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Synopsis

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Thesis Title: **APPLICATION OF SIGNAL PROCESSING TECHNIQUES FOR CONDITI MONITORING OF ELECTRICAL EQUIPMENT**

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The power utilities worldwide now having major capital equipment, such as generators, circuit breaker, power cables and transformers with service age in excess of their designed lifetime. These are where failure can lead to long term unavailability. Maintenance policies for major equipments are being drastically changed, shifting from a time based maintenance towards a predictive approach, in which any corrective operation is carried out as a function of the present conditions of the components. In order to apply the predictive maintenance policy, it is of vital importance to set up monitoring and diagnostic techniques capable of assessing the conditions of equipments and to help in the evaluation of their potential residual life. The enhanced consciousness about the risks for the environment and the safety of personnel in the event of a failure causing a fire or an explosion is again motivating the development of such diagnostic techniques.

Monitoring and diagnostics of electrical equipments, in particular of power transformers which constitute the heart of the electricity generation, transmission , distribution networks are, since long is the object of great interest [1] . The traditional view of transformer life is based on the inescapable ageing of the paper insulation that is used as a multi-turn wrap around the conductors[2]. Paper is a long chain polysaccharide material that ages by chain scission with a related loss in mechanical strength. Standards such as C57-91, IEC 60450 and 60076-1 agree that when the chain number (DP) has reached 200 the mechanical strength is substantially lost (at 20% retained tensile strength). The windings will be prone to turn-turn dielectric failures during either in transient over-voltages or following mechanical vibration in short circuits. This type of generic ageing is a time-temperature related process, enhanced by moisture and oxygen.

As the transformer insulation ages, the paper insulation shrinks resulting in a reduction of clamping pressure, thereby reducing mechanical strength. If now a short circuit occurs and the windings move slightly, magnetic unbalance is created between the windings leading to much higher stresses during subsequent faults. The effect is cumulative, ultimately leading to large movements and electrical breakdown afterwards. The mechanical integrity of a transformer winding is challenged by several mechanisms. Many dielectric failures in transformers are a direct results of reduced mechanical strength due to deformations [3]. It is therefore favourable to detect deformations as early as possible, before they lead to problems or failures. Mechanical deformations do not necessarily change the operational characteristics of the transformer.

Minor deformations in the winding of transformer indicate no significant change in the operational characteristics, but the mechanical properties of the copper might be changed seriously risking rupture on next event. The impulse strength might also be reduced significantly due to damaged insulation and reduced distances. Less severe deformations involve insulation rupture and partial discharges which after some time normally is discovered through oil analysis or tripping the bucholz relay.

Conventional condition monitoring techniques such as dissolved gas analysis (DGA), Capacitance & Power factor and leakage reactance test are unlikely to be able to detect such minor mechanical damage until it develops into a dielectric or thermal fault. So, a specialist technique is clearly required for the monitoring and assessment of mechanical condition of the transformer and to be able to detect the incipient fault in transformer.

It means more advanced diagnostic method for the transformer using latest Digital signal processing (DSP) technique is needed for internal diagnostic information by non-intrusive procedures. Digital signal processing (DSP) techniques are being used for extraction of useful information from signals measured at the terminals of transformer. In this context, signal can be any waveform like impulse voltage, neutral current, electrical and acoustic signal of partial discharge [4]. Over the last two decades, the various DSP techniques are applied by researchers, which has been proven to provide accurate and repeatable measurements [5]. Various approach is there to diagnosis the incipient fault in transformer using advanced DSP methods like:

1. Detection of incipient turn to turn fault by wavelet analysis of impulse neutral current [6,7],
2. Impedance measurement of transformer in frequency range from 10 kHz. up to 10 MHz,
3. Detection of incipient fault by Frequency Response Analysis (SFRA) [8].

There are limitations of each method mentioned above with respect to repeatability of the test result and ability to detect various type of the incipient fault. Out of these three approach, SFRA seems to be promising in both real cases and laboratory investigations. There still seems to be little knowledge on why and how the method works, and how the results can be interpreted. Before making this method a standard test for condition assessment, all interpretational aspects should be investigated. This can either be done by experiments or calculations (using transformer models), or presumably a combination.

The primary objective of SFRA is to determine how the impedance of a test specimen behaves over a specified range of applied frequencies. The impedance is a distributed network of active and reactive electrical components. The components are passive in nature, and can be modelled as resistors, inductors, and capacitors. The reactive properties of a given test specimen are dependent upon and sensitive to changes in frequency. The change in impedance versus frequency can be dramatic in many cases. This behaviour becomes apparent when we model the impedance as a function of frequency. The result is a transfer function representation of the RLC network in the frequency domain [9].

SFRA testing produces traces or fingerprints, which provides information related to the physical geometry of the test specimen. Interpretation of the data is often subjective unless baseline data is available. Baseline data can be a previous test or data collected from a similar test specimen, such as a sister unit [10]. Due to the recent introduction of SFRA diagnostics, the majority of SFRA testing is conducted without baseline data. Interpretation of the first time results can be limited, and results are generally analyzed by comparing phases and recognizing obvious faults, such as severe deformation, open circuits and short circuits. Measured responses are analyzed for any of the following :

- Changes in the response of the winding
- Variation in the responses of the three phases of the same transformer.

- Variation in the responses of transformers of the same design.

