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Effect of Radial and Axial Movement of Winding on Coherence Function in a 220/132 kV, 100 MVA, Auto Transformer

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The short circuit force generated in Powers Transformers due to system fault is known to cause movement of the windings. Several diagnostic methods have been employed to identify the movement of internal components of transformer e.g. Core, winding, coil bulging, coil twisting, Inter turn fault etc. The methods include – Sweep Frequency Response Analysis, Current reflection time, wavelet transform and Coherence Function (CF). The present work reports a detailed analysis of Coherence Function due to radial and axial movement of coil by theoretically simulating the HV winding of 220/132 kV, 100 MVA autotransformer. The results show a variation in magnitude of CF for dominant frequencies and that even a small change in radial or axial distances cause significant change in magnitude of CF. It is observed that sensitivity of detection of winding movement by CF for minor faults is moderately better than Frequency Response, since CF is related to the amount of linearity between input and output. It is observed that CF and FRA are complimentary to each other.

Keywords: *Transformer, Transfer function, Coherence function, Frequency response.*

1.0 INTRODUCTION

Power transformers are subjected to several types of abnormalities. Some of them are over-voltages due to lightning, switching surges and faults. The currents associated with faults could reach up to several kilo amperes, depending on the distance of fault from the transformer terminals. Faults closer to transformer terminals could lead to high transient currents of several kHz, lower damping and high level of D.C. offset. Thus winding of transformers experience abnormal forces causing axial and radial movement. Although, windings are designed and in many cases tested for short circuit, a single fault may not affect the winding geometry. However, cumulative fault may cause the axial or radial movement of winding. Several research papers [1-5] have been published with regard to movement, based on Sweep Frequency Response Analysis (SFRA). It is used as diagnostic tool for detecting movement of inter winding or windings with reference to core. The SFRA method is very effective in detection of winding displacement and fault. It is opined that the SFRA, though effective for overall movement or distortion of winding, it may not truly detect minor movements and localized bulging in the winding with the same accuracy due to low sensitivity of detection by Fourier Transform. Research work [6-9] have been published for detection of fault by Coherence Function(CF) method based on analysis of neutral current for simulated turn fault. It is generally observed that the determination of turn failure on the basis of Sweep Frequency Response Analysis is fraught with uncertainty.

Main reason giving rise to uncertainty is that a turn failure leads to a small reduction in inductance due to low percentage reduction

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in turn compared to overall number of turns. Further, the turn failure in plain disc portion of the winding may lead to increase in overall capacitance. Hence, the frequency could continue to remain almost same.

It is also known that most of the dominant frequencies for high voltage power transformers do not exceed 1 MHz although, Sweep Frequencies are considered up to two MHz in actual measurement. A frequency difference that may occur in the vicinity of one MHz and above could contain noise. In such event the CF method of detection is found to provide additional information. The sensitivity of detection of neutral current variation with the coherence analysis is marginally better than that of frequency analysis for minor faults. Hence, this method using CF is evaluated on the basis of difference in neutral current and Fourier transform for winding movement. Results of CF based on neutral current analysis with and without P.D.[10,11] have also been found to provide satisfactory information regarding P.D. in windings during impulse test. The effect of small movement in axial and radial direction based on CF technique is observed to provide useful information confirming displacement.

In the present work theoretical simulation of radial and axial variation has been carried out for a 100 MVA, 220 kV/132 kV auto transformer. For each variation, FFT and CF are calculated for neutral current with and without movement of the winding. A comparison of FFT with and without displacement provides the difference with regard to frequencies and respective peak magnitudes. The work reports the variation of CF with variation in radius of the winding. The radial variation is simulated by varying the oil gap between LV and HV winding with corresponding increase / decrease in radius of the HV winding. The axial variation is simulated by increasing or decreasing the duct height along the Coil Depth(CD). A close examination of FFT result indicates that both the methods are capable of detecting the movement and CF can be considered as complimentary to FRA.

2.0 MODELLING OF TRANFORMER FOR FFT AND CF ANALYSIS

In order to simulate the condition for CF analysis, the winding of a high voltage auto transformer of 220/132/11 kV as given in Figure 1 is considered.

