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Fault location using Sweep Frequency Response Analysis in Disc type transformer winding

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***Abstract*—Winding faults are the leading cause of power transformer failures. Usually these failures develop in to more serious faults that would result in irreversible damage to the transformer winding and the consequential costs. This contribution is aimed at locating the faults by defining a set of two parameters based on change in impedance due to fault in the winding. Modeling and measurement of 22 kV continuous disc winding is done using circuit simulation package and sweep frequency response analyzer respectively.. The identified parameters are used in localization of faults in the transformer winding. The proposed method for localization of fault by measurement is validated by modeling**

Keywords-Transformer Insulation, Faults, Modeling, SFRA

I. INTRODUCTION)

The power transformer plays a very important role in a power system. Damages to power transformer are unwelcome since the continuity in power delivery may be seriously disrupted. Furthermore repair or replacement is expensive and time consuming.[1] This insulation is mainly affected due to the over voltages caused by lightning and switching surges. In view of increasing demand for reliable and high quality energy supply, electrical utilities are more interested in avoiding transformer failures. However, degradation as a result of ageing under service conditions is inevitable

Deterioration of the insulation may be caused by a combination of electromechanical forces induced by a variety of factors. The chief factors are frequent transformer overloading, mechanical vibrations, high transient voltage stresses, high current stresses particularly in the presence of external short circuits, thermal overloading and contamination[2,6]. Early stages of winding faults may often have negligible effects on the transformer performance; however such faults may rapidly lead to more serious permanent forms such as phase to phase or phase to ground faults. Once the winding faults has occurred, a large circulating fault current is induced in the shorted portion, leading to localized thermal overloading in the defective region of the winding. Over some period of time, the generated heat in the defective region will cause the fault to increase in size, thereby increasing the fault energy level, until a catastrophic fault involving another phase or ground occurs. Accordingly it would be advantageous to detect faults in its earliest stage to prevent further damage to the transformer. Since transformers are one of the most important equipment in power networks, any efforts to increase their reliability, diagnosing and locating their faults would effectively reduce expenditures and transformer outage time.

Attempts to localize the faults in a transformer winding by analyzing the changes in inductance and capacitance have been observed in the literature [1]. Frequency response analysis as one of the well-recognized method for on-site diagnosis of power transformers is based on the fact that, each transformer winding has a unique signature of its transfer function. An attempt to localize the short circuit faults in a transformer winding by observing the impedance changes in sweep frequency response analysis (SFRA) has been presented in this paper

II. IMPEDANCE CHARACTERISTICS OF FAULTY WINDING

Impedance of a transformer winding is subjected to changes during the occurrence of a fault [3]. Changes in the impedance of a winding can be studied by sweep frequency response analysis. This can be done using a sweep frequency response analyzer (SFRA).It essentially consists of measuring the impedances of the transformer windings over a wide range of frequencies. Thus the impedance of the winding for a wide range of frequencies can be compared using sweep frequency response analyzer.

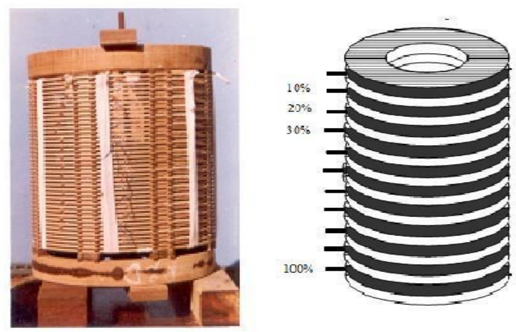

Fig 1. a) 22kV continuous disc winding
b) Schematic diagram of the 22kV disc winding

SFRA is designed to detect winding displacements and faults in power transformers based on the comparison of their resonant frequencies with that of the frequencies corresponding to the healthy winding [4]. The system provides attenuation signature curves that can easily be compared for deviations which indicate core movements, winding faults, deformations and displacements, faulty core grounds and partial winding collapse etc. Sweep Frequency Response analysis on a 22 kV continuous disc model winding has been carried out. The model winding and its schematic diagram is shown in Figure. 1. This winding has 40 discs and each disc has 12 turns in it. The specifications are given in the appendix. Tapping"s were brought out at every disc in order to create inter disc short fault. For instance, 10% and 5% fault is created by shorting 4 discs and 2 discs respectively.

