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Detection of Winding Deformation In Power Transformers

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Abstract :This paper discusses the transfer function method as a tool for detection of winding deformations in power transformers. A series of transfer function measurements on selected transformer rating were carried out on the active part within the transformer and thereafter without bushings, oil and tank. using a network analyzer. The new transfer functions were measured after the application of the vertical and radial deformations to the windings and after the replacement of the active part in the tank and oil refilled. For this particular transformer construction, it is evident that only vertical deformations can be detected by the transfer function method.

Keywords: Power transformer, transfer function, frequency analyzer, transient.

1. Introduction.

Power transformer is the most expensive single element of high voltage (HV) transmission system. Normal operation, time aging and short circuit currents can cause mechanical deformation and displacement of transformer windings. This calls for decreasing the transformers' life cycle costs and to increase the usable service life. The monitoring and diagnosis of power transformers can be extended to all possible types of faults(Claudi and Loppachev, 1998, Islam and Ledwich 1997)..

The ability to withstand short circuit is a basic requirement for the operation of power transformers. This can be affected by thermal and transient mechanical stress which occurs during operation The transfer function is a diagnostic tool for detecting winding faults during standard impulse tests in laboratories(Leibfried and Fesser 2009). There is an evident difference in the characteristics of the transfer function if the fault is inside the transformer or in the test set up. The transfer function method is very sensitive to winding faults The transfer function method records the applied voltage and a response. The two signals are transformed to the frequency domain and the ratio between them is called the transfer function. This characterizes the transformer and deviations in this function can be tracked to partial discharges and short circuits (Malewski and Poulin 1988, Malewski et al 1995).

Applications of low voltage impulse (LVI) include the use of transfer function method for transformer windings diagnostics which will not detect partial discharges, but the sensitivity to voltage independent failures such as winding displacement and short circuits. An induction in winding failures is the deviation in the transfer function after ageing (Akbari et al 2009, Feser et al 2011).

A network analyzer with a built-in-tracking generator and capability to record two signals can be used for a direct application of an alternating voltage to measure the transfer function and increase the frequency of the applied voltage in steps(Liebfried and Feser 1998, Malewski and Poulin 2008).

Principles of the transfer function method.

The transfer function method is based on the two-port network theory shown in Figure 1 below.

Each defined output signal (output Voltages, $\underline{U}_{AV}$ and currents $I_{AV,}1,\ldots.n$) generates one transfer function according to(Akbari et al 2002,):

$$\text{Output Voltages: } I_{f\,Au,\,V}(f) = \frac{\underline{U}_{AV}(f)}{\underline{U}_{E}(f)} \qquad (1)$$

$$\text{Output Currents: } I_{f\,AL,\,V}(f) = \frac{\underline{U}_{AV}(f)}{\underline{U}_{E}(f)} \qquad (2)$$

$\underline{U}_{A,V}$ (f) : FFT of output voltages

$I_{A,V}$ (f) : FFT of output currents

$\underline{U}_{E}$ (f) : FFT of input Voltage

A transfer function signifies a complex quotient of the Fourier transformed output and input signals. The sensitivity to defects and changes in transformers' assemblies for each transfer function is different (Christian et al 2009, Gonzalez et al 2006).

Materials and Method.

A three single-phase transformer units each with four windings were coupled in parallel. The three single phase units were initially connected so that the primary and the two secondary were coupled in wye form while the tertiary windings were coupled in delta.

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Each core is made up of two legs and the windings were arranged according to Figure 1. The secondary windings are the outer winding of each leg. Both terminals of each four windings were available making up a total of eight bushings.

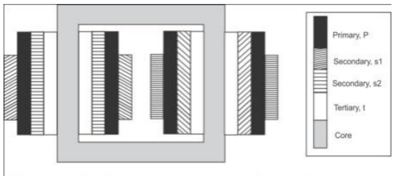


Figure 1. Arrangement of windings

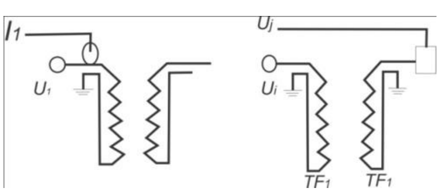
The transfer function can be determined either in the time or frequency domain. A network- analyzer is used to achieve the frequency domain analysis. The required bandwidth was used to control the frequency of a sine voltage excitation. The magnitude and the angle of the complex transfer function was then evaluated. Low or high impulse voltages were used for excitation of the test objects in the time domain while the input and output transients were measured and analyzed. The bandwidth of the exciting signal was made as high as possible. The spectral distribution of the time domain signals were then calculated by using a fast fourier transform. The quotient of output to input signal represents the transfer function in the frequency domain. Figure 2: shows the connection between the network analyzer and the power transformer.

