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Fault detection technique in Transformer by SFRA method

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Abstract:
Power transformer is the most important device for reliable electrical power system. While working with it, many faults may occur. Diagnosis of these faults can be done with different techniques. In this paper we focus on transformer fault detection technique by Sweep Frequency Response Analysis (SFRA). The SFRA is nothing but monitoring the changes occurring in the transformer R-L-C parameters. For costly power equipment SFRA is a proven condition monitoring technique. SFRA measurement is done by using sweep frequency of the range of 20 Hz to 20 MHz applied to transformer in healthy as well as faulty conditions. SFRA gives the results in the form of signature curve in both the cases. Signature differences provide information on the faults.
This paper presents simulation study of transformer equivalent circuit of winding and winding deformation by sweep frequency technique.

Keywords **—power transformer, winding deformation, axial and radial deformation, sweep frequency, signature curve, sweep frequency response analysis**

I. INTRODUCTION

Power transformer is the heart of the electrical power system and it performs a vital role in the area of transmission and distribution [1]. Upon increasing voltage transfer capacity of transformer for transmission, it should have high grade of insulation strength [2]. In general we generate the power at lower voltage rating and then step up it to higher voltage level for transmission by step up transformer. During this action of power transforming, power losses occur.

Number of faults occur in transformers like turn to turn fault, inter turn fault, winding deformation, core deformation, insulation breakdown and short circuit as well. These faults arise due to all day work. Sometimes fault may occur during transportation from manufacturing place to where it has to be installed. During transportation winding and core may deform. Transformer is the complex structure of resistance, capacitance and inductance networks. When mechanical deformation occurs inside the transformer, huge force generated in transformer due to current in it. Due to that force winding deforms racially as well as axially. As a result of this deformation, R-L-C parameters get changed with respect to their previous values.

In SFRA technique we can detect that deformation easily by applying sweep frequency applied to the winding. If SFRA results are not similar like when transformer is in healthy condition, then it indicates the abnormal condition.

II. SHORT CIRCUIT FORCES

Electrical and mechanical failure in transformer generates the force resulting from short circuits which may damage the transformers. Due to these forces, transformer winding deforms radially and axially. Short circuit symmetrical current is 6 to 7 times that of rated current and sometimes is high up to 15 to 18 times the rated current at peak time [3]. The formula for force acting on current carrying conductor during short circuit condition is,

$$F = BIL \quad \text{Newton}$$

where, B – Flux density in Tesla
I – Current in Ampere.
L- Length of conductor in meters

So the resulting forces are very high because they will be increasing in square of current. These forces extend the current carrying conductor radially as well as axially. Due to this mechanical changes occur in winding and so impedance value changes.

III. DETECTION TECHNIQUE

For the detection of fault in transformer various techniques are available. But most commonly used are,

i. Dissolve Gas Analysis (DGA)
ii. Partial Discharge (PD) method
iii. Sweep Frequency Response Analysis (SFRA)

i) Dissolve Gas Analysis

The breakdown of insulating materials within transformers and electrical equipment liberate gases within the unit. The distribution of these gases can be related to the type of electrical fault and the rate of gas generation can indicate the severity of fault. The identity of gases being generated by particular unit can be very useful information about fault. The types of fault depend on what type of gas is generated from transformer oil and ratio of these gases.

ii) Partial discharge method

Due to improper manufacturing process in insulation design of transformer micro voids are formed during the years of service of transformer. Micro void grows to a big cavity as time passes. Due to electromechanical stress potential difference appears across void. This treeing effect occur on the opposite electrodes leads to developing of partial discharge (PD) means conducting path is formed on insulating material surface which causes weak insulation. It is the case of insulation failure condition.

PD is important phenomenon which causes degradation of insulating material in transformer windings. There are number of methods which can detect the actual PD location like Ultra High Frequency (UHF) light emission, chemical method and acoustic emission techniques.

iii) Sweep frequency response analysis

This method can give the proper information about an indication of core movement and winding deformation. This method can be done in four steps.

1) Measurement in healthy transformer
2) Again Measurement in faulty case of sister transformer of similar rating
3) Signature curve of both conditions of healthy and faulty are compared.
4) If any difference between both cases found means fault occurred.

In this method measurement are performed at frequency ranges varied from 20 Hz to 20 MHz. It is most effective method of fault detection comparatively to DGA and PD method. As in both cases we can detect fault and in PD method we can detect insulation failure only. But in SFRA method we can detect number of faults which are related to transformer and also the exact location of fault. So it is more effective than both DGA and PD methods.

