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TRANSFORMER INTERNAL FAILURE DETECTION BY FREQUENCY RESPONSE ANALYSIS (FRA)

Rohini D. Jiwane[1], Prof. T. N. Date [2]

[1] Student of Electrical Dept. (Electrical Power System), Faculty of Electrical Department
K. K. Wagh Institute of Engineering Edu. & Research
Nasik, India
[1]rohini.jiwane@gmail.com

ABSTRACT—

Detection of internal failures in the power transformers is the major issue as these factors are much needed for the power system as far the reliability is concerned and also the replacement cost of these components is more. Mainly the internal faults occur due to winding deformation, buckling of conductors, winding displacements, stretching of conductors and these may cause the transformer failure. Thus the monitoring of the transformer condition is necessary. Although, there are many methods presented for detection of internal failures in the transformer, but frequency-response analysis (FRA) has gained great interest due to its sensitivity to failures in the windings. These failures can be detected by evaluating transfer function changes. The new methodology is based on decomposition of signals to obtain smoothed response for comparison; it gives robustness to the process by defining type of internal fault on winding.

Keywords— **Power Transformer, internal faults, frequency response analysis, maintenance and condition monitoring, case studies, wavelet transform, transformer winding**

INTRODUCTION

Transformers are among the most important equipment of the electrical power systems. Currently, the level of reliability required of electricity companies causes the same to have a high degree of functional characteristics information of their equipment, specially the transformers [1]. Mechanical faults in transformers can pose a great threat to electric power system. There are many conditions when transformers can fail mechanically. Inter-turn short circuit, axial displacement of windings, forced buckling, disk to ground faults, leakage faults, axial bending are some of such catastrophic events. Short circuit events in transformer windings generate strong electromagnetic forces, namely, radial and axial forces.

These forces may cause buckling of conductors, winding displacements, stretching of conductors, which further lead to failure of transformers. Hence, monitoring health of transformers regularly becomes indispensable for uninterrupted and cost effective operation of power systems. The economic implications involving operation of equipment failures electrical network are huge then the integrity of the operation of each one of its components must be ensured. Internal winding faults in transformers can cause huge damages in a very short time, and in some cases the damages are repairable [2], and also about 70%-80% of transformer failures are caused by internal faults [3]. Among these faults, winding turn to turn fault is challenging to monitor and detect, especially at lower magnitude of the fault current. Even though, There are many different techniques available for detecting and/or locating these kinds of faults, but Frequency Response analysis (FRA) got more attention due to its ability to detect these faults efficiently.

LITERATURE REVIEW

This section gives the existing studies carried out to detect the internal failure in the transformer by using frequency response analysis (FRA) and is discussed as follows.

Transformer Tank Vibration Modeling for Detecting Winding Deformations has been presented [1]. The model calculates vibration on the transformer tank starting from some input variables that can be easily measured on the transformer. Tank vibration is also measured, showing a good concordance between estimated and measured values if the transformer is healthy. The model has been tested experimentally on a test transformer fitted with internal and external accelerometers. A deformation has been provoked in the test transformer winding with the aim of testing the model's ability to detect it. The study concludes that the status of the oil pump will affect the vibrations.

It is been stated that diagnosing shorted turns on the windings of power Transformers is based upon online FRA using capacitive and inductive couplings [2]. The main focus was on the in-turn faults in power transformer. To evaluate the effectiveness of the method authors have experimented on the winding of a 35 kV/400 V, 100 kVA oil-immersed distribution transformer. The experiment gives better results in inter turn fault detection.

An Enhanced Diagnosis of Power Transformers using On and Off-line Methods has been illustrated [3]. Both online and offline measurements have been performed on large power transformer, to decide the transformer efficient operation for the year. The study results into better assessment of transformer condition.

It is been discussed in the survey about diagnosis methods for transformer internal winding faults [4]. This helps in further study which illustrates a technique for detection of internal faults in online transformer by considering the harmonic impact of current and voltage measurements. This results into the effective online diagnosis method.

Model of High Frequency Model for Power Transformer using Frequency-Response Measurement is proposed [6]. The experimental verification has been carried out on 130 kVA and 36 MVA three phase power transformers. The outcomes of the calculation and measurement results conclude the validity of the proposed model for full and chopped lightning impulse voltages.

Study on Detection of Mechanical Defects in a 400MVA Transformer by using FRA is discussed [7]. This method shows better results in comparison with the traditional methods.

FREQUENCY RESPONSE ANALYSIS

When a transformer is subjected to high fault currents, the windings are subjected to severe mechanical stresses causing winding movement, deformations and in some cases severe damage. Deformation results in relative changes to the internal inductance and capacitance of winding which can be detected externally by FRA method. Winding damage detection can be accomplished by comparing the fingerprints of healthy winding (or the calculated response using a transformer equivalent circuit) with the fingerprints of damaged winding. Changes in fingerprints can be used to estimate the degree of winding damage and its location.

