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Fault detection technique in Tansformer by SFRA method

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Abstract : The Power transformers are one of the most vital as well as expensive equipment in an electric power system. Therefore, it is the responsibility of utilities to decrease the transformer lifecycle costs and to increase the usable service time. The damage may cause a change in the physical condition of transformer which would be reflected in the electrical parameters- resistance, inductance and capacitance. The insulation performance is influenced by thermal, electrical and mechanical stresses. The displacement of windings can occur during transportation of transformers or during a short circuit near the transformer in the power system. The Sweep frequency Response Analysis (SFRA) can detect the type of fault and the exact location of fault. The result obtained for the various fault condition is compared with the reference set and the conclusion are drawn.

Keywords - SFRA,Ehv,fra,Lvi,Hv.

I.INTRODUCTION

Transformers are the critical part of an electrical utility's asset base. One possibility is to extend the monitoring and diagnosis of power transformers to all possible types of faults. Special monitoring devices for the detection of different types of faults are in use.[1] An internal knowledge of winding and core movements after occurrence of any short circuit fault can be achieved by means of external measurement proposed model by conducting offline SFRA tests.[2] Determining deformations using Sweep frequency Response Analysis is one of the active research areas in transformer diagnostic studies. Sweep Frequency Response Analysis (SFRA) is a tool that can give an indication of core or winding movement in transformers. Literature suggests that changes in frequency response as measured by SFRA techniques may indicate a physical change inside the transformer, the cause of which then needs to be identified and investigated.[3]

II. MECHANICAL INTEGRITY OF A TRANSFORMER WINDING

Winding deformation may be due to mechanical and electrical faults. Mechanical faults occur in the form of displaced winding, hoop buckling, winding movement, deformations and damaged winding. Winding movements may also result from stresses induced by electrical faults such as an interturn's short circuit as a result of lightning strikes. It may also result in insulation damage. Winding deformations in transformers are difficult to establish by conventional methods of diagnostic tests like ratio, impedance/ inductance, magnetizing current etc. Deformation results in relative changes to the internal inductance and capacitance of the winding.

Frequency response analysis is generally applied to a complex network of passive elements. For practical purposes, we will consider only resistors, inductors, and capacitors as passive circuit elements, and they are assumed to be ideal. These three fundamental elements are the building blocks for various physical devices, such as transformers, motors, generators, and other electrical apparatus. When the sinusoidal input signal is applied there will be a dynamic response, dependent on the transfer function which physically is the combination of inductance, capacitance and resistance within the specimen.

III.THEORY AND FUNDAMENTAL

SFRA is based on analysis of a windings transfer function. A signal generator is connected together with a voltage reference to a phase outlet on the transformer and the response is measured on the neutral outlet of the same winding (see figure 1).

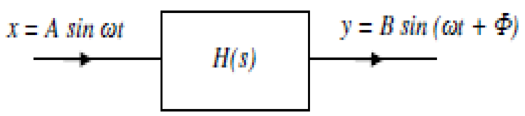

Figure 1

The signal generator produces a sweep of signals (sine waves) with increasing frequency. The reference and response voltages are logged and processed so that a response curve can be plotted. The response curve shows the relationship between the two voltages (attenuation) as a function of the frequency. The phase shift between reference and response are also measured and can be plotted as o function of frequency. With the SFRA method input and output signals are measured at one frequency a time, within a frequency range. How the input signal (x) is affected by the specimen's characteristics will depend upon, what is mathematically described as, the transfer function

$$H(s) = Y(s) / X(s)$$

(where s is a frequency dependent parameter, which for continuous sinusoids equals to $j\omega$). The transfer function will affect how the response will differ from the input.

IV.SHORT CIRCUIT FAULT IN WINDINGS

System short circuit may occur across any two lines or if the neutral point is earthed between any one lines. The effect of system short circuit will produce over currents, magnitude of which are dependent on the system MVA, feeding the fault or the voltage, which has been short circuited and on the impedance of the circuit up to the fault. Short circuit may cause winding movement and shorted turns. Short circuits near transformers usually cause currents of high amplitudes. This leads to extreme mechanical stress of core and coil assembly. The mechanical forces do not always cause a failure. Sometimes there is only some significant damage, which are not recognized and further service is not possible.

VI. FAULT DETECTION TECHNIQUES

If the transformer has been switched off by protective equipment, there is a need to determine whether the transformer can be safely re-energized. Visual inspections require dismantling of the transformer, removing of the transformer oil and are time consuming. Hence effective detection techniques are required. The most commonly used techniques are:
1. Leakage reactance measurement
2. Low voltage impulse
3. Frequency response analysis

Before 1980, LVI tests were performed on transformers in order to obtain the information considering the transformer condition. In this method, a very steep impulse was applied to one of the HV terminals and the response signal across a 50 Ω resistor was recorded. For mechanical faults, neither method (LVI or FRA) is used. For electrical faults, the swept frequency method gives better results because it has a finer resolution at low frequencies. The LVI method is subjected to several disadvantages and hence FRA is widely used to detect winding deformation.

