Mechanical Deformation Diagnostics for Power Transformer

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Abstract— Condition monitoring is a comprehensive program of data collection and analysis of these collected data will provide an early warning of a problem and identify the need for maintenance of the monitored machine in a planned and systematic manner before failure phenomenon occurrence. The transformer is considered to be a complex distributed network of electrical RLC components. Any physical damage to the transformer results in the changes of this RLC network. These small changes in the RLC network within the transformer are highlight in frequency response. Mechanical deformations in power transformer windings can be diagnosed by a reliable and powerful offline method called sweep frequency response analysis (SFRA). This method is based on comparing SFRA signatures or traces to baseline measurement. Any deviations may be attributed to mechanical deformations. A skilled observer can then examines the two curves for any significant differences.

Key words: Power Transformer, SFRA, Winding Deformation, FRA Traces, RLC Network

I. INTRODUCTION

Large transformers are expensive and vital equipment in power generation and transmission systems. They are also one of the most strategically important components, failure of which are a very costly event and lead to long term unavailability of power supply. A strategy needs to be set up for the monitoring and diagnostics of power transformers [1]. This helps in the evaluation of their potential residual life.

Power transformer are subjected very large axial and radial electromagnetic forces because of over-currents during through short circuit faults, tap changer faults, faulty synchronization, ageing ,transportation etc.[2, 3]. These stresses reduce the mechanical strength of the winding which lead to deformation or mechanical irregularity in windings of the power transformer; results in a transformer failure through damaging inter turn insulation by shorted turns. Transformer is expected to withstand and number of short circuits without damage, but if any major winding deformation is produced, the probability of surviving further short circuits is significantly reduced due to locally increased electromagnetic stresses. Also, after certain time period the aging phenomenon will occur in transformer insulation. Due to aging, paper insulation shrinks, consequential in a reduction in winding clamping pressure, which further reduces the mechanical strength of the winding [2]. There are so many methods to find mechanical deformation in transformer but among all these methods SFRA is most suitable method for detecting mechanical movement or to detect mechanical integrity in a suspect power transformer without opening it [1, 4-10]. The transformer is considered to be a complex distributed network of RLC components. Any small physical change to the transformer results in the changes of this RLC parameters. These changes are directly reflected in frequency response traces [8] different frequencies the RLC network offers different impedance paths. Hence, the transfer function at each frequency is a measure of the effective impedance of the RLC network of the transformer. Any geometrical deformation changes the RLC network, which in turn changes the transfer function at different frequencies and hence highlights the area of concern sometimes, transformer failure directly or indirectly depends on the winding deformation. It can be diagnosed by a method called sweep frequency response analysis (SFRA). The frequency response of the winding is compared with its fingerprint and any deviation between the two graphs can be correlated to some kind of deformation [2,11]. The success of the technique depends on the successful identification of the deviation and judging the deviation as normal or abnormal. Identification of large deviations between the graphs is easy; however, minor deviations sometimes create a dilemma. It also depends upon careful scrutiny of the trace resonances and magnitude /phase angle deviations. There are no clear guidelines regarding significant or insignificant deviation levels [5]. Some SFRA equipment manufacturers suggest that ± 3 dB difference between the two response curves is a normal deviation; however, there is no common agreement about it.

There are a few possible reasons [5, 11] which lead to deviations in the frequency response graph which may be misjudged as deformation; however these deviations might have happened due to some inherent phenomenon. Such deviations are due to: (1) the unequal magnetic length of end and centre phase leading to deviations in FR in the low frequency region. (2) Different amounts of residual flux in the transformer winding (3) Difference in the internal lead to the bushing connections (4) Differences in test methods and layouts (5) Difference in the construction of each phase of the transformer winding. One should check whether the deviations are due to the reasons listed above or due to some other deformation. It is necessary to examine the frequency response carefully, and expert opinion is still required for the diagnosis of transformer health. During routine maintenance of the transformer, engineers should record the FRA. Such records should be generated at regular intervals and the trend in deviations, if observed, should be reported to the experts. some researcher has been developed an expert system based on artificial neural network (ANN) system that can helps and expert as decision making about the level of deviation in frequency plot[5,1]

