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A Review towards the Advancement of Sweep Frequency Response Analysis for Interpretation of Winding Deformations.

Anurag Kumar Burman[1], Alok Richariya[2], Dr. R K Jarial[3]

M.tech Scholar[1,2], Associate Professor[3]

Electrical Engineering Department

National Institute of Technology, Hamirpur, India

Abstract—Power Transformers are one of the most important and critical devices of any power system network. These transformers undergo various stresses and ageing regimes during their operational life time. Therefore diagnostic and assessment techniques of these transformers are of utmost importance in larger interest of all electrical utilities. Thus Sweep Frequency Response Analysis (SFRA) is a well established technique for assessing the core integrity and deformations if any, open and short circuit turns, axial or radial shift of the winding etc. that may be caused to it either during manufacturing processes, transportation, commissioning or during service life of the transformer. This test consists of measuring the impedance of the transformer over a wide range of frequencies and comparing the signatures with the reference set of results of that transformer. The difference from the reference may indicate the extent of the damage to the transformer. This paper presents the complete review on diagnostic using SFRA technique and hence its key role in identification of severity of the faults of transformers.

Keywords: SFRA, power transformers, mechanical deformations, commissioning, diagnostic, deformations.

Introduction

Power transformers are one of the most important and a significant asset of power system, and any unexpected outage or transformer failure can have a significant impact on the operational economics of power system. High voltage power transformers are subjected to many transformer stresses and fatigues during their entire lifespan due to transportation, manufacturing, commissioning, short circuit forces and ageing. Such stresses may develop core deformation, mechanical irregularities of the core, deformation of the windings which can lead to the catastrophic failure of the transformer. Hence test to detect the winding disintegrity and deformation are of utmost importance for the safe operation of the transformers.

As we know that SFRA mainly consists of measuring the impedance of the transformer over a wide range of frequencies and comparing the results with the reference set of values. There are basically two methods of injecting the broad range of frequencies i.e., either by injecting an impulse into the winding or by making a frequency sweep using a sinusoidal signal. The former method is generally known as impulse response method and the later one is known by swept frequency method. The basic measurement circuit can be shown as Figure 1.

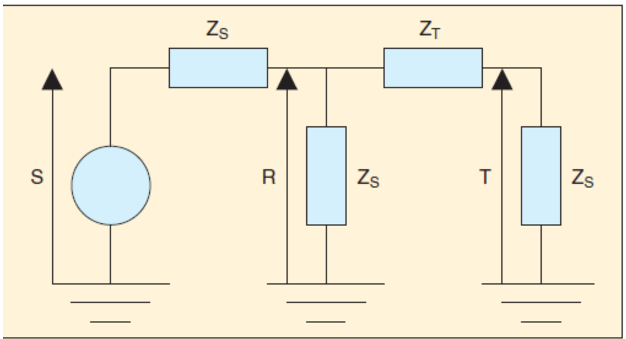

Figure 1. Basic measurement circuit

A detailed merits and demerits of these two methods can be found in [1]. Impulse response method has an advantage of shorter time duration over swept frequency method. Swept frequency method has advantage of better signal to noise ratio, high precision over complete frequency range, less measuring equipment and a wide range of frequency injected.

The swept frequency method is made use of by the world known equipment i.e., network analyzer to facilitate generate the sample signal of 10 to 20 volts, help make measurements depending upon several combinations of transformer connections, obtaining signatures/ patterns of subsequent responses like a two port network and help calculate the results. A number of network analyzer are commercially available in the market such as Doble M5000 series, Omricon network analyzer, Megger's FRAX series and so on .

Network analyzer injects the low voltage signal of 10 volts and records the amplitude response of the signal over a wide frequency range. The analyzer generally records the signal from 20Hz to 2MHZ in decreasing order of frequency. A sample signal can be shown in Figure 2. The sample SFRA signal can be found in [10].