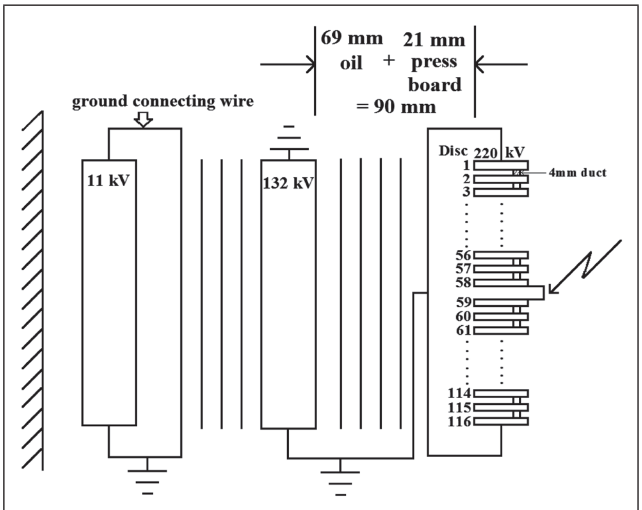

FIG. 1 SCHEMATIC DIAGRAM OF 220/132 kV AUTO TRANSFORMER

High voltage winding is divided into twelve suitable sections and remaining all windings are grounded in accordance with the guidelines for standard tests by lightning impulse voltage. Since, the high voltage winding of transformer is centre entry type with two-group configuration, only one half is taken into account for simulation purpose.

The inductance and capacitance associated with the six sections are calculated and required matrices are formed. A method of calculation of inductance and capacitance parameter, matrix formation, impulse voltage calculation has been reported in earlier publications [12]. The equivalent network comprising self and mutual inductances and series and shunt capacitances is shown in Figure 2.

FFT of neutral currents with and without fault are taken with simulated fault. The comparison between two FFTs provides an indication of the inter turn failure. Larger differences in FR have been observed for winding movement or winding failures.

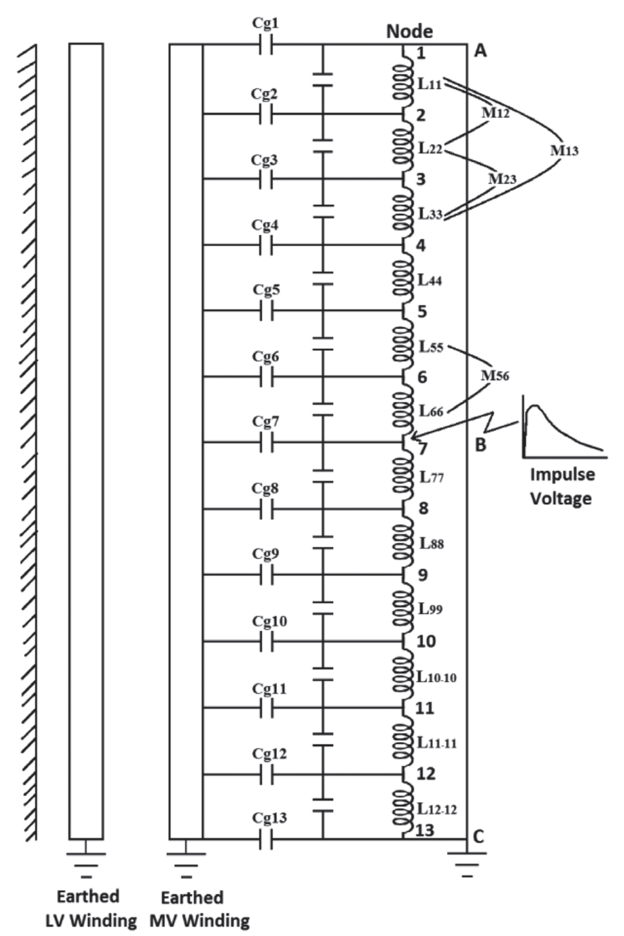

FIG. 2 EQUIVALENT CIRCUIT OF 220/132 kV TRANSFORMER

The method of CF calculation using real and imaginary value of FFT is discussed in earlier publications [6,7,10,11]. The present work uses the similar concept for winding movement in radial and axial directions.

3.0 RESULTS AND DISCUSSION

In order to simulate radial variation the radial gap between HV winding and core is changed. The neutral current is calculated with HV and core dimensions as per manufacturer details. The average radius of HV Winding as per design is specified to be 673.5 mm. The oil gap is increased by increasing the radius to 673.6 mm and once again neutral current is calculated. The neutral currents calculated for the two conditions are given in Figure 3.

The FFT of the neutral current corresponding to the above condition is shown in Figure 4(a) and their CF is Figure 4(b).

