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SWITCH FREQUENCY RESPONSE ANALYSIS TEST OF POWER TRANSFORMER

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ABSTRACT

Power transformers are one of the most important and costly equipment in power generation, transmission and distribution systems. As the transformers operate, they get degraded due to different loading and environmental operating stressed conditions. In today competitive energy market with the penetration of distributed energy sources, the transformers are stressed more with minimum required maintenance. The modern asset management program tries to increase the usage life time of power transformers. With prognostic techniques using condition monitoring and SFRA is one of the most important tests to monitor the condition of power transformers.

Sweep Frequency Response Analysis (SFRA) testing proven their importance in Transformer Condition Monitoring and replaced the Internal Inspection of Transformers after heavy fault current tripping and other tripping. Internal inspection is time consuming and not preferable until utmost necessary as each and every inspection reduces life of power transformer.

SFRA has proven their importance in internal fault finding of power transformer and magnifying the fault inside the transformers. SFRA test is very useful for taking decision for repairing of power transformers at site or at factory.

Keywords :- SFRA; POWER TRANSFORMER; MECHANICAL INTEGRITY; RADIAL AND AXIAL MOVEMENT

I INTRODUCTION

SFRA is a tool that can diagnoses the mechanical integrity of the transformers. SFRA is used to find out early detection of incipient fault inside the power transformer. SFRA highlights the faults and helpful to take decision regarding repairing of power transformers at site or at factory and about severity of faults.

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SFRA test is carried out at factory before dispatch transformer consider as finger print and transformer is being tested with SFRA at site, result is compare with it a in service after commission whenever tested with SFRA always compare with finger print.

SFRA test not only find out fault in the transformers but highlights the faults and in some cases when other test not clarify the faults at that time SFRA pin point the faults .

SFRA can provide information regarding mechanical integrity of winding and not for mechanical strength of windings.

2 SFRA Theory

SFRA is typically used to detect winding displacements. In early day for winding displacement leakage reactance (i.e. short circuit impedance) measurements used, but leakage reactance has been found only to identify radial movements and no any information provided by leakage reactance test regarding axial movements. To identify axial movements SFRA test required. A short circuit causes unidirectional pulsating forces that are proportional to the square of the short circuit current. This leads to sever mechanical stress on the windings and might cause damage.

Other than short circuit or charging current mechanical thrust withstand by transformer winding while in transportation, i.e. journey form factory to site. Hence most of all transformer manufacturers started to take SFRA test before dispatch of transformer and at site. SFRA proved its position as a factory acceptance test. While in service due to earthquake chance of deformation in core and such change can be detected by SFRA.

IFRA and SFRA

Frequency response analysis can be taken with two ways by applying Impulse with desired frequency and with sweeping frequencies.

Impulse Frequency Response Analysis(IFRA)

In this method a low voltage impulse that has adequate frequency content is applied to the test object and the corresponding response signal measured. The response is sampled, stored, in the time domain and transformed to frequency domain using fast Fourier transformer (FFT) IFRA require less time, but drawback is very noise sensitive and in switch yard noise always present hence it is difficult to analyze the signatures. Over and above its resolution is poor and usually unrepeatability make IFRA not in use

Sweep Frequency Response Analysis (SFRA)

In this method, a constant amplitude sinusoidal signal is applied with sweep Frequency from 20 Hz to 2MHz, and the magnitude and phase shift measurements are taken at pre defined frequency points. The sampling rate is 200 samples per decade. SFRA is less sensitive to noise, but it is time consuming. Due to development in computer software it is possible to take SFRA within short time. As SFRA less sensitive to noise it is more in practice than Impulse Frequency Response Analysis. SFRA test indicate mechanical integrity of core and winding of power transformers, SFRA can be taken at higher frequency more than 2 MHz but more than 2 MHz its became more sensitive on lead connection on bushing rather than Impedance of Transformers hence chance of deviation more and repeatability of test is less at higher frequency. SFRA became more popular than IFRA due its repeatability, lesser sensitive to noise and higher resolution and easy to compare.

SFRA Basics

The Sweep Frequency Response Analysis (SFRA) is a method to measure the frequency response of the electrical passive elements (RLC) for power apparatus. The result is a transfer function which produces a fingerprint related to the mechanical geometry of the transformer being tested.

In transfer function

H(F) =Y (f)/ X(f)

In a passive device there are three basic components:

- Resistors * capacitors *inductors

They each have a different response to an AC signal. Their response is closely related to their geometry: both internal and in relation to other components.

In Alternating power we know that angular frequency

$$\omega = 2\pi f$$

Resistance value not changed with frequency, for the resistor R the reactance value is R at all the frequency, but inductance and capacitive reactance vary with applied frequency as under.

$$XC = \frac{1}{2\pi fc} \text{ and } XL = 2\pi fL$$

Resistance: flat response v. frequency

Inductor: Increased impedance with increased frequency; dead short at low frequency

Capacitor: Reduced impedance with increased frequency; open circuit at low frequency

Response in dB can be given as $20 \log_{10} (V_O / V_i)$

Transformer as R, L and C network

Power Transformer is complex network of R, L and C parallel combination.