Sweep frequency response is a major advance in transformer condition analysis, allowing you to see inside of transformers. Sweeping through the frequency range of interest gives rise to S in SFRA, to distinguish it from impulse method, which estimate the response rather than measure it. The transformer can be considered like a linear system due to the application of low voltage signal and it is possible to know how the transformer behaves when the frequency is changing because the measure of the system represents the behavior of the machine.

VII.DIAGNOSING FAULTS

Faults, such as short-circuited turns, change the magnetizing characteristics of the transformer and, hence, the low-frequency response. Circulating currents loops, if they are sufficiently large, redirect leakage flux into the core and also change the low-frequency response. An ungrounded core changes the shunt capacitance of the winding closest to the core and also the low-frequency response. The medium-frequency response is sensitive to faults that cause a change in the properties of the whole winding. A significant increase in the medium-frequency resonances normally indicates axial movement of a winding. A significant decrease normally indicates radial movement of the inner winding. The high-frequency response is sensitive to faults that cause changes in the properties of parts of the winding. Localized winding damage causes seemingly random changes in the high-frequency response, often leading to the creation of new resonant frequencies.[1]

When a transformer is subjected to high through fault currents, the mechanical structure and windings are subjected to large mechanical stresses. These stresses may cause serious deformation of winding and precipitate a transformer failure. Winding deformation is difficult to determine by conventional measurements of ratio impedance and inductance and capacitance of the winding structure. These changes can be detected externally by FRA method.

VIII. INSTRUMENT DISCRIPTION

Sweep Frequency Response Analyzer (SFRA) detects potential and mechanical problems that other methods are unable to detect. Major utilities and service companies have used SFRA method for more than a decade . The actual measurement is compared to the reference and gives the direct answer if the mechanical parts of the transformer are not changed.

Double's M5000 series uses sweep frequency response analysis to detect the mechanical failure or changes of windings through short circuits, mechanical stresses or transportation. The instruments sends an excitation signal into the transformer and measure the returning signal. Comparing these signals with the baseline or other results allows you to identify the deviations and confirm internal mechanical problems.

IX.PURPOSE OF SFRA measurement

SFRA measurement is used for the following reasons:-
- After short circuit testing of power transformer
- Detect core and winding movement.
- Access mechanical destortions in transformer.
- Due to electromagnetic forces from fault currents.
- Transformer relocations [2]

X.MODELLING OF TRANSFORMER WINDING

A simplified equivalent circuit for one outside phase of the winding of the 8 MVA, 110/22 kV, wye-delta power transformer, using cascade π section is modeled for eight sections which equals to the number of winding disc in the transformer refer fig-(2). The model consists of eight sections. The equivalent circuit is useful in modeling and is sensitive to winding changes. Conversely, a change in response could be related to a calculated amount of winding deformation. In a winding there exists capacitance between the adjacent turns within a disc or layer, capacitance between the adjacent discs or layers, capacitance to ground and to other windings. Similarly there exists self and mutual inductances as pertaining to the individual turns, the disc/sections, one part the winding to another or one whole winding to another. Although both capacitance and inductance are of distributed nature, for practical computation purposes these have to be lumped in varying degrees according to the desired accuracy. Also, the effect of the winding resistance is not significant and can therefore be neglected.

XI.SIMULATION OF FAULTS

The Frequency response analysis can detect many type of faults includes short circuit fault, interturn fault, failure of transformer oil and mechanical displacement. These faults are thus simulated and the frequency response is obtained.

Short circuit fault

Short circuit faults are simulated by including a resistor between the nodes at which the fault occurrence is to be analyzed refer fig-(3) and table-1.The circuit may be studied for various resistor values like 100 Ω, 1 kΩ and 10 kΩ. It can be seen from the analysis that the behavior of the circuit changes from that resembling a short (R=100 Ω) to that resembling an unfaulted case (R=10 kΩ). The intermediate value (R=1 kΩ) shows the transition. For the analysis purpose, consider R=100 Ω, which resembles a short.

Interturn fault

The inter-turn faults are better expressed by variation in series capacitance. The occurrence of short between the turns is indicated by including a resistor (R=100 Ω) across the series capacitance of winding. Similarly, the fault across each winding can be simulated and frequency response is obtained. The frequency response analysis for short circuit fault across adjacent discs of the winding refer fig-(4) and table-2.