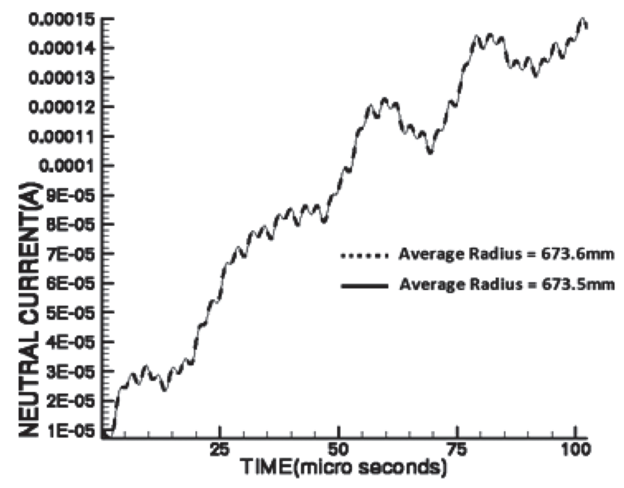

FIG. 3 NEUTRAL CURRENTS FOR RADII 673.5 mm AND 673.6 mm

The neutral currents for the two radii as shown in Figure 3 indicate a marginal difference in the magnitude of neutral current over the entire time range.

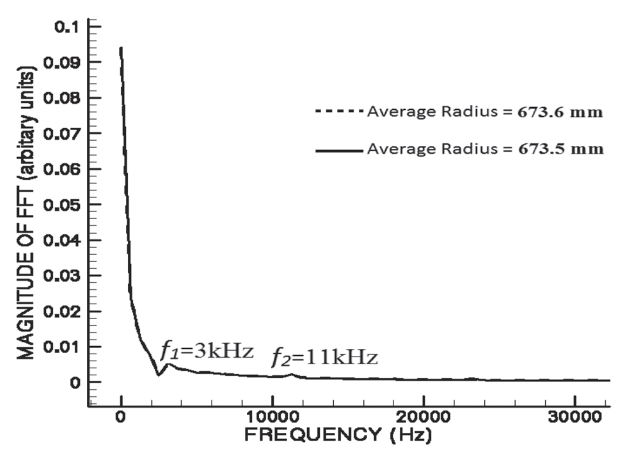

FIG. 4(A) FFT OF NEUTRAL CURRENTS FOR TWO RADII

Similarly, it is observed from Figure 4 (a) that there is a negligible difference between the two with regard to FFTs in respect of both frequency and magnitude. However, there is a considerable deviation in CF from unity for the above neutral currents at the associated frequencies as given in Figure 4 (b). As shown there are four dominant frequencies where considerable deviations from unity has occurred. These frequencies remain almost same for small radial variation upto 1 mm between 672.5 mm and 673.5 mm.

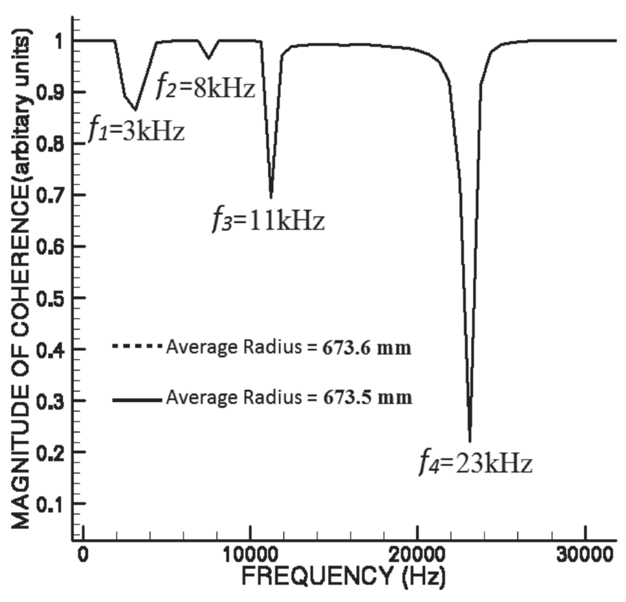

FIG. 4 (B) COHERENCE BETWEEN NEUTRAL CURRENTS OF FIG. 3

No definite trend is established between CF and radius for a given frequency. This is probable due to presence of other frequencies as seen in Figure 4 (a) and 4 (b) and changes in CF related to frequencies based on linearity of calculation as a function of frequency.

