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Sweep Frequency Response Analysis (SFRA) For Detection of Transformer Mechanical Integrity

Kaushikkumar Dhola[1], Shaktisinh Gohil [2], Bhavin Seta[3]

[1]*Electrical Engineering, Parul Institute of Engineering and Technology, Vadodara,*
[2]*Electrical Engineering, Parul Institute of Engineering and Technology, Vadodara,*
[3]*Electrical Engineering, Parul Institute of Engineering and Technology, Vadodara,*

Abstract — *Transformer is no nuisance equipment. It is static equipment and it works reliably unless it is abused. Transformers do not develop fault within itself, if maintained periodically as per manufacturer's recommendation. However, the same transformer when subjected to external abnormalities, it can develop fault due to some of the reasons. This paper presents technical details regarding Sweep Frequency Response Analysis (SFRA) and the role it plays in transformer test and maintenance. SFRA is an electrical test that provides information relating to transformer mechanical integrity. A new technique for a better and faster sweep frequency response analysis (SFRA) results' interpretation like External Short Circuit which exerts electromagnetic forces on transformer windings. The winding can move laterally and thus it weakens the mechanical structure of transformer. The physical displacement or damages either during earthquake, lightning or other environmental events, In above situation, to diagnose the problem, prevent expensive equipment breakdown and to take control of the equipment, the technique of "Sweep Frequency Response Analysis (SFRA)" can be employed to detect the faults in Transformer core and Winding movement.*

Keywords- *SFRA; SFRA Test; Method of SFR; Uses; advantages and SFRA analysis can detect problems*

I. INTRODUCTION

Sweep frequency response analysis (SFRA) for the assessment of winding displacements and deformation in power transformers. Sweep Frequency Response Analysis (SFRA) is a powerful and sensitive method to calculate the mechanical integrity of core, press frames, windings and clamping structures within power transformers by measuring their electrical transfer functions over a wide frequency range. Every electrical network has a unique frequency response it is called 'fingerprint'. Network faults or vibrations can cause changes in this frequency response. Testing the frequency response particularly of transformer after transporting transformers and after faults at high currents has occurred. The testing solution is for checking if windings have been damaged and then initiate any further action that may be necessary.

Sweep frequency response analysis to detect mechanical failure or movement of windings from short circuits, mechanical stresses, or transportation. The instruments send an excitation signal into the transformer and measure the returning signals. Comparing this response to other results (such as from similar units) allows you to identify deviations and confirm internal mechanical problems.

The standard definition of frequency response analysis (FRA) is the ratio of a steady sinusoidal output from a test object subjected to a steady sinusoidal input. Sweeping through the frequency range of interest gives rise to the S in SFRA, to distinguish it from impulse methods, which estimate the response rather than measure it. SFRA is a prove technique for making accurate measurements. As compared to the "impulse" technique, SFRA is preferred for frequency domain measurements. Impulse results have poor resolution, lack the range required for a portable field instrument translating in poor diagnosis and are usually unrepeatable It covers the full dynamic range and maintains the same energy level for each frequency, providing accurate, consistent results. A high signal-to-noise ratio across the entire 20 Hz to 2 MHz (default range) frequency range ensures valid measurements.

1.1. How to work SFRA

Transformers consist of multiple complex networks of capacitances and resistors that can define a unique signature when tested at discreet frequencies and plotted a curve. The distance between conductors of the transformer forms a capacitance. When movement of the conductors and windings are change in this capacitance. This capacitance being a part of complex inductance, Resistance and Capacitance network, any change in this capacitance will be reflected in the curve or signature. Impedance of an ideal resistor, capacitor and inductor are conceders.

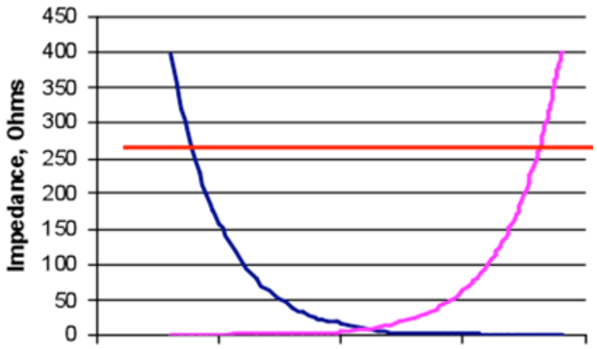

Figure 1. Impedance of an ideal resistor, capacitor and inductor

Where fig.1 is,

- Resistance (red colour): Flat response vs. frequency
- Inductor (blue colour): Increased impedance with increased frequency; dead short at low frequency
- Capacitor(pink colour):Reduced impedance with increased frequency; open circuit at low frequency

SFRA test is carried out to obtain the signature of the transformer frequency response by injecting various discreet frequencies. This reference is then used for future comparisons as well as detects the problems regarding power transformer. A change in winding position, degradation in the insulation, etc. will result in change in capacitance or inductance thereby affecting the measured curves. Tests are carried out periodically or during major external fault like short circuits and results compared against the initial signature to test for any problems.