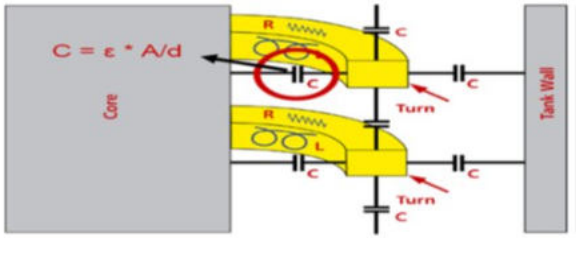

Figure 2.1: Transformer R,L C network

Power Transformers can be represented as shown in below figure and it is lungs of R, L and C and it also in series and parallel combination of its overall value and its total impedance Z very with manufacturers to manufacturers.

Impedance of the R, L and C parallel network is varied as shown in below figure with respect to frequency .It is maximum at resonant frequency.

Transformer as a two port network

Z12 represents the impedance of transformers winding under test.Z11 and Z22 represent the impedance to ground through the insulation of the winding and bushing. If Z11 and Z22 change due to any way it will affect the SFRA response. For this reason it is important that the grounding of the transformer, the SFRA instruments and cable shield ground at the base of bushings. Z_{22} represent the impedance between two earthing point of transformers bushings and it should be zero, otherwise its affect the SFRA measurements.

From two ports network following two equations derived.

$$V_{IN} = Z_{11} I_{in} + Z_{12} I_{out}$$
$$V_{out} = Z_{21} I_{in} + Z_{22} I_{out}$$

SFRA analysis can detect problems in transformers

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

Schedule of SFRA test

- When there is evidence of transportation problems.
- When an abnormal event has happened, for instance, an out of phase synchronization.
- When a long duration short circuit has occurred.
- When a weakness of the winding mechanical pressure system is known.
- After short circuit testing of power transformer
- After impulse testing of Power transformer
- Quality assurance during manufacturing
- After bushing failure followed by line protection operation
- Differential protection & Buchholz/PRD operation on line faults

III Measurement Technique and Analysis of SFRA

Two types of measurement are done for complete analysis of winding deformation using FRA method.

1.Impedance measurement

This method consider the effect of any variation in impedance of a winding due to its inter-turn capacitance, self & mutual reactance. The voltage signal Vi is applied between the winding terminals at variable frequency (10 kHz. To 10 MHz) and current I is measured at each frequency.

Hence, impedance Z (Vi/I) is measured for each frequency and a curve is obtained between impedance Z and frequency .

2 Voltage Ratio Measurements

Due to any displacement in winding, winding to ground capacitance will change. This method can detect this type of changes very easily. The voltage signal Vi is applied between the LV neutral of the winding and tank ground at variable frequency (10 kHZ. To 10 MHz).

Ratio of the output voltage to ground at R-phase LV terminal Vo and input voltage Vi i.e. Vo/Vi is measured at each frequency.

Measurement Technique

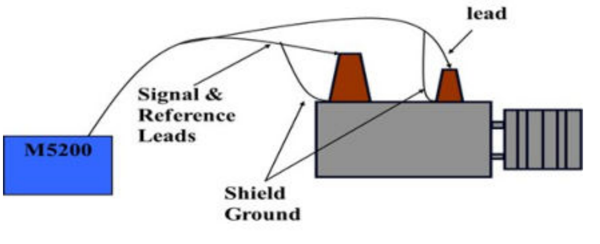

Figure 3.1: Measurement technique.

The sweep frequency response analysis test involves measuring the frequency responses of each individual winding. The frequency response is measured by injecting a sine wave signal with respect to earth at one end of winding to be tested and measuring the signal amplitudes at the other end of the

winding.
The attenuation (in dB) of the transmitted signal relative to reference signal at the input terminal is measured over a frequency range from 20 HZ to 10 MHZ.

Frequency band of SFRA

As narrated in following figure one can divide SFRA signature into broadly three division and accordingly faults can be found out . However its division can be varied with manufactures to manufactures design but most of all the transformers come in to these criteria.

Low frequency area is known as core area and core related issue reflects in thisarea and some winding faults also in this area. A residual magnetism effect reflectsin this area. Any change in frequency range from 10000 to 100000 indicates problem in winding and its movement. From 1 MHz to2 MHz known as OLTC and Bushing lead area and position measurements lead also affect in this area.

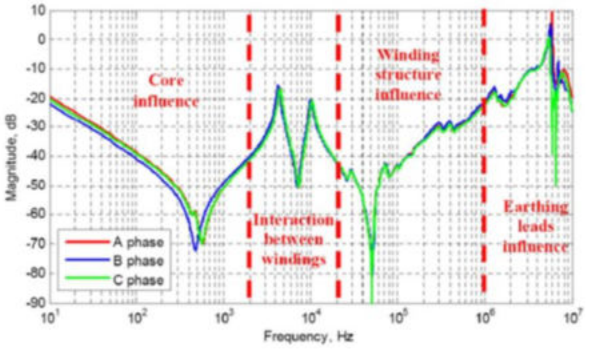

Figure 3.2: Division of SFRA test

Three approach for SFRA analysis

For analysis three approach possible as under

1. Time based

In this approach SFRA tests analysis is done with comparison with finger print .i.e. factory test if possible if not available than latest test of SFRA will be consider as finger print and compare with this. Such comparison known as time based comparison.

2. Type based

In this approach SFRA tests analysis is done with similar type of transformer with same manufactures and this approach applied when finger print not available.

3. Phase based

In this approach SFRA tests analysis is done with phase to phase comparison. A and C phase can be compared but B phase cannot compare this approach not proper but used when above two approach not possible.

IV Conclusions

SFRA is a tool that can diagnoses the mechanical integrity of the transformers.

The **VALUE** of an SFRA measurement is in the **Repeatability**: we can avoid false positives and false negatives in decision making

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