Figure 2: Connection between the network analyzer and the power transformer.

The applied voltage was measured up on the transformer bushings.The response was either the applied current or the induced voltage on the other terminals. The voltage was applied at one side of a winding while the other side was grounded as shown in Figure 2. The other side of the winding was grounded when measuring the voltage response on a winding while all the other transformer terminals were opened during the measurement.

Two different transfer functions are defined:

$$TF_{1=} \frac{U_{i\,(w)}}{I_{i\,w)}} \; [0] \wedge TF_2 = \frac{U_i(w)}{I_j(w)} \qquad (4)$$



Where i and j refer to the numbering on the windins. The transfer function is also called the winding input impedance.

The transfer functions of the three transformer units were compared to reveal the difference in ageing of the transformers.

Figure 3 shows the transfer function of the high voltage winding of all transformer units. The transfer functions are equal for the whole frequency range.

This applies to the other measured transfer functions. This implies that there are no damages in this transformer.

In steps, the bushings were removed, the oil pumped out and the active part lifted out of the tank.

The influence of the bushing, oil and tank on the input impedance of the winding is shown in Figure 3. The general effect of removing the oil is a shift of the transfer function towards higher frequencies.

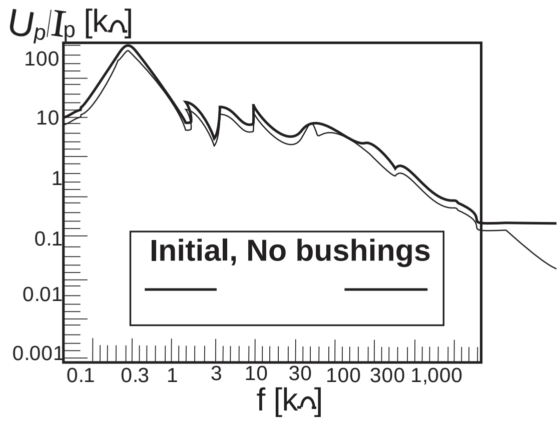


Figure 3(a)

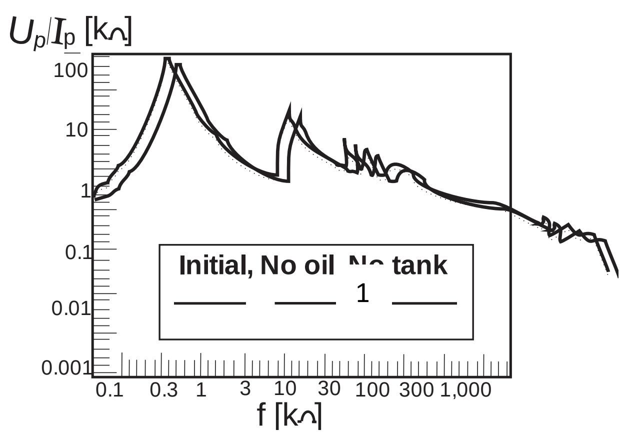


Figure 3(b):

Figures 3(a) and (b): Effect of the transformer bushings, oil and the tank on the input of the primary windings

Artificial damages were then applied to the outer secondary winding. The vertical deformation was introduced by cutting off the pressboard ring supporting the outer winding. As a consequence, the secondary winding was lifted a little bit downwards.

The effect of this larger vertical deformation was seen in the transfer function TF 2 only. The effect of the induced voltage on the vertical shift of the open secondary winding S1 is shown in Figure 4. The effect of the vertical shift is significant in a frequency band of around 100k HZ.

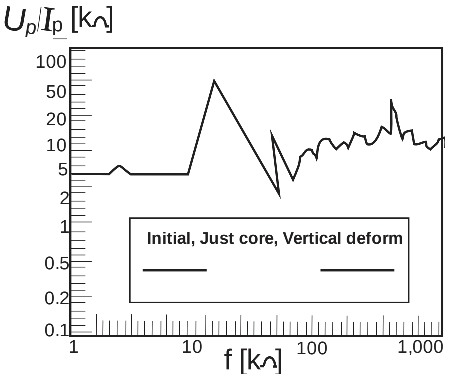


Figure 4: Effect of a vertical deformation on the windings.