II. SWEEP FREQUENCY RESPONSE ANALYSIS TEST (SFRA TEST)

This is very reliable and sensitive method or tool kit for condition monitoring of the physical condition of transformer windings. The test can be done with the unit full of oil or empty. The winding of transformer may be subjected to mechanical stresses during transportation, heavy short circuit faults, transient switching impulses and lightening impulses etc. These mechanical stresses may cause displacement of transformer windings from their position and may also cause deformation of these windings. Windings collapse in extreme cases, such physical defects eventually lead to insulation failure or dielectric faults in the windings.

Sweep Frequency Response Analysis Test or SFRA Test can detect efficiently, displacement of transformer core, deformation and displacement of winding, faulty core grounds, collapse of partial winding, broken or loosen clamp connections, short circuited turns, open winding conditions etc.

2.1. Principle of SFRA Test

The principle of SFRA is quite simple. As all the electrical equipments theoretically have some resistance, inductance and some capacitance values hence each of them can be considered as a complex RLC circuit. The simplified network behaviour of a transformer's active part is shown as fig.2.

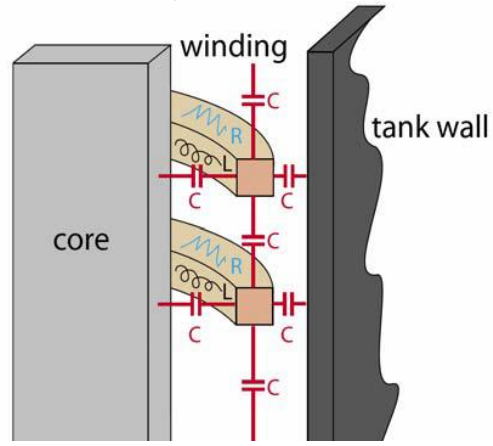

Figure 2. The simplified network behavior of a transformer's active part

The term theoretically means some equipment may have very low or zero resistance compared to their inductance and capacitance values again, some equipments may have very low or zero inductance compared to their resistance and capacitance and again some equipments may have very low or zero capacitance compared to their resistance and inductance but theoretically all of them can be considered as RLC circuit although may be R = 0, or L = 0 or C = 0. But in most cases the resistance, inductance and capacitance of an equipment have non zero values. Thus most of the electrical equipments can be considered as RLC circuit hence they response to the sweep frequencies and produce unique signature. As in a transformer each winding turn is separated from other by paper insulation which acts as dielectric and windings themselves have inductance and resistance, a transformer can be considered as a complicated distributed network of resistance, inductance, and capacitance or in other words a transformer is a complicated RLC circuit. Because of that each winding of a transformer exhibits a particular frequency response.

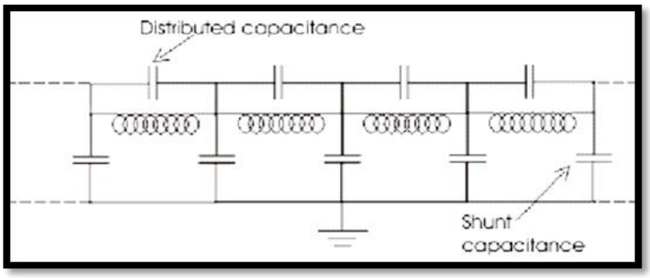

Figure 3. Distributed RLC network of transformer

In Sweep Frequency Response Analysis (SFRA) a sinusoidal voltage Vi is applied to one end of a winding and output voltage Vo is measured at the other end of the winding. Other windings are kept open. As the winding is itself a distributed RLC circuit it will behave like RLC filter and gives different output voltages at different frequencies. That means if we go on increasing the frequency of the input signal without changing its voltage level we will get different output voltages at different frequencies depending upon the RLC nature of the winding. If we plot these output voltages against the corresponding frequencies we will get a particular patter for a particular winding. After transportation, heavy short circuit faults, transient switching impulses and lightening impulses etc, if we do same Sweep Frequency Response Analysis test and superimpose the present signature with the earlier patterns and observe some deviation between these two graphs, as per as bellow we can asses that there is mechanical displacement and deformation occurred in the winding. In addition to that, SFRA test also helps us to compare between physical conditions of the same winding of different phases at the same tap position. It also compares different transformers of the same design. For example as shown in fig.4, the actual signal and the reference signal compare in frequency response, where frequency response is not match at blue circle.