IV. SIMULATION RESULTS

The Sweep frequency response analysis method is simulated under MATLAB / Simulink environment. The results found from the same for different cases are explained in this section. These cases are explained below. A 10 section equivalent circuit of the transformer winding is used for simulation purpose.

Case I. Unfaultcondition(Healthy) :

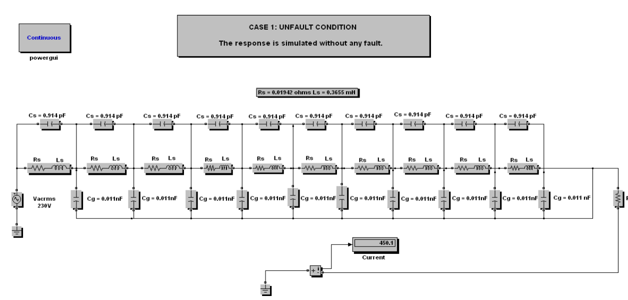

Figure 1: Transformer model for Unfault condition

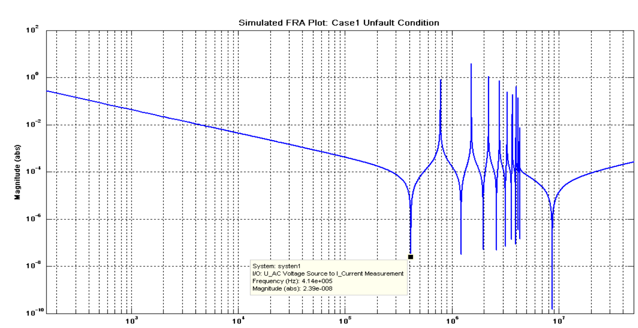

Figure 2. Simulated SFRA plot for case 1

After medium frequency range winding inductance effect is completely cancelled due to series and shunt capacitance of windings. The current measured is found to be 450.1A. Further analysis can be considered from first resonance point.

Case II: Inter Turn fault

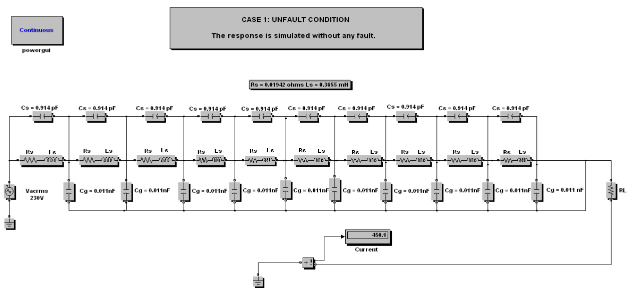

Figure 3. Transformer model for inter turn fault condition

The following figure 3 shows the transformer model for inter turn fault condition.The fault is created in 4th turn of transformer winding. The plot found from this model is shown in figure 4 below

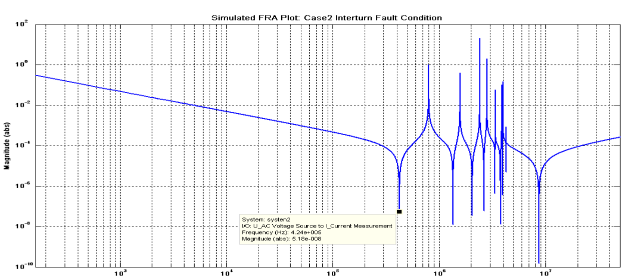

Figure 4. Simulated SFRA plot for case 2.

From figure 4, we notice that significant waveform displacement occur compared to no fault waveform. The first resonance point is occurring at 424 KHz. Also in medium frequency range there is slight waveform displacement as compared to unfault condition waveform. But from 2 MHz to 4.23 MHz range, big displacement is occurring. The current measured at inter turn fault condition is 500.1A. Compared to unfault condition 50A increase is observed. Increased current produces an abnormal heat which will affect transformer insulation and also leads to winding burn out.

Case III: Turn to Turn Fault Condition

The transformer model for turn to turn fault is shown below in figure 5. Here the fault is created between turns 3rd and 4th turn of transformer winding. The plot obtained from this model for turn to turn fault is shown in figure 6.