II. FRA MEASUREMENT TECHNIQUES

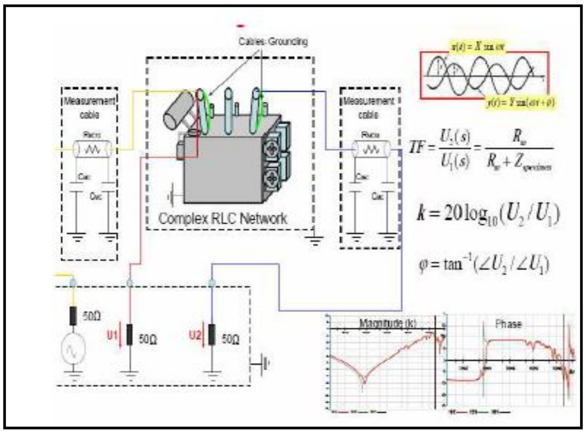

Fig. 1: Circuit connection of FRA

There are two types of SFRA Measurement

1) Voltage Measurement
2) Impendence measurement

A. *Voltage Measurement*

The transformer winding can be represented as a passive, linear two-port network composed of resistance, inductance and capacitance. After the deformation of windings the parameters, mainly the inductance and the capacitance, have a change and this will alter the impedance of winding and the performance of the network. The changes of transfer function can be adopted as the criterion of the winding deformation. SFRA is usually done by injecting a low sine wave low voltage (5 V P-P) signal of variable frequency(Sweep Frequency) from $10H_z$ to $2 MH_z$ into one terminal of a transformers winding (generally HV) respected to tank as in fig 1. The voltage measured at the input terminal is used as the reference voltage Vs for the SFRA calculation and measuring the response signal on another terminal Vr of the same winding keeping (other winding terminal are floating or grounding. This is performed on all accessible windings following according guidelines. The FRA response amplitude is the ratio between the response signal (Vr) and the source voltage (Vs) as a function of the frequency (generally presented in dB). The comparison of input and output signals generates a frequency response as in fig2. This is known as a Voltage measurement.

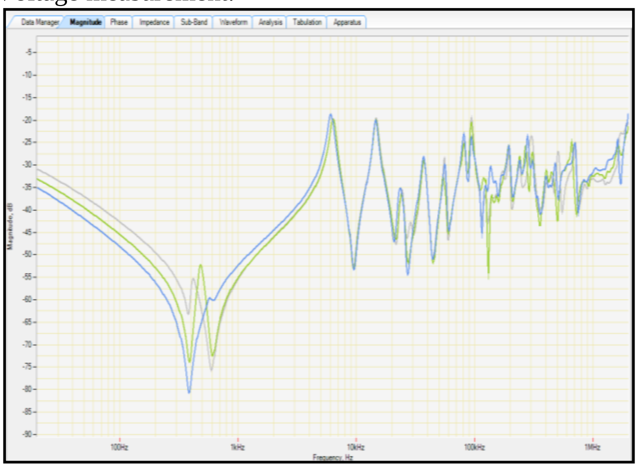

Fig. 2: Voltage FRA response of 40 MVA 132 kv Patan [courtesy: GETCO]

B. *Impedance Measurement*

If the voltage measured at the input terminal is used as the reference voltage Vs for the SFRA calculation and measuring the response signal as input current on same input terminal Is of the same winding keeping (other winding terminal are floating or grounding) then FRA Impendence response is the ratio between the source voltage (Vs) and source current Is .This measurement was done specially on laboratory transformer by using DSO where FRA kit was not available. Fig 3. Shows Impendence FRA response

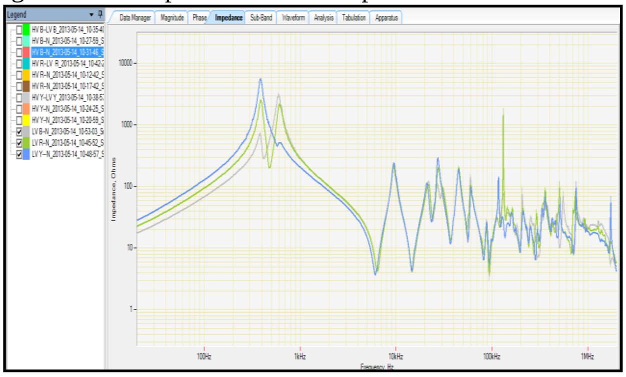

Fig. 3: Impedance FRA response of 40 MVA 132kv Patan

III. FRA TEST CONNECTION METHODS

There are so many types of connection methods for SFRA Measurement as in Fig.4

A. *End-to-end Open Circuit (6 tests)*

3 tests on HV side
3 tests on LV side

B. *End-to-end short-circuit (3 tests)*

3 tests on HV side (with corresponding LV shorted)
These above nine tests are compulsory for all FRA Measurement

