Transformer Winding Deformation Analysis using SFRA Technique

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Abstract

The sweep rate response analysis is widely used technique for establishing veiled fault and circumstance observance of power electrical device. The action is administrated by providing a coffee voltage signal of changeable frequencies to the electrical device windings and measures each the input and output signals. These 2 signals provide the specified response of the magnitude relation is named the transfer operate of the electrical device from that each the magnitude and section may be obtained. Frequency response is modification as deliberate by SFRA techniques might indicate a state change within the electrical device, so causes of fault recognized and examination is needed for root cause analysis.

Keywords: Power Transformer, Sweep Frequency Response Analyzer Double M5100, SFRA, SFRA Traces, Winding Deformation

I. INTRODUCTION

Power transformers are the foremost high-priced and vital part in a very high voltage power system. They’re usually concerned in energy transfer in power transmission and distribution networks, changing ac voltage or current from one level to a different level reckoning on the receiver finish. Throughout its life, it’s subjected to chiefly electrical, mechanical and thermal stresses. The most reason behind the stresses may be as a result of ageing of insulation, throughout transportation, and therefore the most crucial reason may be a tangency event. Throughout tangency, the present within the electrical device winding is gigantic as compared to traditional current. The high magnitude of tangency current has harmful impact on the electrical device and alternative equipment’s related to it.

The interaction of tangency current and therefore the mutual flux (linking each the first and secondary windings of electrical device) offers rise to great amount of magnetic attraction forces that are chargeable for the deformations occurring within the transformer winding. The winding is subjected to chiefly 2 sorts of deformations, axial deformation as a result of the action of axial force and radial deformation as a result of the action of radial forces on that. The deformations within the winding could result in permanent failure of the electrical device, if unknown for long amount of your time. The tangency stand up to capability is drastically reduced as a result of deformation within the winding.

II. SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA)

This method can give the proper information about an indication of core movement and winding deformation. In this method measurement are performed at frequency ranges varied from 20 Hz to 20 MHz. We can easily detect the deformation in winding on discrete frequency ranges.

This method can be done in four steps:
- Measurement in healthy transformer
- Again Measurement in faulty case of sister transformer of similar rating
- Signature curve of both conditions means healthy and faulty compared.
- If any difference between both cases found means fault occurred.
A. Different SFRA Method

We can perform SFRA test in different ways but mostly used methods are discussed as follows.

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

B. Short Circuit Forces

Short circuit events generate large magnitude of current in the transformer winding. The interaction of the current and leakage flux density result in extreme electromagnetic forces to act on the winding. The basic equation for the calculation of electromagnetic forces is

\[ F = I \times B \]  \hspace{1cm} (1)

Where \( B \) is leakage flux density vector, \( I \) is current vector and \( L \) is winding length.

There are basically two categories of short circuit forces involved in the deformation action on the transformer windings, which are axial force defined by expression in (2) and radial force defined by expression given in (3). In Fig. 2 (b), the resolution of forces and leakage flux density in radial and axial direction is shown. The leakage flux density can be resolved into two components, one in the radial direction, \((KL)\) and the other in the axial direction, \((KN)\). The action of radial leakage flux density with the current density \((J)\) results in axial force \((ON)\).

\[ ON = \iint (R \times KL) TL TN \]  \hspace{1cm} (2)

Similarly, the interaction of axial leakage flux density with the current density results in radial force \((OL)\).

\[ OL = \iint (R \times KN) TL TN \]  \hspace{1cm} (3)

C. Radial Forces

The forces generated by the action of axial leakage field and perpendicular to the direction winding height are called the radial forces. The axial field is maximum at the middle part, in the air gap between the two windings. Hence the radial force will be maximum at that portion too. The forces acting on the inner winding produces a compressive stress and that acting on the outer winding produces a tensile stress. Let us consider an outer winding, which is subjected to hoop stresses. The value of the leakage...
field increases from zero at the outside diameter to a maximum at the inside diameter (at the gap between the two windings). The peak value of flux density in the gap is given in value of winding ampere-turns and / is winding height in meters.

\[ B_{gp} = \frac{\sqrt{2} N_{lu}}{H_w} \]  

(4)

The whole winding is in the average value of flux density of half the gap value. The total radial force acting on the winding having a mean diameter of \( D_m \) (in meters) can be calculated as [11]:

\[ F_x = \left[ \frac{1}{2} \frac{\sqrt{2} N_{lu}}{H_w} \right] \times \sqrt{2} Nl \times \pi D_m \]  

(5)

For the outer winding, the conductors close to gap (at the inside diameter) experience higher forces as compared to those near the outside diameter (force reduces linearly from a maximum value at the gap to zero at the outside diameter).

The effects of radial forces are the tensile stress on the winding resulting in forced buckling and free buckling as shown in Fig. 2(a) and (b) respectively.

\[ e_x = \frac{50.8 \times S}{Z_{pu} \times H_w \times F} \]  

(6)

Where S is rated power per limb in KVA, \( H_w \) is winding height in meters, \( Z \) is in per-unit impedance and f is frequency in Hz. The inner winding being closer to the limb, by virtue of higher radial flux, experiences higher compressive force as compared to the outer winding. In the absence of detailed analysis, it can be assumed that 25 to 33% of force is taken by the outer winding, and the remaining 75% to 67% is taken by the inner winding.

