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DETECTION OF MECHANICAL FAULTS ON TRANSFORMER WINDING USING FREQUENCY RESPONSE ANALYSIS (FRA)

Rohini D. Jiwane
[1]Student Electrical Department (Electrical Power System),
University of Pune, K. K. Wagh Institute of Engineering Education & Research,
Nasik-422003, Maharashtra, India
Prof. T. N. Date

Abstract— Frequency Response Analysis (FRA) is the only reliable technique often called as tool for determining mechanical faults in transformer winding. There are many techniques available for the electrical fault detection. But FRA is the only tool for detection of internal (electrical as well as mechanical) faults in Power Transformer. FRA relies on graphical analysis interpretation of its signature/fingerprint and it is specially used to detect mechanical faults on transformer winding. As transformer is very simple but vital and expensive equipment in Electrical power system, hence it is prime responsibility of utility to increase the usable service time as well as decrease transformer life-cycle cost. Therefore it is mandatory to monitor transformer for fault before it occurs as it is capital intensive unit and very complex task for repairing or replacing once fault occurs.

Keywords— Power Transformer, internal faults, frequency response analysis, maintenance and condition monitoring, case studies component

I. INTRODUCTION

The transformer is simple yet very important equipment in the power system network. Faults both internal and external to the transformer can cause considerable damage to the transformer and it is very difficult task to repair as it includes various possible type of faults and required trained personnel also replacement of unit required large principal amount. Faults external to the transformer are taken care of by the protection scheme used in the line. For protection against internal faults in the transformer, various techniques have been adopted. The protection technique selected depends upon type of faults and also upon type, rating, size and the importance of transformer being protected. Internal faults in the transformer can be categories in two viz. electrical faults and mechanical faults. Faults should be detected in its initial level because of economic motivation; preventive tests and diagnosis are of benefit to predict fault condition. Advanced diagnostic techniques and recently introduced online monitoring (pre-fault diagnosis) approaches for Power Transformer provided means to enhance the present maintenance and protection scheme. There are many techniques for diagnosing electrical faults in transformer but there is no reliable technique to find mechanical faults in transformer winding.

As to keep Power System in normal operating condition, it is necessary to keep the transformer in healthy condition. During operation or transportation or natural calamities (e.g. seismic wave) transformer may experience mechanical or electrical faults. Diagnostic of the transformer condition is essential way to maintain the equipment in proper operating condition. There are several diagnostic methods widely applied to transformers. The diagnostic methods greatly improved the maintenance quality of transformers. However, some faults such as transformer core damage or coil displacement/deformation and other mechanical damages are difficult to be assessed using the present classical methods. Frequency response analysis (FRA) is the method to diagnose mechanical deformation in the transformer winding.

This paper deals with the diagnosis of the internal faults (mechanical) in Power Transformer by using FRA, which is most frequent tool for determining mechanical faults in transformer winding. Transformer winding can be modeled as a network of capacitance, resistance, self-inductance and mutual inductance; values of these parameters are changed when fault occurs on the winding; frequency response of the winding will change accordingly. Hence, FRA is sensitive to changes and hence fault can be detected in very simple manner.

II. LITERATURE REVIEW

FRA is a tool to detect mechanical deformation within Power Transformer, it is sensitive to failure in the winding and is depends on graphical analysis. Many techniques proposed which relies on transfer function comparison, polar plot, locus plot, plotting in between I-ΔV, current and voltage, etc. This comparison is between present and previous results. Modeling of transformer is nothing but the lumped network of resistance, capacitance and inductance. [6]-[16].

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A new method of transfer function analysis using Spectral Density Estimates in conjunction with a min-max index and coefficient correlation function calculation has shown excellent experimental results in identifying mechanical displacements in the winding of power transformers [2].

By considering change in distributed capacitance as well as mutual inductance, a sight axial displacement could be detected through FRA and considering capacitance and inductance elements variation, accurate buckling deformation can be emulated using transformer circuit model [3] & [4].

One of the technique is based on numerical simulation of a continuous parameter model of a transformer with frequency signature of healthy transformer obtained by MATLAB code [5].

III. POWER TRANSFROMER

Power transformers are used in transmission network of higher voltages for step up and step down application (400 KV, 200 KV, 110 KV, 66 KV and 33 KV) and are generally rated above 200 MVA [1].

A. Some causes of internal faults in transformer

- Short Circuit Faults in winding results into over currents and its magnitude is depend on MVA rating of transformer. It causes winding movement and shorted turns also extreme mechanical stresses not always causes failure but sometimes leads to damage [5].
- Over voltage surges due to lightning strokes and switching operations causes flashover which leads to turn to turn fault.
- Transportation of transformer can cause damages to its internal structure. Even if a minor damage can lead to breakdown of the transformer e.g. at a future short circuit current.
- Seismic Events such as earthquakes can cause mechanical stress on transformers and causes internal damages.