C. *Capacitive inter-winding (3 tests)*

3 tests from HV to LV with all other terminals are floating

D. *Inductive inter-winding (3 tests)*

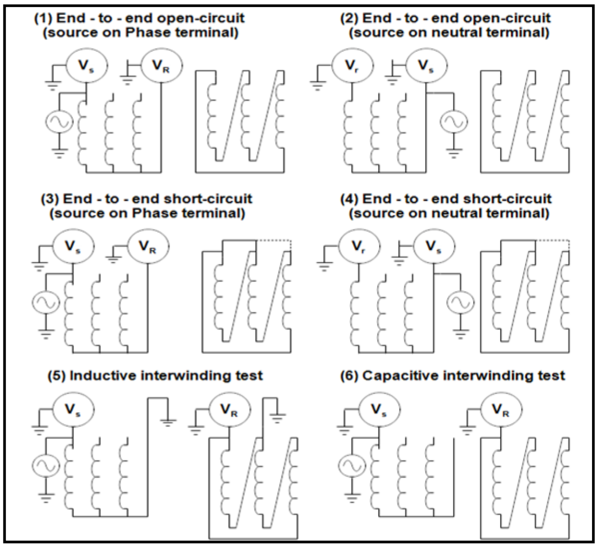

Fig. 4: Different Test connection methods for FRA measurement

IV. WINDING DEFORMATION

Winding deformation in a power transformer means, mechanical movement and mechanical movement is to each other or to ground. The important point for winding deformation in a working normal transformer is short circuit which creates radial and axial forces. Defined as a displacement of transformer parts like coils, core, leads, or accessories with respect Principal forces depend on the design of a transformer. In core type transformer principal forces are radially directed, however, these forces are axially directed in shell type transformer. This deformation can measure either impedance or phase angle measurement. In Impedance measurement winding deformation leads to change the inductances or capacitances of the tested transformer. Any change in the geometry of transformer either resistance, inductances or capacitance will change the transfer function of the frequency response. This deformation may be caused by large electrical and mechanical stresses due to shipping forces, seismic forces or as through-faults, Tap changer and faulty synchronization. This is the one of the most intention of FRA test to detect mechanical movement or deformation of power transformer winding. Amplitude and phase angle measurement are used for detection of deformation in winding. Generally phase angle measurement is not widely used for winding deformation as it does not provide whole information about transformer fault. In phase angle displacement, the difference between the phase angle of a reference Frequency Response Analysis (FRA) which is performed at the factory or at an earlier date in the substation or before a short-circuit test and an actual (new) measurement which is performed after transformer relocation or after suspected damage or after the short-circuit test. Phase angle displacement can also define as a difference between phase angle measurements on two different phases of the same transformer or between a transformer and a sister (duplicate) or near-duplicate transformer. An axial and radial force on winding due to short circuit fault current creates winding deformation. Major deformation modes caused by fault currents are [2]

The SFRA test is non-destructive and OFF-Line test and it can be carried out for any voltage rating of Power Transformer. The SFRA measurement can be a part of regular transformer maintenance. The SFRA Analyzer identifies the following abnormalities in the transformer before they lead to failure.

- Radial "Hoop Buckling" Deformation of Winding
- Axial Winding Elongation "Telescoping"
- Overall- Bulk & Localized Movement
- Core Defects
- Broken or loosened clamping structures
- Shorted turns and open winding
- Contact Resistance
- Winding Turn-to-Turn Short Circuit
- Open Circuited Winding
- Winding Looseness due to Transportation
- Residual Magnetization
- Floating Shield

V. INTERPRETATION OF FRA TRACES

The measured frequency range is divided into three sections: high frequency, middle frequency and low frequency section. Because of the diversity of structure of windings, the distribution of pole points of transfer function is different. So, in order to reflect the state of winding, division of the frequency range must be reasonable depending on the design of winding. By comparing future traces with baseline traces, the fault can be noted. Different faults are identified in different frequency bend as in fig.5

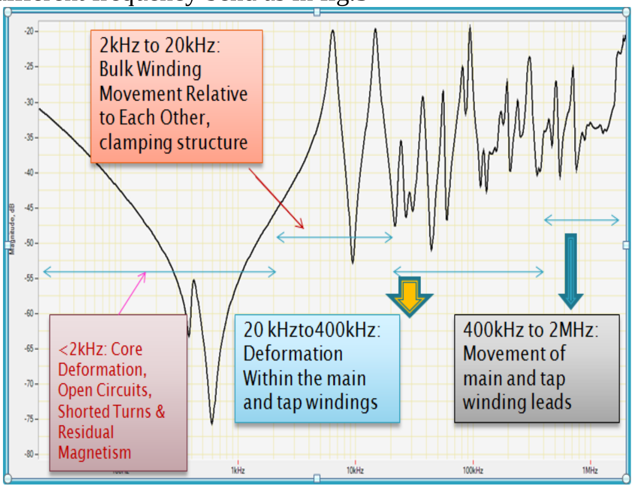

Fig. 5: 40 MVA Frequency response Of Patan Substation

VI. CONCLUSION

This Paper represents the basic introduction of why condition monitoring is required for costly and vital components such as a power transformer &FRA philosophy. How the FRA works and what faults are measured by SFRA technique are presented. SFRA is a powerful tool for the detection of winding movement and other faults that affect the transformer impedance. It also covers low frequencies range can detects core deformation faults, short circuit or open turns and residual magnetism .SFRA measuring directly in frequency domain compare to time domain hence no further mathematical modeling required. An advantage of this method was that in absence of reference responses expert can take decision successfully to diagnose the mechanical deformation of the power transformer by comparison of response to the different phase of the same transformer and a comparison of response from sister transformer.SFRA when used in conjunction with other diagnostic tools can provide a complete condition assessment of the transformer.

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