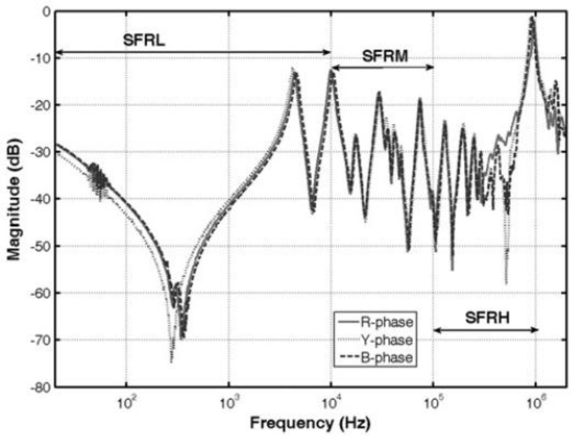

Figure 2. Sample SFRA curve

The fault to be detectable the fault must cause either inductance or capacitance of the winding to change by a significant amount. The faults which do not cause any change in these values are not detectable by the test. The faults such as short circuit turns change the magnetizing characteristics of the transformer and thus change the lower frequency response.

Circulating currents redirect the leakage flux into the core and hence change the low frequency response. The shunt capacitance of the winding is changed by an ungrounded core which also change the low frequency response.

Basically medium frequency response is susceptible to faults that cause changes in whole winding property. A considerable increase in the medium frequency response indicates the axial movement of the winding and a considerable decrease in the medium frequency response indicate the radial movement of the winding.

The high frequency responses are mostly sensitive to the faults that results changes in the properties of the part of the winding. The localized winding damage results in the random change in high frequency response and often leading to the creation of the new resonant frequencies. Tank or cable grounding also affect the high frequency response. Poor tank grounding is generally easy to find as it change all the windings but basically confined to one winding.

The comparison can be done basically by three ways. Firstly time based comparison in which comparison is made on the same winding using same set of instruments earlier. It generally gives idea about the ageing pattern of the transformers. Secondly. Inter-phase comparison is possible with three phase transformers owing to differences in the magnetizing inductance among the three phases lead to changes in the FRA results of three phases. Thirdly, comparison among sister transformers is also possible. It can be particularly helpful for the single phase transformers forming the banks of three phase.

Comparison can be done by plotting the graph of amplitude against frequency and observe the differences such as changes in shape of curve, creation or elimination of resonant frequencies and large shift in the existing resonant frequency. A technique is to calculate statistical indicators of the amount of agreement or disagreement of the two curves. This is more transparent because these statistical indicators clearly indicate the amount of differences between the two curves[2].

Instrument description

There are a wide range of instrument available ranging from Doble M5000 series to Megger's FRAX SFRA analyzer to detect mechanical failures and movement of the windings from mechanical stresses, short circuit stress, transportation and ageing. The instrument sends an excitation signal to the transformer and measure the returning signal. It allows us to compare the signal from the baseline signals and reach to a proper conclusion regarding the deviations and confirm the mechanical disintegrity. The SFRA analyzer identifies the following abnormalities before the catastrophic failure

a. Core movement
b. Winding disintegrity and displacement

c. Hoop buckling
d. Partial winding collapse
e. Faulty core grounds
f. Shorted turns
g. Open winding
h. Broken or loosened clamping structures

Figure 3. Latest Doble M5400 SFRA test kit

The latest instrument of Doble is M5400 which has the following features and shown in figure 3.

- 1. Provides a frequency response from 10HZ to 25 MHz
- 2. Measures frequency response logarithmically spaced intervals of 1.2%
- 3. Auto-scales each frequency measurement for an overall dynamic range of 80 dB with a ±1 dB accuracy.
- 4. Highest combination of dynamic range and accuracy available.
- 5. Ensure transformer performance, reduce maintenance costs and increase the service life of transformers

Theoretical background

Before the invention of SFRA method, impulse testing of power transformers were carried out which was proposed by W.Lech and L.Tyminski in 1960 for the detection of deformations in the transformers [13]. In this method neutral current was analyzed against the impulse voltage. And in 1966 they published results as "Detecting transformer winding damage-The low voltage impulse method:, in the electric review, ERA, UK.

The swept frequency response method was invented by Dick and Erven of Ontario hydro research laboratories in 1978 and their literature can be found in [3]. After that in 1988-1990 the trials were proved by the European utilities, internationally via euro Doble and CIGRE. Since then many case studies were published and advancement is being carried out in this method simultaneously.

Apart from the advancement in the interpretation of FRA results there is still a need to improve the interpretation technique of FRA signature. Diagnostic method which is based on non physical analysis through waveform comparison and indicators of statistics is discussed in [4]. The paper conclude that this method of interpretation is not feasible until now since one of the most important parameter which is winding series capacitance is not accurately determined in the transformer.