Radial deformations are now added as the next stage by pressing a thrust bolt into the other secondary winding.

The transfer function $TF_2 = U_p/U_{s2}$ was measured during the compression process.

The changes observed were attributed to the radial deformation.When the thrust bolt was removed, the transfer functions returns to its original shape. The presence of the thrust bolt has the same effect on the transfer function as a minor short circuit as shown in Figure 5.

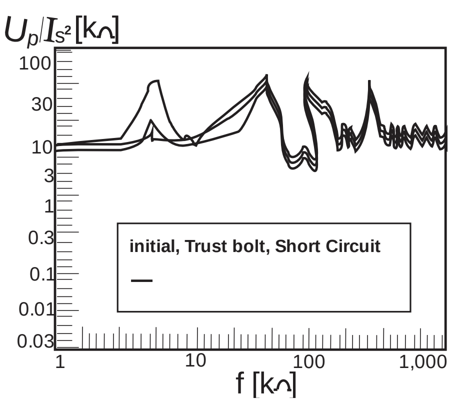


Figure 5: Effect of the presence of the thrust bolt and a short circuit in addition to a radial deformation on the windings.

The transfer function method is less sensitive to winding deformation when the oil and tank are not present. The active part was lifted back into the tank and the oil refilled. Several transfer functions were measured during this process. By reassembling the transformer, it implies that the sensitivity of the transfer function method is improved by the presence of the transformer tank. The transfer function between the high voltage winding and the damaged medium voltage windings after refilling the oil is shown in Figure 6.

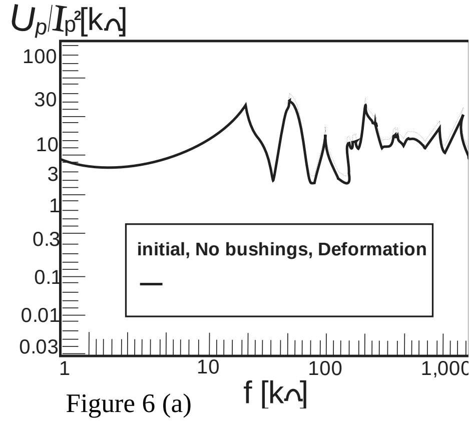


Figure 6 (a)

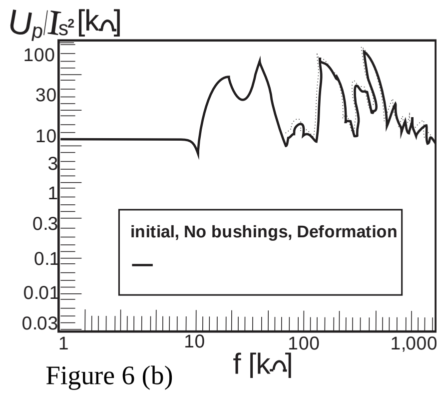


Figure 6 (b)

Figure 6 (a) and (b): Effect of deformation: Active part lifted back in tank and oil refilled.

Discussion of results.

The transfer function method has been used to detect the vertical deformation applied to the first secondary winding. The radial deformation applied to the second secondary winding was not detectable by the transfer function method. This is because the secondary winding of the investigated transformer consisted of several parallel coupled groups. Thus, a deformation in one of these groups have less effect on the total response of the windings.

The effect of deformation is not observed in the transfer function TF_1 , because they just reflect the response of a single winding and not its relation to other windings. The effect of the vertical deformation is observed in all transfer function TF_2.

Conclusion:

The transfer function method has been used to investigate a four-winding transformer with special focus on one of the single-phase units. The method represents a sensitive approach in the detection of faults in test set-ups and transformers.

The transfer functions were recorded directly by a network analyzer in the frequency domain, applying a low voltage signal in the frequency range of 100Hz-10MHz

The importance of bushings, transformer tanks and oil is investigated. Artificial damages were applied to the outer secondary windings. The vertical deformation is detectable by the transfer function method. The practical frequency range where changes in the transfer function are observed is 200-100KHz.

Recording induced voltages on other windings results in the most sensitive transfer function. The presence of the transformer tank and oil increase the sensitivity of the method. The sensitivity of the transfer function method with time domain measurements of voltages and currents was sufficient in a frequency range of 10Khz to 1Mhz..Below 10 Khz, the tail of the impulse was too short and above 1MHZ, the signal to noise ratio became too small. .

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