List of faults that can be detected by FRA are as follows-

- Shorted turns
- Multiple grounded neutral
- Core magnetization
- Open winding
- Short circuit winding
- Coil burning
- Axial deformation
- Radial deformation
- Disc to disc short circuit
- Loss of clamping pressure
- Loosened turns
- Poor grounding

Some causes of internal faults in transformer

1) Short Circuit Faults in winding results into over currents and its magnitude depends on MVA rating of transformer. It causes winding movement and shorted turns ,also extreme mechanical stresses do not always cause failure but sometimes lead to damage [5].
2) Over voltage surges due to lightning strokes and switching operations cause flashover which leads to turn to turn fault.
3) Transportation of transformer can cause damages to its internal structure. Even a minor damage can lead to breakdown of the transformer e.g. at a future short circuit current.
4) 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

Reasons for adopting FRA

1) Prediction of response of the circuit for any input.
2) 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 circuit response to more complex inputs.
3) 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.
4) Define frequency ranges to determine particular fault [16]

FRA application in transformer:

The standard FRA measurements can be performed under following conditions:

1) On all new transformers for fingerprinting purposes
2) As part of routine electrical tests

3) after relocation
4) After long duration short circuits
5) After repairs to tap changer
6) After any vacuum treatment, purification and regeneration
7) After any type of fault
8) After any type of maintenance

RESEARCH METHODOLOGY

The proposed methodology has the following steps FRA responses smoothing, comparison procedure of FRA responses, Detection of abnormalities, Complementary diagnosis using mathematical indicators, Definition of dynamic ranges for a given frequency response, Fault identification and are explained below with the block diagrams.

A. *FRA responses smoothing:* The decomposition process of FRA responses (trace smoothing) is performed by applying the DWT. Both present and reference responses undergo successive smoothing steps, obtaining seven smoothed versions of the original transfer functions, denoted as for increasing the decomposition level. The frequency range used is 20 Hz–2 MHz. The functions obtained from the present and reference responses are compared for each decomposition level following a particular procedure.

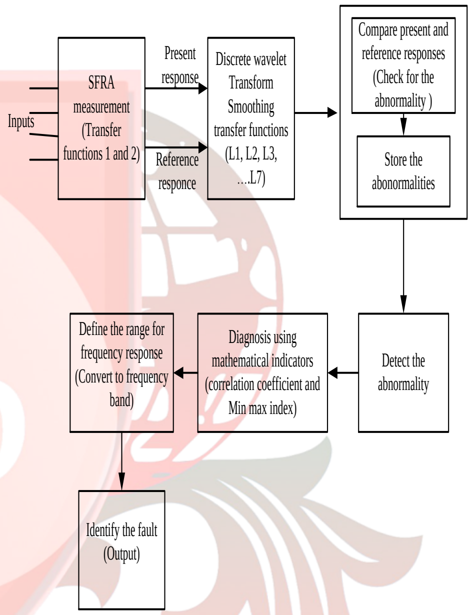
B. *Comparison procedure of FRA responses:* The comparison of smoothed versions of present and reference responses is done starting with Upper level and then continuing with the successive levels in decreasing order. For a given decomposition level, the analysis is performed from low to high frequencies, using the logarithmic scale for the abscissa (frequency), which produces an expansion of the response trace at low frequencies and a compression at high frequencies. In the case that the comparison leads to abnormal differences in a given decomposition level, the frequency bands containing these abnormal values are stored and not rescanned when comparing traces at lower decomposition levels. This is because the corresponding detection limits of all smoothing levels are defined in such a way that if the detection occurs in one level, this will also occur at lower levels. Thus, the detection takes place through the comparison of the “most representative components” of the responses, that is, the components that remain after the filtering process, leaving aside response trace components having fast variations, which are to be compared at lower decomposition levels. This ensures that the detection of an abnormal difference is due to an actual failure, since a deviation arises in the basic form of the compared responses, and not from differences due to noise.

C. *Detection of abnormalities:* The upper level smoothed versions of the present and reference transfer functions are initially compared to detect abnormalities. In this level, any abnormality can only represent a failure, since the effects of external disturbances and measurement problems have been extremely filtered. The comparison begins at 20 Hz and continues toward higher frequencies, checking whether the limit for failure differences established for this decomposition level (1.42 dB for upper level for measurements in the same phases [15]) is exceeded or not. Difference limits for the remaining decomposition levels are also necessary, since the smoothing levels are different. In case of detecting abnormal differences in a given frequency band, it is stored as an abnormal band for that level of decomposition, and the upper limit of this frequency band is set as the starting frequency for the comparison in the next level of decomposition. If no abnormalities are detected, the starting frequency value remains the same for the next search. The comparison continues this way up to the first decomposition level (L), where the comparison process ends.