To detect electrical parameters of transformers for the diagnostic of failures and interpretation of FRA results in low and mid frequency range new method based on impedance is proposed in [4]. It detects the frequency-dependent impedances of core sections, leakage, zero-sequence paths, and winding capacitances. It also interpret the various standard and non-standard frequency responses which is voltage ratio and input impedances [5]. The studies so far concludes that the SFRA method alone is not sufficient to detect any kind of detail of failure because of the mechanical winding failure are associated with leakage inductances and different capacitances.

Recent research and advancement attempted to show that interpretation of SFRA results by applying statistical and mathematical indicators are quite successful. Statistical indicators are well established technique used by mathematicians. They are basically based on degree of agreement and disagreement between two sets of measurements or normal and abnormal conditions. These parameters are exact and transparent and also can be accomplished by automation detection procedures. Some parameters such as correlation coefficient and maximum absolute difference are proposed in [6]. These Statistical approach become a useful tool to overcome a problem of universally acceptance as previously there is no method which is accepted universally. Many researchers attempted different statistical indicator to interpret SFRA results such as correlation coefficient (CC), standard deviation, mean square error, absolute difference (DABS), minimum maximum ratio(MM), spectrum deviation, ratio of area under curve and deviation of area under curve, t-test, f-test, harmonic mean etc[11],[12],[6],[10].

The application of fuzzy logic algorithm(FLA) for the for automatic analysis and interpretation of SFRA results are proposed in [7]. FLA evaluates the curve obtained by subtracting the current and the reference frequency-response curve in three different frequency ranges, each related with a particular defect type, i.e., short circuit between turns, radial and axial displacements. FLA is then adopted to take into account that the uncertainty in the identification of the different defects in these three frequency range. Using this techniques different types are identified using de-fuzzification into different predicates. Then each predicate is related to a particular defect with a membership function that shows coincidence with the degree of output. The validation test shows that the this algorithm is capable to distinguish between the normal and abnormal condition of the transformer and different types and levels of the winding faults. This method has many advantages that it is less susceptible to background noise and or small differences or external effects. Thus this method can be most reliable in diagnosis of the transformer[7].

Digital image processing can aim at improving the diagnosis of the SFRA results using pictorial representation. Digital image can represent a two dimensional matrix that consist of finite or limited number of pixels into it with the dimension of X × Y. the most important step in this acquiring the results in SFRA polar plot image. This method of interpreting can be built in any frequency analyzer to give a facility for automatic image capturing in polar plot. It is basically based on geometric dimension, texture analysis and invariant moment extraction techniques that are used to standardize and digitize the process of fault identification using SFRA analyzer[8]. It can be widely used to identify and quantify the results of SFRA. This technique is simple, fast, easy to accommodate in the FRA analyzer and to automate the results of SFRA for fault identification.

Future prospects of SFRA

One latest technique is proposed for the interpretation of faults using SFRA by the use of magnitude and angle of FRA signature in one single polar plot. It will capture all the features of SFRA in one plot to increase the reliability of the interpretation [9]. This method also helps to automate the results so that reliability of expert opinion can be astonished and results can be widely accepted. It is easy to implement with the FRA analyzer incorporated with digital image processing so that automation can be one in a more efficient way.

There is a need of improvement in the online monitoring of the SFRA results. For on line monitoring the injected signals must be exclusively controlled signals and mathematical procedure must be lighter so that a fast and continuous monitoring can done. For instance wavelet transform can be applied to filter the signals which can be a good tool to interpret the SFRA results.

Conclusion

The present paper covers salient points of the established tool, SFRA which is a proven and most widely used technique for the interpretation of winding deformations. It is widely accepted technique worldwide to determine the winding disintegrity. Since the variations in FRA comparisons can change from transformer to transformer, it is not an easy task to detect the catastrophic failure type and failure level based only on waveform identification alone. So, Continuous advancement is going out to standardize the results so that there will be no need of experts and one method can be universally accepted. Automation and digitization of the SFRA results are being carried out so as to display the fault with highest accuracy and which can be accommodated with the FRA analyzer. Progress is also going on the online SFRA monitoring so that there will not be a need of shutdown of the transformers.

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