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# DIAGNOSIS OF TRANSFORMER USING FREQUENCY RESPONSE ANALYSIS

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*Abstract*— Frequency Response Analysis (FRA) is a tool that can give an indication of core or winding movement in transformers. This is done by performing a measurement, through a simple one, looking at how well a transformer winding transmits a low voltage signal that varies in low frequency to high frequency. The primary objective of SFRA is to determine how the impedance (Z) of a test specimen behaves over a specified range of applied frequencies 20Hz to 2MHz. A tool to investigate mechanical integrity of transformers, when the transformer after relocation, after an incident like any fault occur in the substation and to get a baseline and to get the developing faults in the transformers.

*Keywords— **FRA***, **Mechanical integrity, relocation.**

## I. INTRODUCTION

Power transformers are main component of Electrical Power Transmission and Distribution networks. They are also the most expensive equipment within the substation. Their performance will determine, to a large extent, the quality of power supply. It must be necessary to continuously monitor and assess the condition of transformers in order to ensure reliability and availability of power supply. Frequency Response Analysis (FRA) is a technique used to externally monitor and assess the condition and mechanical integrity of transformer windings “Adel et al (2015)”. This FRA technique calculates and computes frequency-dependent variables of the transformer’s windings, (i.e.,) inductance and capacitance. It is the distributed winding parameters that will change when the windings are; short-circuited, open-circuited, deformed, or loose. The FRA test is performed by injecting a low voltage impulse waveform into one end of a transformers winding and measuring the voltage appearing at the other end of the same winding. The ratio of the transfer function of the input to the output voltage is then plotted on a frequency domain graph. FRA can be used and applied as a reliable transformer condition-monitoring tool to help assess winding condition without the need to open the transformer for inspection. The FRA technique can help maintenance personnel identify suspect transformers, enabling them to take those transformers out of service before failure. Frequency Response Analysis (FRA) is a tool that can give an indication of core or winding movement in transformers, inter-turn shorts, bushing clamp failure and developing faults etc., “Muhammad et al”.

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The rest of the paper is organized as follows. Proposed FRA method introduction, SFRA measurement, Frequency response analysis test kit at field, Test leads, Physical test connection of transformer bushings and testing method in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

## II. PROPOSED FRA METHOD

### *A.* Introduction :

The principle of FRA is quite simple. As all the electrical equipments theoretically have some resistance (R), inductance (L) and some capacitance (C) values hence each of them can be considered as a complex RLC circuit. The term 'theoretically' means some equipment may have very low resistance compared to their inductance and capacitance values. Again, some equipment may have very low inductance compared to their resistance and capacitance. And again some equipment 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 Resistance (R) = 0 or Inductance (L) = 0 or Capacitance(C) = 0. But in most cases the R, L and C of an equipment have non zero values. Hence most of the electrical equipments like transformer, generators can be considered as RLC circuit and they response to the sweep frequencies and produce and unique signature.

As in a transformer each winding turn is separated from other by insulated paper which acts as dielectric and windings themselves have inductance (L) and resistance (R), a transformer can be considered as a complicated distributed network of resistance (R), inductance(L), and capacitance (C) or in other words a transformer is a complicated RLC circuit. A transformer does relate to its Impedance, the impedance is related to the Capacitive and Inductive elements of physical construction of the transformer. The impedance is a distributed network of active and reactive electrical components. The components are passive in nature, & can be modeled as resistors, inductors, & capacitors. The reactive properties of a given test specimen are dependent upon and sensitive to changes in frequency. Change in impedance versus frequency can be dramatic in many cases. This behavior becomes apparent when we model the impedance as a function of frequency (f). The result is a transfer function representation of the RLC network in the frequency domain.