A. *Measurement Setup*

The measurement is done using FRAX (Meggar) and setup is shown in Fig.2. The impedance of the winding is measured under healthy condition and for various percentages of short circuits at different locations along the

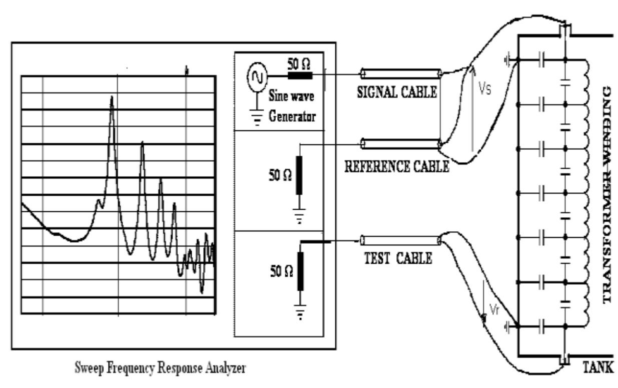

Figure 2. Experimental Set up [5]

winding. The short circuits are created by short circuiting the corresponding disks for each case .Short circuits of 5%,10%,25% and 50% at different locations along the winding are created and impedance is measured for each case.

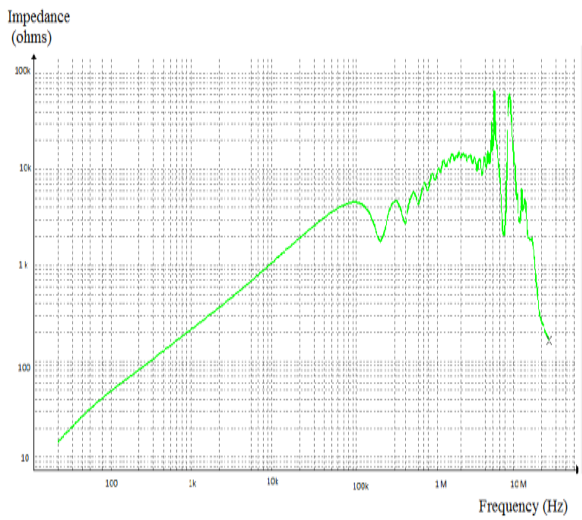

Figure 3a Impedance characteristics for healthy winding

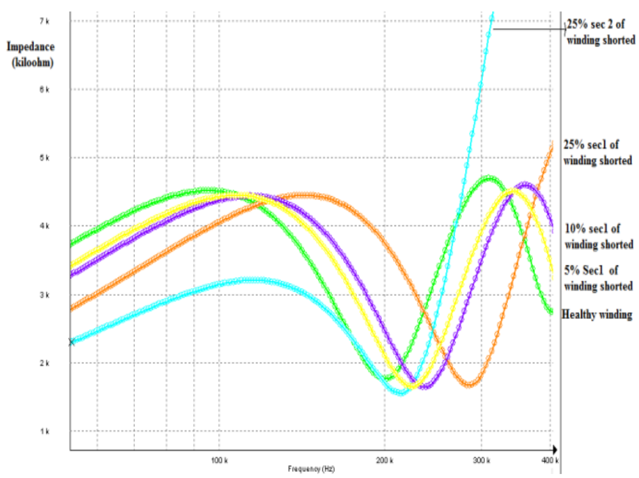

Figure 4 .Measured winding Impedance- characteristics for different faults

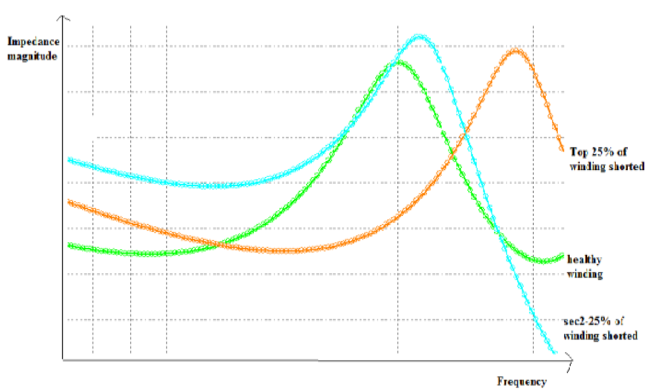

Figure 5a. Measured winding Impedance - characteristics for 25% faults in the winding