Failure of transformer oil

The failure of insulation or dielectric is simulated by adding a resistor across the ground capacitance. The ground capacitance denotes the distance between the core and the winding, which indicates that a fault has occurred between the winding and the core. The resistor (R=100 Ω) is included across each ground capacitor and the frequency response is obtained refer fig-(5) and table-3.

Axial displacement of winding

The axial displacement of the winding is referred as vertical displacement. The vertical displacement is simulated by causing a change in the coupling value between two windings. Hence the coupling value is reduced by 0.1 and 0.2 for each section and the frequency response is obtained refer fig-(6) and table-4.

Radial displacement

The displacement of winding from the core is referred as the horizontal displacement. Horizontal displacement causes a change in the ground capacitance value. Hence the ground capacitance value is increased for each section and the frequency response is obtained refer fig-(7) and table5.

XII. FIGURES AND TABLES

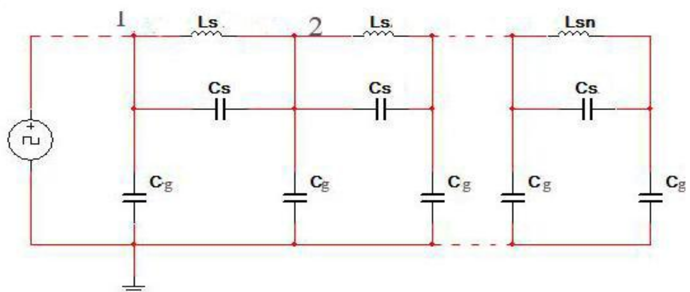

Fig (2): Equivalent circuit of 8 MVA transformer winding

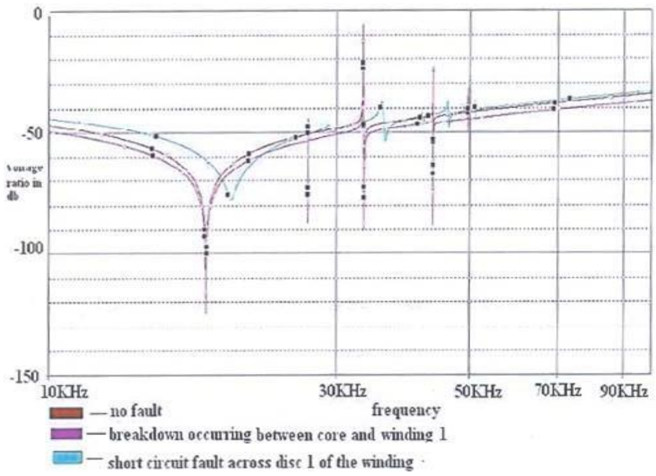

Fig (3): Comparison of no fault with short circuit fault across disc 1 of the winding and breakdown occurring between core and winding at resonant frequencies.

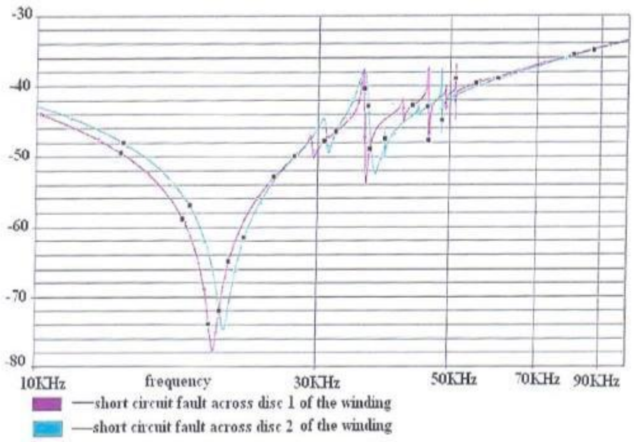

Fig (4): Comparison of short circuit fault across disc 1 and disc 2 of the winding.

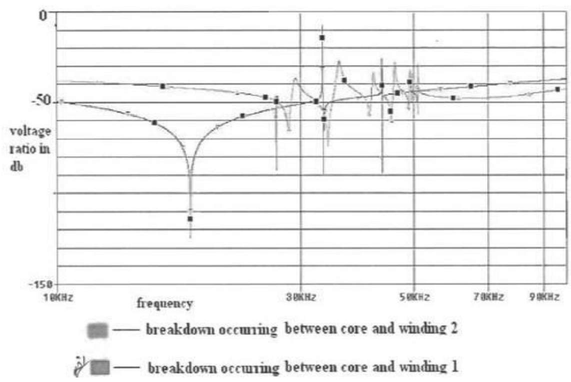

Fig (5): Comparison of breakdown occurring between core and winding 1 with breakdown occurring between core and winding 2 at resonant frequencies.