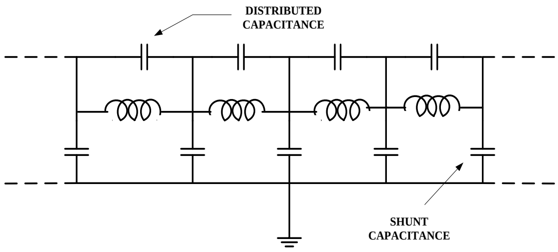


Figure 1 - Distributed RLC Network of Transformer

Resistor-inductor-capacitor (RLC) circuits:

To summarize, in a circuit where the supply alternates at a frequency f, and an angular frequency ω, is given by:

$\omega = 2\Pi f$ -------------------- Eqn (1)

We can identify the reactances of discrete ideal (pure) components as:

For a resistor, value R, the reactance is R at all frequencies

For a capacitor, the reactance, Xc, is given by:

$Xc = 1/2\Pi fc$ ------------------- Eqn (2)

Xc reduces as frequency rises. Current leads voltage by a quarter of a cycle (90̊) in a capacitor; alternatively, it could be said that voltage lags current by a quarter cycle.

For an inductor the reactance, $X_L$, is given by:

$X_L = 2\Pi fL$ -------------------- Eqn (3)

$X_L$ Increases as frequency (f) rises. Voltage leads current by a quarter of a cycle (90°) in an inductor (or current lags voltage by a quarter cycle).

The impedance of individual components varies with frequency (f) , as shown in Figure 2.

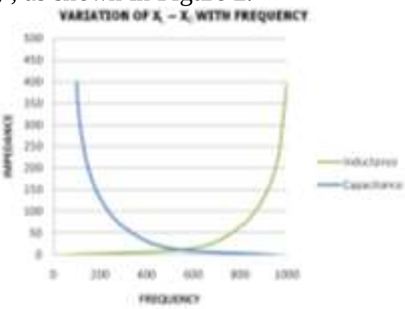


Figure 2 - Variation of $X_L$ and Xc with Frequency

B. SFRA Measurement:

Sweep Frequency response analysis plots the ratio of the transmitted voltage (Vout) waveform to the applied voltage (Vin) waveform in dBs, as defined in Equation 5. The impedance attenuates the input voltage signal.

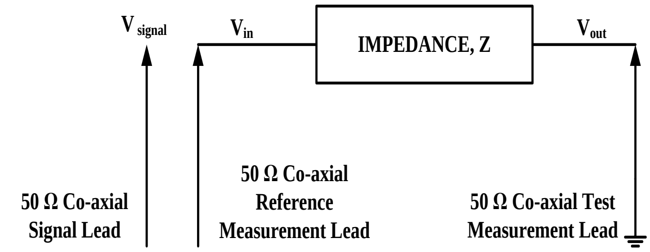


Figure 3 - Measurements of Voltages for SFRA

The basic measurement circuit is shown in Figure 3. To remove the effects of test leads, a three lead system is used to measure both input and output voltages simultaneously.

Coax test leads of 50 ohms are used to apply a source voltage and measure that voltage as $V_{in}$; consequently $V_{out}$ is referenced against the 50 ohms test lead to ground.

$V_{out}/V_{in} = 50 / (Z+50)$ --------------- Eqn (4)

Where Z is frequency dependent for an inductor or capacitor or a combination of the two. We were to measure this circuit using an SFRA test set; we would plot the response in dB rather than in ohms.

The response in dB's is calculated via the equation:

Response in dB's = $20 \log_{10} (V_{out}/V_{in})$ ------ Eqn (5)

"Al-Amin. et al (2016)"

From Equation (7) the response D in dBs for Impedance, Z is given by,

$D = 20 \log_{10} (50(Z+50))$ ---------- Eqn (6)