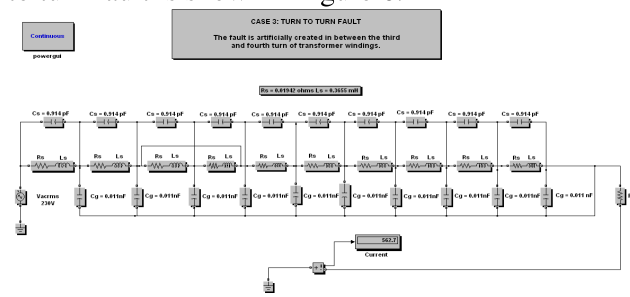

Figure 5.Transformer model for turn to turn fault condition

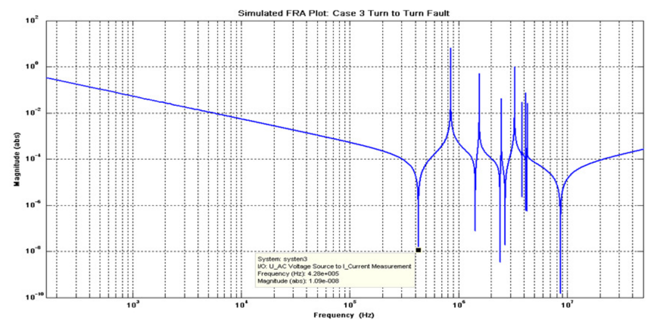

Figure 6: Simulated SFRA plot for case 3

The plot shown above gives SFRA behavior for turn to turn fault condition. From figure 6 we can notice that significant waveform displacement occur compared to unfault waveform. The first resonance point is observed at 428 KHz. At turn to turn fault condition the waveform obtained gets completely displaced from 1.4417 MHz to 4.3697 MHz as compared to reference set. The current measured for turn to turn fault condition is 562.7A. When compared to unfault condition the increased current is found to be 112.6A, which thermally stresses the insulation used in transformer winding. Due to this unexpected thermal stress the insulation is degraded.

Case IV: Change of ground capacitance:

The transformer model for change in ground capacitance is shown above in figure 7 and the plot for this condition is shown in figure 8 above. The change of turn to ground capacitance value occurs due to radial displacement of transformer winding. For unfault condition the value of ground capacitance is 0.011 nF. For analysis purpose, the turn to ground capacitance is changed to 52.6 pF.

From comparison of figure 2 and figure 8, significant waveformdisplacement is observed in figure 8. We can notice that waveform of figure 8 is entirely collapsed because of capacitance which is inversely proportional to frequency. The first resonance point is appearing at 190 KHz. From 190 KHz to 221 KHz, waveform displacement occurred. In this case the current is found to be 450.1 A.

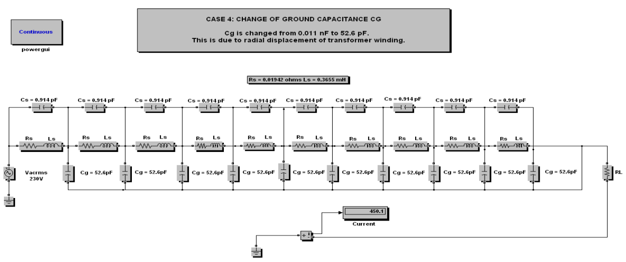

Figure 7: Transformer model for change in ground capacitance condition

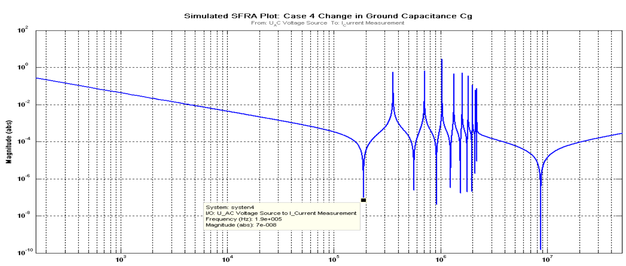

Figure 8: Simulated SFRA plot for case 4

IV. CONCLUSION

The transformer is considered as a heart of power transmission system. During its duties it can undergo some faults like inter turn fault, turn to turn fault, winding deformation, etc. Every transformer winding has its own signature and it is very sensitive as it changes winding parameters. This paper presents simulation of transformer winding fault detection using sweep frequency response analysis. The three faults cases like inter turn fault, turn to turn fault and change in ground capacitance are simulated and are compared with reference to unfault condition. On comparing faulty condition with healthy condition, we notice the change in current value due to change in impedance value of complex network. So this change in current value and resonant frequency can detect or diagnose the fault in the transformer winding. FRA can be a very effective tool for condition monitoring.

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