Fault Detection in Transformer Using Frequency (Sweep) Response Analysis

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ABSTRACT
Power transformers are the most expensive and important component in a high voltage electric power system. During its lifetime, it is subjected to mainly electrical, mechanical and thermal stresses. Due to these stresses fault may occur in it. Various techniques are available for detection of such fault. Here in this paper we focused on transformer fault detection technique by frequency response analysis method. The FRA monitors the changes occur in RLC network parameter during fault. FRA measurement is done by using sweep frequency which is range between 20 Hz to 20 MHz feed up in both healthy & faulty transformer. FRA gives output in the form of signature curve in both the cases. From that output we can conclude about fault condition. This paper presents simulation study of Transformer equivalent circuit of winding deformation by SFRA.

Keywords
Power Transformer, winding deformation, sweep frequency response analysis.

1. INTRODUCTION
Power transformer is the most important device for reliable electrical power system. They are generally involved in energy transfer in power transmission and distribution networks, converting ac voltage or current from one level to another level depending on the receiver end. During its lifetime, it is subjected to mainly electrical, mechanical and thermal stresses. The main reason behind the stresses can be due to ageing of insulation, during transportation, and the most critical reason is a short circuit event. 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 gradually as well as axially. As a result of this deformation, R-L-C parameters get changed with respect to their previous values. In FRA technique we can detect the winding deformation easily by applying sweep frequency applied to the winding. If FRA results are not similar like when transformer is in healthy condition, then it indicates fault occurred.

2. DETECTION TECHNIQUE
Various techniques are available for the detection of fault in transformer ,but in this paper focused on some of the best methods

- Dissolve Gas Analysis (DGA)
- Partial Discharge (PD) method
- Sweep Frequency Response Analysis (SFRA)

2.1. Dissolve Gas Analysis (DGA)
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.

2.2. Partial discharge Method (PD)
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 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. 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.

2.3. Frequency response analysis

In this method we can collect the accurate information about core movement and winding deformation transformer. following steps are needed to perform FRA

- Measurement of parameter unfaulted transformer
- Measurement in faulty case of sister transformer of similar rating
- Signature curve of both conditions are compared.
- If any difference shown between both cases it means fault occurred.

Measurement are performed at frequency ranges between 20 Hz to 20 MHz. as compared to above both methods it is most effective technique. In FRA method we can detect so many of faults which are closely related to transformer winding and location of fault as well.

3. SIMULATION RESULTS

The frequency(sweep) response analysis method is simulated under MATLAB / Simulink software. 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. Unfault condition(Healthy):

The transformer model for sweep frequency response analysis is developed in MATLAB / Simulink. The following figure 1 shows the transformer model for healthy condition. From this model SFRA response for Unfault condition is found which is shown in figure 2 below. For a wide range of frequency, the equivalent circuit of transformer winding includes numerous inductance, resistance and capacitance elements. There are mutual inductive and capacitive coupling between the winding elements, which are effectively determining the SFRA response of winding including multiple resonance and anti-resonances.

The first resonance is occurring at 414 KHz. Beyond this resonance point, inductance of transformer winding dominates. After first resonance point magnetic effect of point tries to increase but winding inductance effect is screened. This process continuously repeats several times so that medium frequency range has more number of resonance points.
Figure 2. Simulated SFRA plot for case 1.

Case II: Inter Turn fault

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.

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 3. Transformer model for inter turn fault condition
Figure 4. Simulated SFRA plot for case 2.

From figure 4, we notice that significant waveform displacement occurs 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

CASE 4: CHANGE OF GROUND CAPACITANCE CG

Cg is changed from 0.011 nF to 52.6 pF.
This is due to radial displacement of transformer winding.

Figure 7: Transformer model for change in ground capacitance condition
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 waveform displacement 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.

4. 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.

REFERENCES


