on transformer

- Resistance Measurement
- Inductance Measurements
- Voltage and turn ratio
- Open circuit test
- Short circuit test

D. Transformers

Using the above calculation date we designed two identical 3 phase 1 KVA transformers. Out of which core of one transformer's has been intentionally deformed. The fig.1 shows the final hardware. The transformer on right hand side is the one whose core has been deformed. A provision has been made to vary the stamping of transformer from top side of core. The transformer on left hand side of Fig.1 shows the healthy transformer.

Fig.1 Healthy and deformed 3-Phase, 1KVA transformers

IV. Conclusion

On the basis of all the tests to be performed on these the two transformers; healthy and core deformed, we will discuss its parameters, analyze the difference between the two results and we can easily conclude the parameters that would get affected because of deformation in core.

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