Examples of fault conditions in winding that can be detected by FRA:
Mechanical faults:
Winding deformation (including hoop buckling),
Winding movement (axial displacement, radial displacement),
Partial collapse of winding,
Core displacement,
Broken or loosened winding or clamping structure
Electrical faults:
Shorted turns or open circuit winding,
Poor ground connection of the transformer tank

B. Reasons for adopting FRA

- Prediction of response of the circuit for any input
- Sinusoidal waveforms have the elegant property that they can be combined to form other waveform which is usually non-sinusoidal. Thus frequency response allows us to understand a circuit´s response to more complex inputs
- Designing of circuits with particular frequency characteristics is possible Changes in the winding geometry have an effect on the characteristic frequencies. Hence winding deformation can be detected more effectively by this method
- Define frequency ranges to determine particular fault [13]

C. FRA application in Transformer

As a standard FRA measurements can be performed under the following conditions:

- On all new transformers for fingerprinting purposes
- As part of routine electrical tests
- after relocation
- After long duration short circuits
- After repairs to tap changer
- After any vacuum treatment, purification and regeneration
- After any type of fault
- After any type of maintenance

IV. SYSTEM REPRESENTATION AND METHODOLOGY

A. System Representation

FRA is a transformer failure diagnosis technique. It is solely based on the measurement of the frequency response at two different moments in the transformer service life, or sister transformers which are then compared to get the transformer present condition. Two terminal pairs of the transformer are chosen as input and output, normally according to the proposed measurement layouts or standardized tests. The ratio of output to input signals is considered as the response of the system to a frequency varying signal, i.e. transfer function of the transformer for a given test layout is as shown in Fig. 1.

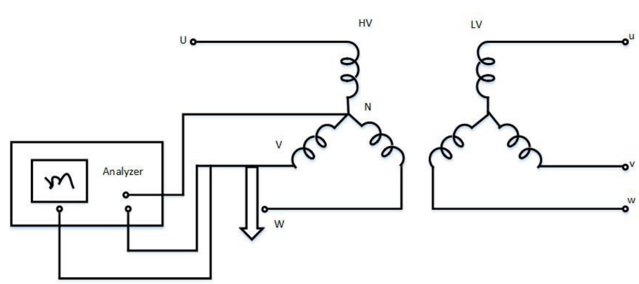

Fig. 1. Setup for FRA measurement

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For measurement frequency range is from 20 Hz to 2 MHz in this frequency range, it is easier to detect electrical and mechanical failures and disturbances. Since power transformers can be modeled by means of an electrical network of inductance, resistance and capacitance [6], as shown in Fig. 2 changes in these parameters leads to change in transfer function and hence frequency response. Comparison between two transfer functions of the same transformer gives the detection of failure if noticeable changes in FRA.

Transformer winding is nothing but the lumped parameter consists of resistance, inductance and capacitance and can be represents as shown in Fig. 3. Limitation of this technique is due to fault in measurement process, disturbances occurs in the response and this response considered to be failure. Higher order disturbance signals are filtered out, but lower order disturbances produce are difficult to identify. Hence new technique is proposed to eliminate the effect of disturbance signal.

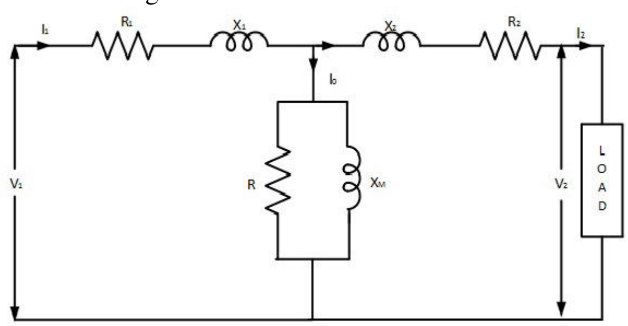

Fig. 2. Simplified Representation of Transformer in terms of R, L and C

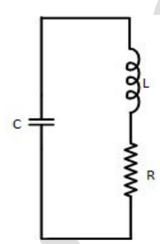

Fig. 3. Representation of winding lumped parameter

B. Basic Assumptions and Facts

- Consider faults as active part that produces variations in the frequency response
- Obtained fingerprints which are to be compared should be obtained from various conditions and time.
- To avoid faulty conclusion comparison should be done with filtered and decomposed output.
- Consider maximum level for decomposition of output signal to eliminate effect of disturbances is 7.
- This technique adds robustness to the fault detection system