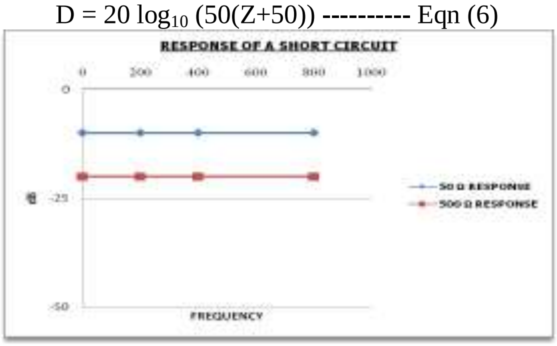


Figure 4 - RESPONSE OF A SHORT CIRCUIT

*C.* Frequency Response Analysis Test Kit At Field:

Figure 5**. M5200 FRA kit at field**

Figure.5 shows that the field connection of Frequency response analysis test kit. Details of the test kit as follows:

Yellow BNC termination is the source channel. Red BNC termination is the Reference channel, Black BNC termination is the Measurement channel. Ethernet port is interfaced with the laptop computer. Laptop is used to record the FRA kit processed output waveforms. It is used to maintain the history of the transformer analyzed (previous datas) finger prints. Black copper cable used for test kit ground.

D. Test Leads:

Figure 6-Test Leads

Figure 7-Earth lead

Figure 6 shows that the test leads used in the Frequency Response Analysis kit.

Details as follows: Red color clamp is the source input and green color clamp is the corresponding ground clamp. Black color terminal is the measurement clamp and black clamp is the corresponding ground clamp.

Figure 7 shows that the copper ground cable for the test kit.

E. Physical Test Connection Of Transformer Bushings:

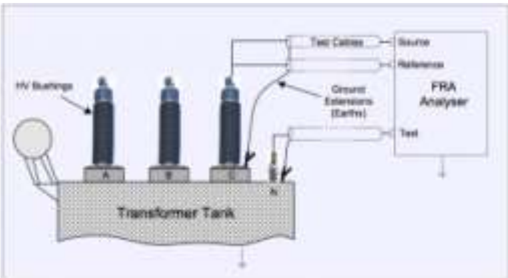


Figure 8- Test Connection

Figure 8 shows that the Open circuit test of the connection details at Power transformer using Frequency Response Analyser.

Source channel cable Red clamp connected at the top of the HV bushing and corresponding green cable connected to the turret of the bushing. Test channel cable Black clamp connected to the top of the Neutral bushing and corresponding green cable connected to the turret of the neutral bushing. Test kit ground cable connected to the ground. After proper connections made test starts through the laptop and the output traces were recorded in it for analysis. The recorded wave form compared with previous bench mark or previous records and the deviated frequency range noted for analysis of kind of fault occurred in transformer.

III. EXPERIMENT RESULT

A. Bushing Clamp Failure Generator Transformer Traces:

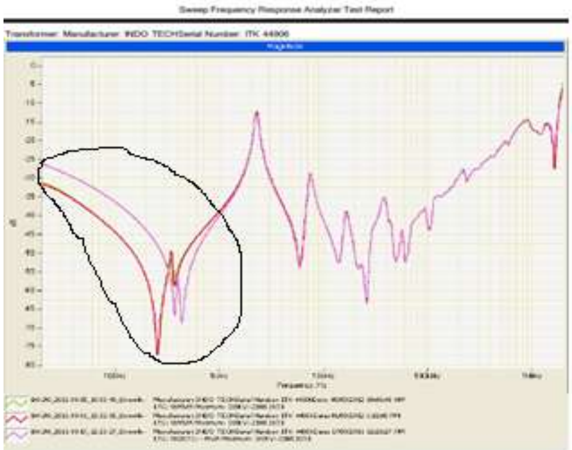

Figure 9-Open circuit test result HV-W ph

Figure 9 shows open circuit HV W phase (1W – 2W), marked portion shows that the deviation of plots.