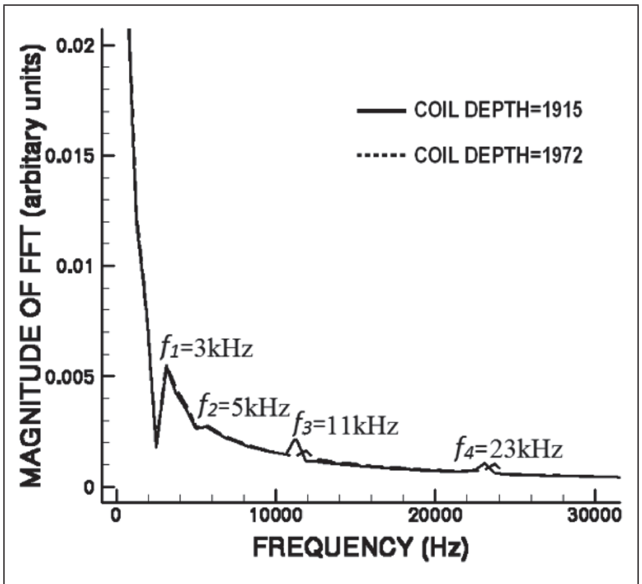

FIG. 5 (A) FFT OF NEUTRAL CURRENT FOR TWO COIL DEPTHS

Similar analysis is performed by varying coil depth from 1915 mm to 1972 mm. The variation in CD is achieved by varying the oil duct gap uniformly along the height of winding. For every variation in duct thickness, neutral current and FFT are calculated. CF is calculated for original duct and reduced/increased duct sizes. Figure 5 (a) shows the FFT of neutral current for CD of 1915 mm and 1972 mm.

It is observed that there are four dominant frequencies 3 kHz, 5 kHz, 11 kHz and 23 kHz. The magnitude and phase differences related to these frequencies are relatively low as seen in Figure 5 (a). A plot of CF as shown in Figure 5 (b) shows a marked deviation from unity, having the lowest values of about 0.21 at 11 and 23 kHz.

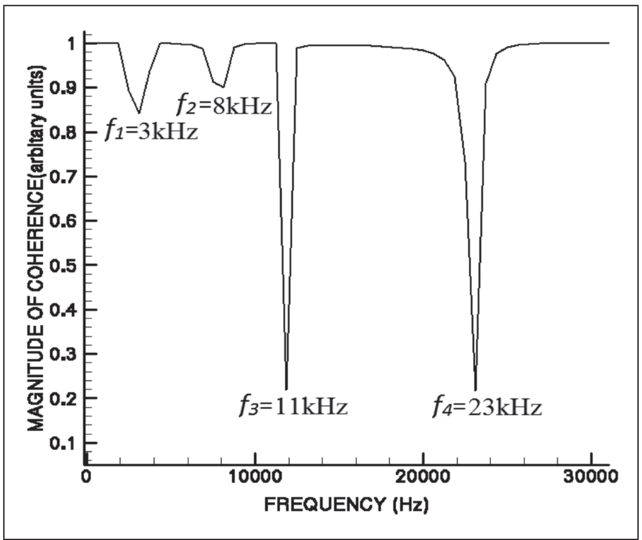

FIG. 5 (B) CF FOR THE FFT OF FIG. 5 (A)

To understand the variation of CF by varying coil depth results are obtained as shown in Figure 5(c).

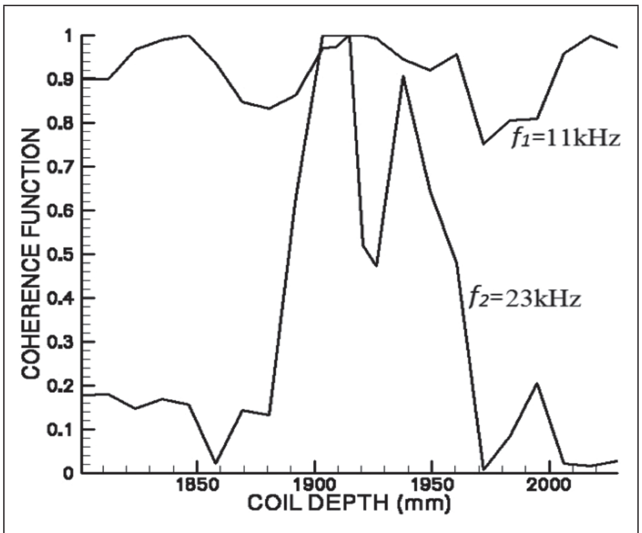

FIG. 5 (C) VARIATION IN CF FOR TWO DOMINANT FREQUENCIES

As seen in Figure 5c, the CF for two frequencies viz. 11 & 23 kHz have dominant variation. In each frequency there is a variation in magnitude for various CD between 1800 mm. min. and 2050 mm. max. No specific trend for a given frequency is observed since, new frequencies appear as a result of change in L and C. However, from all the results discussed above, it can be inferred that there exists a deviation in CF value from unity if the axial or radial variation of winding occurs and that its sensitivity of detection is higher than that obtained in FFT. Since the fault in a system gives rise to high current in transformers, the force generated due to fault current introduces variation in radial and axial direction. Therefore, Coherence Function can be used as an advantageous diagnostic tool.

4.0 CONCLUSION

Paper describes a method of determining CF for radial or axial variation in the winding of a transformer. The axial variation is achieved by varying the duct thickness uniformly along the height of the winding. The radial variation is done by varying the oil gap between HV and medium voltage winding. Calculation shows that both FFT and CF of neutral current can detect the movement in the winding. It is observed that the sensitivity of CF is higher and complementary to FFT.

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