D. *Complementary diagnosis using mathematical indicators:* The frequency bands containing abnormal differences (differences exceeding the limits) detected in each decomposition level are to be analyzed using mathematical indicators to determine whether they are correlated to a failure or not. The indicators used in this methodology are the correlation coefficient (CC) and the min max index (MM). The application of this step adds robustness to the method. Note that the indices are applied only to the frequency region containing abnormalities and not to the entire frequency range, so that sensitivity increases.

E. *Definition of dynamic ranges for a given frequency response:* To identify the type of failure, it is important to divide the frequency range in frequency bands, since a given type of fault is usually detected at a certain frequency band [2], [5].While fixed frequency bands have been used in the past, this is not optimal because its applicability varies with the shape of the given transfer function. To avoid this, a subdivision in frequency bands, whose limits are based on the characteristics of the FRA response of a given case study, should be used.

F. *Fault identification:* Based on the results obtained in previous stages, the type of fault can be investigated and identified according to the frequency band where the abnormalities occur.



Block Diagram For Proposed System

The flowchart given below describes all the process of working-

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

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.

CONCLUSION

This is the reliable technique to detect mechanical failure occurs on the transformer internal winding. This technique decomposes the present signal and gives the failure and abnormal condition of health of transformer. It also defines the type of internal fault that occurs on the transformer.

One can perform additional measurement on the faulted tap and can account for percentage change in parameter at which it will contribute to change in physical structure of winding and failure occur.

The result will look like as shown in Fig. 3.

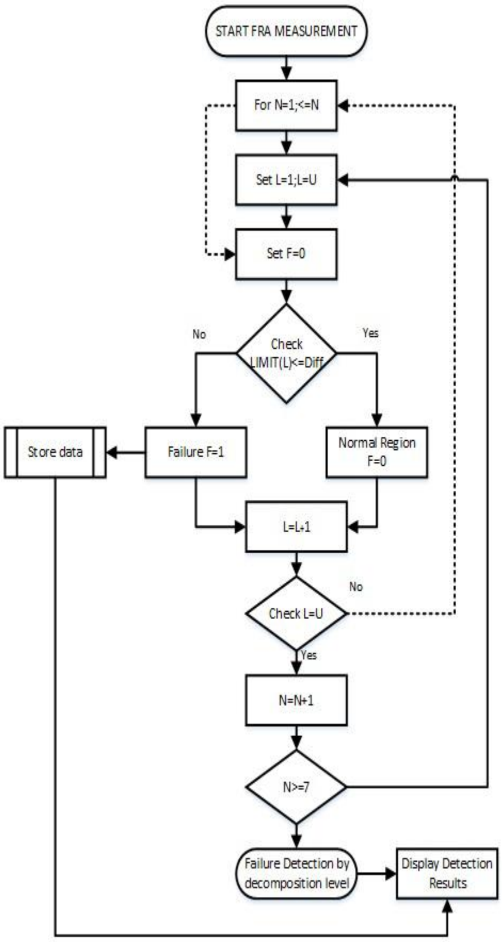


Fig 2 Flowchart representing process of detection of failure [17]

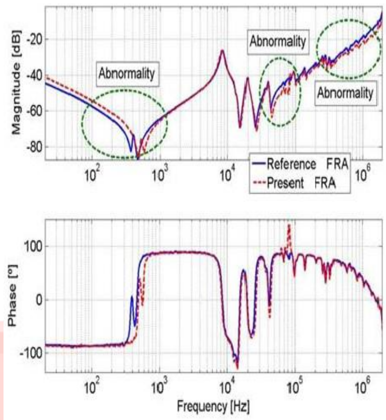


Fig. 3 Power Transformer frequency response comparison [15]

Transformer is nothing but made up of resistance, inductance and capacitance as shown in Fig 4. Hence, changes in these basic parameters will lead to change in working condition, which is nothing but the abnormal condition of hype transformer which leads to the fault. Therefore accounting for these parameters gives us the changes and parameter leading to the types of fault as shown in Table 1.

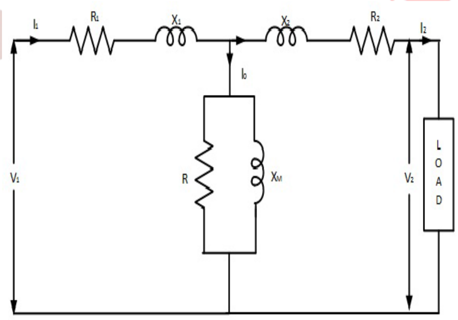


Fig 4. Simplified Representation of Transformer in terms of R, L and C

Table 1 Identification of type fault [17]

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

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