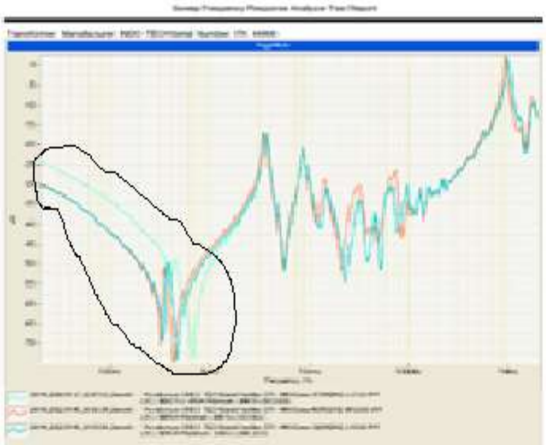

Figure 10- Open circuit test result IV-W ph

Figure 10 shows open circuit test IV side W phase, marked portion shows that the deviation of plots.

From that traces we came to know that two traces were coincided, it were measured during annual maintenance and one trace was not matched with other two, it was measured at the time of commissioning.

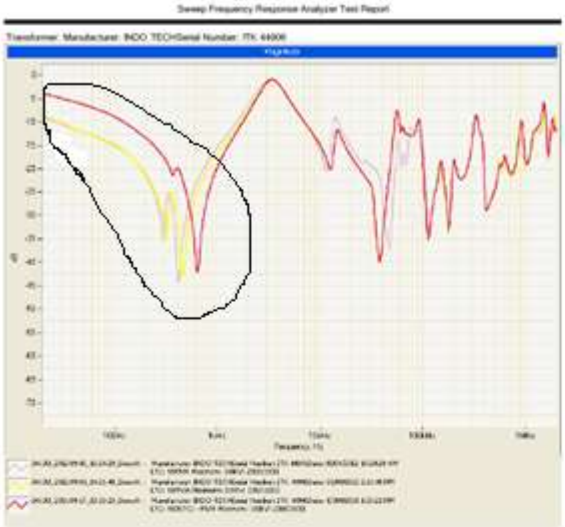

Figure 11-Open circuit test result LV –W ph

Figure 11 shows that Open circuit test LV side W phase, marked portion shows that the deviation of plots.

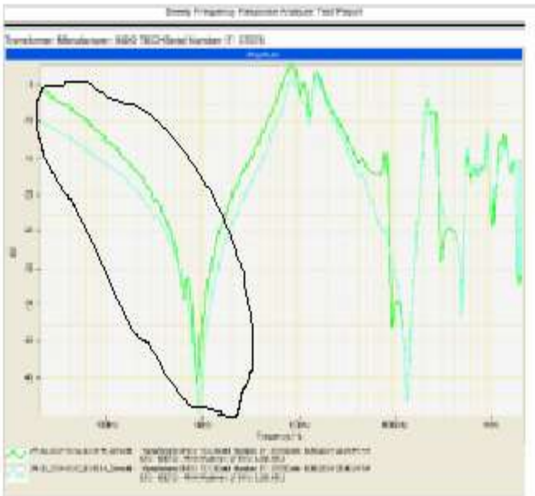

Figure 12-Open circuit test result 2W

Figure 12 shows that Open circuit test on LV side 2W – 2U, marked portion shows that the deviation of plots.

From that output we came to know that the traces were measured during annul annual maintenance was deviated from the commissioning time trace.

In all traces the deviation occurred at the initial stage of traces, i.e., in the frequency range of 100 Hz to 1 kHz range. It covers the bushing portion of the transformer, hence we went for physical inspection and find out the bushing clamp failure fault and rectified it.

B. Images Of Damaged Bushing Clamps:

Figure 13- Faulty portion of bushing

Figure 13 shows that the clamp damages identified at bushing .

Figure 14- Damaged bushing clamp

Figure 14 shows that the damaged clamps after released from the bushing of the transformer.

## IV.CONCLUSION

The FRA is a powerful 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 method for the condition assessment of power transformers can deliver such a diversity of information. After the analysis of the results, it appears that SFRA can easily and reliably be used to detect inter-turn faults, it should be possible to indicate the exact location of the fault and, possibly, at what stage it happened in transformers. From our Case studies 20 Hz to 1 kHz range bushing portion defects has been identified.

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