C. Proposed Methodology

1) FRA measurements are done on the highest, lowest and nominal tap position, to get conditions of each winding of transformer
2) Obtained output signal undergoes decomposition level for elimination of disturbances present.
3) This response undergoes 7 level of decomposition at different frequency level. These decomposition level are defined using historical data and frequencies are classified into 3 bands as low, medium and high [2] & [13]
4) Process started from low frequency to high frequency and from high decomposition level to low successively on each transformer winding to get abnormalities. Once fault obtained it is saved and process continues for each level
5) These abnormalities obtained are nothing but the faults
6) Flowchart of given process as shown in Fig. 4

Where,
L&U - lower and upper limits for each decomposition level
N - no. of decomposition level
F - Variable to store abnormalities/fault
LIMIT - limit for given level

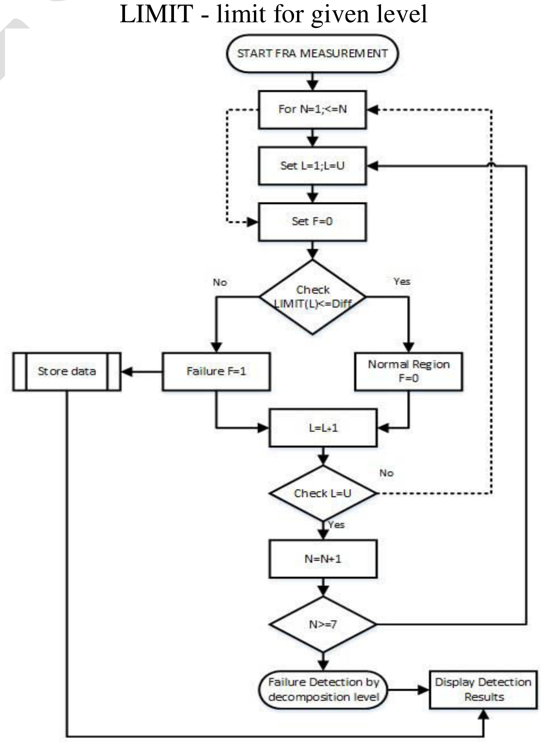

Fig. 4. Flowchart representing process of detection of failure

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Diff - calculated value differences

Flowchart describes flow of process for detecting fault till all the levels checked against abnormalities. Once abnormalities detected then it is saved in the memory and again checked for the remaining levels.

7) For measurement frequency ranges from 20 Hz to 2MHz
8) Type of fault is identified by defining frequency band. Using historical data present type of fault can be easily determined
9) In simple manner, fault is described as the change in resistance, inductance and capacitance. Change in parameters leads to failure.

When fault occur on the transformer value of this parameter changes and hence frequency response and transfer function MATLAB code is generated for all this procedure. Transfer functions of high-voltage windings normally look like the ones depicted in Fig. 5. This figure shows the reference and present transfer functions and the differences between them. If marked differences in the responses are found.

Type of Fault and Its Related Parameter

Parameter	Type of Fault
Inductance	Disk deformation, short circuit between windings
Capacitance	Disk movement, buckling, loss of clamping pressure, ageing of insulation
Resistance	partial discharge, shorted or broken disk

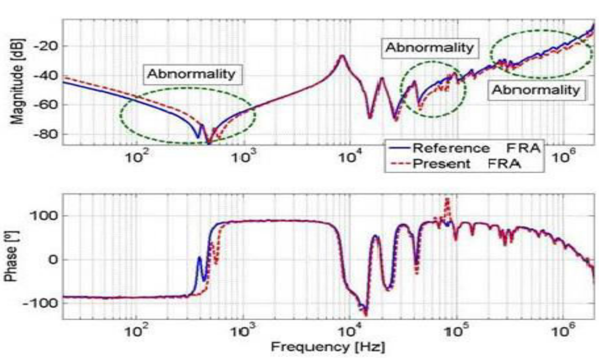

Fig. 5. Power Transformer frequency-responses comparison [2]

CONCLUSION

This method is easy and reliable to detect failure on transformer winding. This is only technique to detect mechanical fault on transformer fault also limitations due to disturbances has been overcome by simple means of decomposition of signals.

This technique is improve and hence defining various decomposition levels and frequency band easily fault and its type is determined.

This technique is based on numerical simulation of transformer.

FUTURE SCOPE

Additional measurement can be done on the faulted tap position after any type of fault has occurred. One can account for percentage change in parameter at which it will contribute to change in physical structure of winding and failure occur.

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