The failure modes for axial forces include:

- Forced mode Buckling
- Free mode buckling
- Stretching of outer windings and spiraling of end turns in helical windings

D. Axial Forces

The forces generated by the action of radial leakage field and acts in a direction parallel to the winding height are called as axial forces. The influence of axial forces will be extreme at the winding ends causing maximum bending of the conductors. The forces produce compressive stress on the winding conductors which acts towards the center of the winding. The axial forces are supreme at the ends of the winding as the radial leakage field between the two windings is maximum at the ends. While the axial forces will be minimum at the center as the axial leakage field is maximum between the air gaps of the two windings. For an asymmetry factor of 1.8, the total axial compressive force acting on the inner and outer windings taken together is given by the following expression:

The failure modes for axial forces include:

- Conductor tilting
- Conductor axial bending between spacers
- Displacement of the complete winding
- Axial overlap of conductors
III. MATLAB/SIMULINK

Simulation of sweep frequency response analysis for the detection of fault in transformer has been done by using MATLAB/SIMULINK software 2012. In reference paper PSPICE software has been used for the same but by using MATLAB/SIMULINK software we observed the fine result as compare to the PSPICE software. Sim power system toolbox has been used for the simulation.

IV. RESULT AND ANALYSIS

A. No Fault Condition

In this case 10 winding model of 16 MVA, 33KV/11KV transformer developed. But it is case of no fault condition every turns of winding is similar as per manufacturing design.

\[ R_s = 0.01942 \, \Omega, \]
\[ L_s = 0.3655 \, mH, \]
\[ C_s = 0.914 \, pF, \]
\[ C_g = 0.011 \, nF \]

The following fig.5 shows the transformer model for healthy condition. From this model plot for Normal condition is found which is shown in fig.6 below.

![Transformer model for Normal condition](image)

![Simulated plot of SFRA for case 1](image)

The response shows the conventional condition of electrical device. This response is found once there’s no fault within the electrical device. For wide selection of frequency the equivalent circuit of electrical device winding includes varied inductance, resistance and capacitance components. There are a unit mutual inductive and electrical phenomenon coupling between the winding components, that area unit effectively determinant the SFRA response of winding together with multiple resonance and anti-resonances.

The primary resonance is happening at 414 kHz. On the far side this resonance purpose, inductance of electrical device winding dominates. once initial resonance purpose magnetic result of purpose tries to extend however winding inductance result is screened. This method endlessly repeats many times so radio frequency varies has additional range of resonance points. once radio frequency vary winding inductance result is totally off owing to series and shunt capacitance of windings. this measured from the undulation is found to be 450.1 A. any analysis are often thought of from initial resonance purpose.

B. Inter Turn Fault Condition

This is second case studied for the simulation of same rating transformer for SFRA. In this case fault is artificially created in fourth turn of transformer 10 segment winding.

\[ R_s = 0.01942 \, \Omega, \]
\[ L_s = 0.3655 \, mH, \]
\[ C_s = 0.914 \, pF \] and \[ C_g = 0.011 \, nF \]

![Transformer model for inter turn fault condition](image)

![Simulated SFRA plot for case 2.](image)
Compared to Normal condition 50 A hike is observed. Increased current produces an abnormal heat which will affect transformer insulation and also leads to winding burn out.

C. Turn To Turn Fault

This is third case studied for the simulation of same rating transformer for SFRA. In this case fault is artificially created in between the third and fourth turn of 10 segment winding in transformer.

In this case the electric resistance parameter knowledge taken from the reference paper [2].

\[ R_s=0.01942 \, \Omega, \quad L_s=0.3655 \, \text{mH}, \quad C_s=0.914 \, \text{pF} \quad \text{and} \quad C_g=0.011 \, \text{nF} \]

The plot shown on top provides SFRA behavior for address flip fault condition. From fig. ten we will notice that important undulation displacement occur compared to traditional undulation. Additionally these waveforms area unit compared to show to show fault. The primary resonance purpose is ascertained at 428 kHz. At address flip fault condition the undulation obtained gets fully displaced from one.4417 MHz to 4.3697 MHz. compared to reference set. the present measured at address flip fault condition is 562.7. Once compare to traditional condition the accumulated current is found to be 112.6 A That thermally stress the insulation utilized in electrical device winding. Because of this sudden thermal stress the insulation is degraded. During this case we have a tendency to study the simulation of address flip Fault and got the SFAR plot frequency Vs magnitude signal plot. Scrutiny the on top of plot with plot of traditional condition once more we will observe the modification in resonant frequency and current worth furthermore. Therefore from on top of comparison we will conclude that it's condition of fault.

V. CONCLUSION

The analysis of winding deformation is meted out by considering a benchmark winding that exhibits an analogous high frequency behavior as a electrical device. The winding parameters like series capacitance, ground capacitance, self and coefficient of mutual induction area unit taken from reference for simulation, at healthy condition. Further, the diagnostic methodology used here is sweep frequency response analysis (SFRA) that could be a sensitive and powerful procedure. Victimization the parameters values and applying SFRA, fingerprint graph for the healthy winding is obtained. this can be taken as reference plot for comparison with the unhealthy response appreciate axial and radial deformation. Henceforth, the parameters computed area unit accustomed make SFRA curves for the radial and axial deformation. the proportion of deviation in resonant frequencies, information measure and input current is discovered in tabular type. the placement and kind of deformation will be evaluated by the integrated use of SFRA plots.

REFERENCES