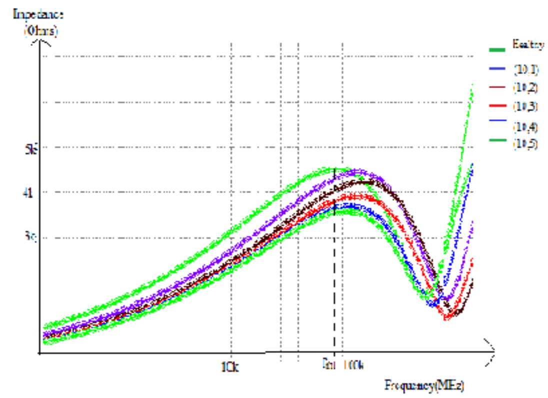

Figure 5b. Measured winding Impedance - characteristics for 10% faults in the winding

Figure 3 shows the impedance characteristics for healthy winding. It is observed that the impedance of the winding is comparatively small at lower frequencies and it increases gradually as the frequency is increased. Multiple resonances can be observed in the impedance. The measured impedance-characteristics for different fault cases of the winding is shown in Figure 3a.The impedance characteristics shows a definite variation with the percentage of fault. A shift in the resonant frequency is occurred depending on the location and percentage of fault. As the percentage of fault increases, the shift in the resonant frequency is increased. Change in impedance magnitude is also observed for each case. Figure 4 shows the dependence of impedance characteristics on the location of fault. T he shift in resonant frequency and the corresponding magnitudes for 25% and 10% faults in the winding can be better observed in the Figures 5a and b respectively. The percentage of change in impedance is different for faults at different locations. Since considerable shift is observed in the first resonant frequency, compared with the higher order frequencies, only the impedance values corresponding to the first resonant frequency of winding for all fault cases is considered for analysis.

B. *Parameters for localization of fault*

The impedance characteristics of the healthy winding and the faulty winding are shown in Figure.6. The impedance of the healthy winding at its first resonant frequency is observed which is indicated as Za. The first resonant frequency of the healthy winding is f_a and that of the faulty winding is f_b. The magnitudes of the impedances at the first resonant frequency for faulty winding is indicated as Z_b .The impedance magnitudes for all the fault cases at the first resonant frequency of the healthy winding is denoted as Z_c .

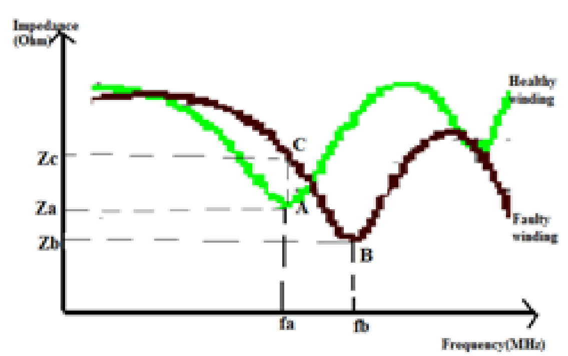

Fig.6 Impedance response of the healthy and faulty Winding at resonant frequency.

Two parameters can be defined based on the measured impedances at the resonant frequencies. These parameters can be defined as follows.Parameter-1 is indicated as Z_{ab} and parameter-2 is indicated as Z_{ac} ,which are defined as follows.

$$Z_{ab} = (Z_a - Z_b)/Z_a \ *100$$
$$Z_{ac} = (Z_a - Z_c)/Z_a \ *100$$

Z_{ab} indicates the percentage shift in impedance of the faulty winding at its first resonant frequency in compared with the impedance of the healthy winding at the first resonant frequency healthy winding. Z_{bc} indicates the shift in impedance of the winding at the first resonant frequency of healthy winding due to fault .

The calculated parameters Z_{ab} and Z_{ac} for each percentage of faults at different locations along the winding are given in Table 1a and 1b. These parameters show a considerable decrease in magnitude as the location of fault moves away from the centre of the winding, making it useful for localization of fault.