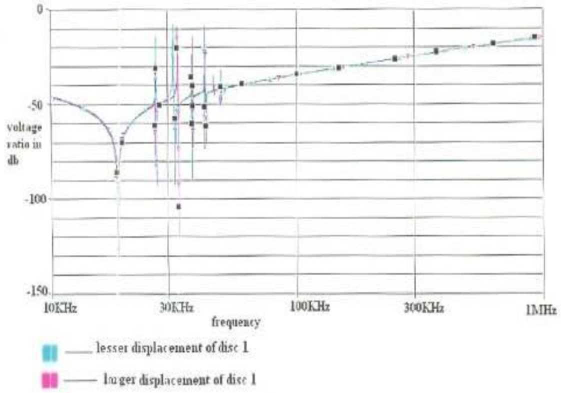

Fig (6). Comparison of axial displacement of disc 1.

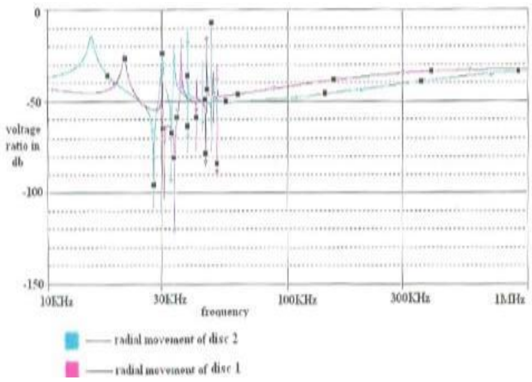

Fig (7). Comparison of radial displacements of disc 1 and disc 2.

Poles	**Resonant Frequencies of NoFault Responsein kHz**	**ResonantFrequenciesof ShortCircuitFaultAcross Disc1ofTheWinding in kHz**	**Resonant Frequencies ofBreakdown OccurringBetween Core and Winding 1 in kHz**
1	26.903	29.141	26.884
2	33.167	35.752	33.197
3	43.391	41.476	43.311
4	49.636	45.825	49.556
5	-	49.102	-
6	-	51.015	-

Table 1: Comparison of no fault with short circuit fault across disc 1 of the winding and breakdown occurring between core and winding at resonant frequencies

Poles	**Resonant Frequencies of Short Circuit Fault Across Disc 1 of the Winding in kHz**	**Resonant Frequencies of Short Circuit Fault Across Disc 2 of the Winding in kHz**
1	29.141	30.669
2	35.752	35.760
3	41.476	38.905
4	45.825	44.218
5	49.102	48.350
6	51.015	50.886

Table 2: Comparison of short circuit fault across disc 1 and disc 2 of the winding**.**

Poles	**Resonant Frequencies of Breakdown Occurring Between Core and Winding 1 in kHz**	**Resonant Frequencies of Breakdown Occurring Between Core and Winding 2 in kHz**
1	26.884	29.289
2	33.197	35.777
3	43.311	41.754
4	49.556	45.952
5	-	49.181
6	-	51.062

Table 3. Comparison of breakdown occurring between core and winding 1 with breakdown occurring between core and winding 2 at resonant frequencies

Axial Displacement in Disc 1	
	FREQUENCY OF FIRST POLE IN kHz
LARGER DISPLACEMENT	26.588
LESSER DISPLACEMENT	26.509
DIFFERENCE BETWEEN THE FREQUENCIES	79

Table 4. Comparison of axial displacement of disc 1

Radial Displacement in	**Frequency of Peak Occurrence in kHz**
DISC 1	20.898
DISC 2	14.792

Table 5. Comparison of radial displacements of disc 1 and disc 2.

XIII.CONCLUSIONS

Every transformer winding has a unique signature that is sensitive to changes in the parameters of the winding, namely resistance, inductance, and capacitance. Frequency spectrum of a transformer is very sensitive to any deformation or displacement of the winding. Frequency response analysis is a very effective tool for diagnosing transformer condition. It is particularly useful in detecting any fault that is due to mechanical damage to the winding. The technique is also very reliable for detecting any short circuit to the winding. Results from a measurement can be analyzed through several techniques via graphical presentation. However, reference is needed for better interpretation. The reference can either be from historical data of the same transformer or from sister transformers. In many cases, historical data for transformers already in operation is difficult to get owing to shutdown requirement. Sister transformers are used in those cases as the reference measurement. The interpretation of the results is meanwhile a great help in determining further action to be taken especially for suspected transformers. FRA can be a very effective tool for condition monitoring. It can avoid catastrophic failure in transformers and also help maintenance engineer to estimate time and cost for repairing the transformer after the fault before undertaking maintenance

XIV.REFERENCES

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