In all the above cases the appearance of new features or major frequency shifts are cause for concern. The phase responses are also being recorded but normally it is sufficient to consider only amplitude responses. Since transformer designs and applications vary, the SFRA results inherit diverse properties and characteristics and basic circuit of transformer winding applicable to SFRA has to be analyzed [11].

As the experience grows with Sweep Frequency Response Analysis in world, it is useful to discuss the measurements and results in context of the practical application where SFRA has been used for decision support . It is important to highlights the various aspects of SFRA plot variation due to design and external parameters. By understanding these points, it will be easy to understand how good we are in taking measurements and making conclusion which is supported by evidence from other test data also. SFRA is now accepted, as part of routine test for new transformer at manufacturer place and as a post-fault investigation test for aged transformer.

The Sweep frequency Response Analysis (SFRA) diagnosis is made based on the comparison between two SFRA responses and any significant difference in low frequency region, shift of existing resonance, creation of new resonance, change in shape of plot would potentially indicate mechanical or electrical problem with the winding and core of Transformer. However, the ability to interpret such differences when comparing the SFRA responses is of a great challenge and then expertise to further analysis of the plot for classification of fault is very limited today for the users who are not very familiar with SFRA and need experts for the conclusions and findings. Hence, There is a need for the expert system based tools to assist in the analysis of SFRA results.

Literature survey was carried out to understand the research work done in the field of expert system design for fault classification of transformer using SFRA data. In literature [16] expert system was designed using Artificial Neural network (ANN) and it has been trained with various training algorithms and models of neurons in hidden layers and output layers. The training algorithm for fault classification of Transformer by the ANN was based on SFRA data obtained from theoretical study of simulated data for various fault on Transformer.

Although it gives guideline on how to proceed for design of expert system based on ANN for the classification of fault on transformer, validity of the method is not full proof as the ANN was trained with simulated data from a Transformer circuit model. There is a need to implement the method by using the practical SFRA data obtained from faulty transformer from the field. Once, the ANN is trained by SFRA data of identical group of transformer for a particular rating, design and make, it can predict the healthiness of other transformers of same group without the need of base data as the ANN can be designed with adaptive algorithm [15] .

Therefore the motivation behind the work presented in this thesis are:

1. To evaluate the performance of various DSP techniques applied in the condition assessment of transformer based on repeatability of the test result and its prediction capability.

2. Then, to derive a appropriate method to detect the incipient fault in transformer and validate the method with practical data collected from field and focus on SFRA mainly.

3. To establish a guideline for the understanding the electrical parameter that govern the shape and features of the SFRA response based on the experience from thousands of data collcted from field. Then, this knowledge can be utilised to analyse the experimental results and classify the fault for different make, design and rating.

4. After establishing all the norms for detection of incipient fault, design of an expert system applying DSP methods is needed. Based on the collected database and experience, fault prediction norms should be developed in expert system for effective use of SFRA by our maintenance engineer as asset management tool.

A brief description of the work in thesis is mentioned below:

Chapter 1 introduces the need of monitoring and diagnostics of electrical equipments, in particular of power transformers and the scope of work to be carried out in this thesis.

Chapter 2 discusses the degradation of the solid Insulation of transformer happening due to a combination of thermal, chemical, mechanical & electrical stresses. The mechanical mode of failure in transformer due electromagnetic forces and the existing techniques for assessment of mechanical condition of transformer [12] are discussed in this chapter.

Chapter 3 is about various digital signal processing method applied for condition monitoring of transformer practically and discusses the limitation of each method. Various approach is studied and work done to diagnosis the incipient fault in transformer using advanced DSP methods like : Detection of incipient turn to turn fault by wavelet analysis of impulse neutral current, Impedance measurement of transformer in frequency range from $10kHz$ up to $10MHz$. Detection of incipient fault by Frequency Response Analysis (SFRA) using practical data from transformer in service.

Chapter 4 discusses about the basic of Sweep Frequency Response Analysis (SFRA) as a tool that can give an indication of core or winding movement in transformers. Changes in frequency response as measured by SFRA techniques may indicate a physical change inside the transformer, the cause of which then needs to be identified and investigated.

Chapter 5 describes about Interpretation of SFRA responses based on the Transformer circuit Modeling to accurately represent the behavior of a transformer across the wide range of frequency. Model circuit parameters for SFRA have been developed in several frequency regions and the dominant components in each frequency region [13] is defined.

Chapter 6 addresses one of the major factors that influenced the SFRA responses, the winding structure and the existing condition of transformer itself without any sign of mechanical damage. Comparison of SFRA plot for sister unit with full and partially filled oil, Variation due to residual moisture of winding, Variation due to residual magnetism of the core & Effect of electrical interference on the SFRA plot is discussed.

Chapter 7 focus on Classification of fault based on the practical experience with SFRA analysis, the frequency range from $10Hz$ to $2MHz$ is sufficient for the analysis [14] and can be divided into three frequency band. These frequency band are governed separately by the inductive effect of core, self and mutual inductance of the winding, series and shunt capacitance of the overall winding structures and the lead/tap connections.

Chapter 8 describe the experts system design based on ANN and Feed forward neural networks which can detect the multiple faults and incipient mechanical and electrical fault of transformer. ANN has been trained for faults like open circuit, high impedance, short circuit, Tap changer related faults, overall axial, radial shift and core related faults in the transformer. The database used for the training is based on the real data collected form the field both for the healthy transformer and faulty transformer of various type and make worldwide.

Chapter 9 concludes the main findings and significant contributions of the thesis and provides a few suggestions for further research work in this area.