TABLE 1a. Parameters Z_{ab} and Z_{ac} for 5% faults

Percentage and Location of fault	Zab (%)	Zac (%)
5-section 1	1.44	2.54
5-section 2	2.33	4.38
5-section 3	4.34	6.6
5-section 4	7.94	9.07
5-section 5	9.71	11.13
5-section 6	12.29	13.06
5-section 7	13.94	14.59
5-section 8	15.44	15.85
5-section 9	16.31	16.64
5-section 10	16.65	16.92
5-section 11	16.46	16.74
5-section 12	16.11	16.42
5-section 13	15.18	15.62
5-section 14	13.65	14.31
5-section 15	11.94	12.71
5-section 16	9.6	10.99
5-section 17	7.07	8.93
5-section 18	4.59	6.77
5-section 19	2.73	4.62
5-section 20	1.61	2.58

TABLE 1b. Parameters Z_{ab} and Z_{ac} for 25% and 10% faults

Percentage and Location of fault	Z_{ab} (%)	Z_{ac} (%)
25-section 1	1.45	12.03
25-section 2	28.99	31.14
25-section 3	28.63	30.86
25-section 4	1.9	11.88
10-section 1	1.7	4.09
10-section 2	6.64	9.71
10-section 3	13.1	15.01
10-section 4	18.11	19
10-section 5	20.6	21.06
10-section 6	17.75	20.86
10-section 7	12.87	18.68
10-section 8	5.8	14.78
10-section 9	1.67	9.53
10-section 10	1.44	3.99

Figure 7 shows the variation of Z_{ab} and Z_{ac} with the location of the fault for 5%, 10% and 25 % faults along the winding.. Here both the parameters show symmetry with respect to the centre of the winding. Similar is observed for 5% and 25% faults. Hence the faults which are symmetrical with respect to the centre of the winding cannot be identified using these parameters. Hence the derived parameters can only be used to locate the position of the fault from the centre of the winding.

C. *Proposed Method for Localization of faults*

The percentage of short circuit for a faulty winding can be determined from the percentage reduction in the impedance of the winding with respect to the impedance of the healthy winding at very low frequency. The percentage reduction in the impedance corresponds to the percentage of short circuit in the winding.

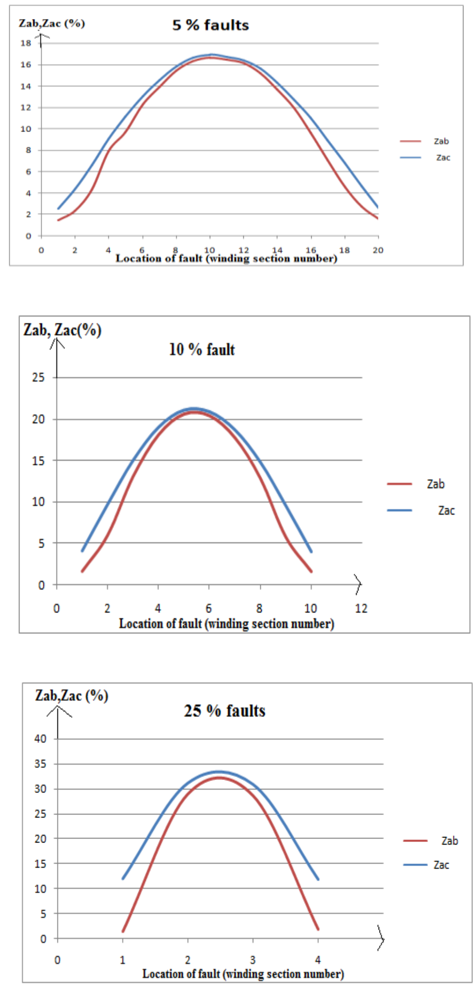

Figure 7.Parameters Zab and Zac (Vs) Location of fault for 5%, 10% and 25% faults

The calculated parameters for each fault condition yield a method to locate the fault. It is seen that there is a gradual decrease in the value of both the parameters Z_{ab} and Z_{ac}, when the location of fault moves away from the centre of the winding. The calculated parameters for each fault condition can be used as a reference value for each percentage of faults, which can be used to locate the fault. Given the frequency response of the faulty winding and comparing it with the impedance of the healthy winding, the parameters Z_{ab} and Z_{ac} can be computed. Thus by comparing the parameter values (Z_{ab} and Z_{ac}) with the reference values for the corresponding percentage of short ,the location of short circuit fault from the centre of the winding can be determined.