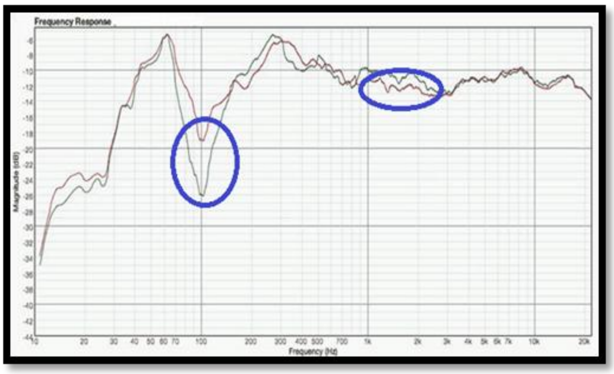

Figure 4. Frequency Response

2.2. Analysis of Test

Low frequency response

- Winding behaves as a simple RL circuit formed by series inductance and resistance of the winding (At low frequencies capacitance as almost open circuit)
- At low frequency winding inductances are determined by the magnetic circuit of the transformer core.

High frequency response

- At high frequency winding behaves as RLC circuits

- Winding exhibits many resonant points
- Frequency responses are more sensitive to winding movement

III. METHOD OF SFRA

The SFRA is a comparative method, meaning an evaluation of the transformer condition is done by comparing an actual set of SFRA results to reference results.
Three methods are used:

- Type-based – SFRA of one transformer will be compared to an equal type of transformer.
- Time-based – current SFRA results will be compared to previous results of the same unit.
- Phase comparison – SFRA results of one phase will be compared to the results of the other phases of the same transformer.

3.1. Uses of SFRA

- Periodic checks as part of regular maintenance
- Immediately after a major external event like short circuit
- Transportation or relocation of transformer
- Earthquakes
- To obtain initial signature of healthy transformer for future comparisons
- Pre-commissioning check

IV. SFRA ANALYSIS CAN DETECT PROBLEMS IN TRANSFORMERS AS FOLLOWING

Figure 5. Problem in core and winding

- core movement
- winding deformation – axial & radial, like hoop buckling, tilting, spiraling
- displacements between high and low voltage windings
- broken clamping structures
- partial winding collapse
- shorted or open turns
- Hoop buckling
- Shorted turns and open winding
- faulty grounding of core or screens
- problematic internal connections
- Detect hidden transformer faults
- Shorted turns and open windings

- Bushing Failures

4.1. Advantages of SFRA

- Sweep Frequency Response Analyzer to ensure transformer performance, reduce maintenance cost, and increase service life.
- Check new transformers to verify condition.
- Improve the quality of your regular inspection program.
- Combat system problems, such as short-circuit faults that can damage transformers.
- Inspect for damage if the transformer has experienced mechanical stress or after earthquakes, lightning, or other environmental events.

4.2. Application of SFRA

Power transformers are specified to withstand mechanical forces from both transportation and in-service events, such as faults and lightning. However, mechanical forces may exceed specified limits during severe incidents or when the insulation's mechanical strength has weakened due to aging. A relatively quick test where the fingerprint response is compared to a post event response allows for a reliable decision on whether the transformer safely can be put back into service or if further diagnostics is required.

V. SFRA TEST RESULT DATA SHEET AS PER BELOW

Date of Test:	Time of Test:
Name of Industries:	Location:
Test Object:	Manufacturer:
Serial No.	Year Of Built:
Phase Design:	Winding Configuration:
KVA Rating:	KV Rating:
LTC Position:	NLTC Position:
Purpose of Test:	Temperature:
Tested By:	

VI. CONCLUSIONS

In this paper, The SFRA is a powerful and sensitive method for the detection and diagnosis of defects in the active part of power transformers. It can deliver valuable information about the mechanical as well as the electrical condition of core, windings, internal connections and contacts. No other single test for the condition assessment of power transformers can deliver such a diversity of information. Therefore the SFRA is an increasingly popular test.

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