III. SIMULATION OF 22 kV WINDING

A 22 kV continuous disc winding having 40 discs , each having 12 turns is modeled in circuit simulation package. The parameters of the winding such as inductance, shunt capacitance and series capacitance of the winding are computed using Finite Element Method (FEM) analysis and found to be 45mH, 467 pF, and 2.2 pF respectively. The lumped parameter model of 22 kV winding with 40 RLC sections is shown in Figure 8.The winding is simulated for healthy and faulty conditions for different locations of fault along the winding.

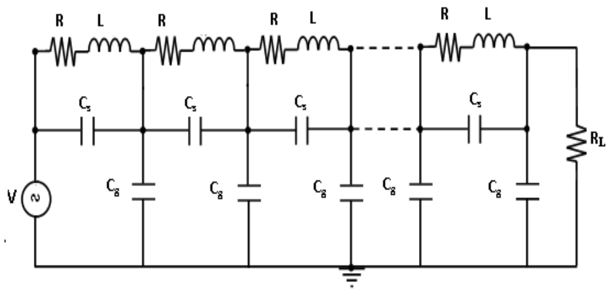

Figure 8. Lumped parameter model of the 22 kV disc winding

Due to symmetry, faults in only one half section of the winding are considered for simulation.The Pspice model of 22 kV winding is simulated for healthy and faulty conditions for different locations of fault with respect to the centre of the winding and the impedance characteristics of the model is obtained for each faulty condition. The parameter Z_{ab} and Zac is calculated for each case. The parameter values Z_{ab} and Zac with respect to location of fault within one half of the winding are shoiwn in figure 9 and 10 respectively.

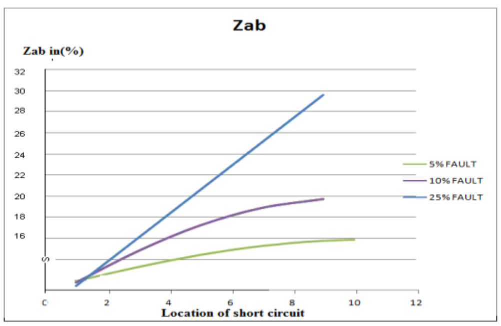

Figure 9. Parameter Z_{ab} (Vs) Location of short circuit for various percentage of faults

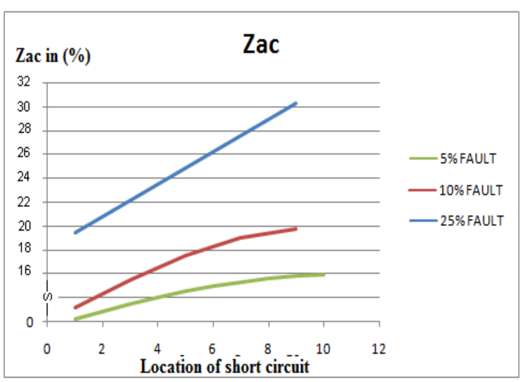

Figure 10. Parameter Z_{ac} (Vs) Location of short circuit for various percentage of faults

The derived parameters for each fault condition shows a gradual decrease in magnitude as the location of the fault moves away from the centre of the winding, for each percentage of faults. The parameter values by simulation shows a similar pattern when compared with those obtained by measurement. This clearly indicates the reliability of the proposed method to locate the fault based on the derived parameters.

IV. CONCLUSION

The two proposed parameters based on the changes in the impedance values at the resonant frequencies yields a method to locate the position of fault from the centre of the winding. The impedance response of the winding for short circuit faults at various locations along the winding by measurement on 22 kV winding shows considerable changes when the location of the fault changes. The analysis of the impedance characteristics of the winding by modelling also confirms the reliability and validity of the proposed parameters in locating the fault. Further studies are carried out in differentiating the faults occurring on either side with respect to the centre of the winding.

APPENDIX

Specifications of Disc winding

Sections per coil	40
Turns per sections	12
Size of conductor	4.5*1
Coil diameter (inner)	300
Mean diameter	319.5
Coil diameter (outer)	339
Height of section axial	313
Depth of windings (radial)	19.5
Axial and radial spacing	3
Section clearance	3
Core thickness	3
Core height	313
G.I. sheet is placed inside the windings to act as a core and the core is earthed. All dimensions are in mm	

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