Transformer Health Monitoring

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Abstract: A standard power system encounters numerous faults and crisis. Therefore, health monitoring has great potential for enhancement in the reliability of operation, reduction in consequential damage and improving operational efficiency at lower operational cost. Paper in this domain primarily focuses on distribution transformers. Transformer breakdown results in unwanted power loss. Analysis of various faults in a distribution transformer can lead us to prevent the power losses due to abrupt changes in tr0ansformer operation. An analysis of the faults like external short-circuit in transformer, high voltage disturbance, insulation breakdown between winding and earth, short-circuit of winding and faults in core of a transformer can help in estimating their occurrence. A methodology based on current signal analysis is adopted, through an embedded system. The main aim of the project is to design such type of testing system through which consumers can determine conditions of a transformer, enabling them to diagnose and repair the faults.

Keywords: Transformer; Distribution Transformer; faults; current; signal; analysis; conditions; diagnose; repair

I. INTRODUCTION

Energy demand has increased tremendously over the past decades due to sporadic increase in industrialization and human population. Increase in energy demand and utilization affects electricity generation. There is no doubt that any nation that wants to progress must ensure an uninterrupted power supply. As a result there is a greater need to address the problems of power interruptions caused at the distribution level of power grid which is mostly due to malfunctioning of a distribution transformer. Various attempts have been made to put an end to the existing problem of unwanted sudden power breakdowns, but the situation still prevailed. To address this concern methodology of current signature analysis has been adopted. This paper aims at using statistical tools to analyse the cause of numerous faults that lead to unexpected breakdown, and identify frequency of occurrence of a fault type in a distribution transformer.

Need for Development

Increased sensitivity to the effects of thorough fault currents on large transformers has motivated some separate individual distribution entities to evaluate the effectiveness of their maintenance plans regarding distribution transformers. Another major aspect of a thorough fault monitoring program is the identification of the fault event and the capturing of the data necessary to support the analysis. It shall involve distribution transformer and its proposed protection through on-site Fault Detector Data Acquisition System. Monitoring transformers for problems before they occur can prevent faults that are costly to repair and result in a loss of service. Regular monitoring of health condition of a transformer not only is economical but also adds to increased reliability. So it is possible to take proper solution before converting minor fault into a major fault.

II. TECHNIQUES (ADOPTED IN PAST)

The faults which occur in a transformer are broadly classified as being internal and external faults. External faults can be broadly be classified as being overloads, over- voltage, over-fluxing, under frequency, and external system short circuits whereas internal faults are mostly winding phase-to-phase, phase-to-ground, winding inter-turn, over-fluxing, partial discharge etc. Experience shows that up to 80 percent of all faults in transformer are internal faults and hence lots of methodologies are present in tackling the diagnostic issues in transformer which all involve different complexities. Some of the more common ones are double Fourier series [1], numerical analysis of current symmetry [2], and implementation of Genetic algorithm to create an optimum solution based on constrained and non-constrained data [3], utilizing high frequency analysis for fault diagnosis [4], Parks vector approach for winding fault diagnosis of transformer [5], back-propagation neural network coupled with discrete wavelet analysis for effective fault diagnosis [6], combination of artificial neural networks with winding transfer function [7], finite element analysis of internal winding faults in distribution transformer [8], Purely experimental modelling of faults in transformer for fault diagnosis [9] [10], frequency response analysis of transformer under fault conditions [11], bacterial swarming algorithm for classifying frequency response [12]. All the techniques devised above by the respective authors utilize a different model and approach to model a real-life transformer and hence each individual technique had its own drawback and limitation. In this paper, we will attempt to model the various faults in transformer with special emphasis on establishing winding faults via harmonic analysis. The efforts will be geared towards eventually developing a computationally less intensive methodology capable of running in real-time on an embedded platform.

III. PROPOSED METHODOLOGY

A. Fault Identifying System

It should be noted that the Fault Detector Data Acquisition System is set up to be triggered (start the data acquisition) at the proper level of fault current and voltage. This will result in adequate voltage and current readings to be taken at the appropriate locations. There are numerous inputs, which need to be considered when performing the post thorough fault event analysis of transformer health. Transformer age, electrical loading, any movement due to physical relocation, physical design, maintenance and inspection history, as well as fault event data at regular intervals, and results of subsequent testing are a few considerations. The physical design of the transformer will help to determine the failure modes that might be possible. Differences between transformer designs may necessitate the use of different strategies in the specifics of post event testing and analysis. There are many relay platforms that are capable of waveform capture of system faults on both the high and low side of large distribution transformers. There is increasing use of digital fault recording on the transmission side as well as the generation side. However, one key aspect of all the data collection available from the various data acquisitions and event capture equipment is the organizational and management structures that are required to be present to analyse and act on the collective aspect of information that is derived from the analysed data.

B. Techniques That Shall be Adopted

i. Equations for mathematical approach

The mathematical approach to which this paper adheres is Frequency domain analysis of the harmonic present in the recorded fault reading. The Mathematical definition of voltage and current of power system are as follows

$$v(t) = V_m(\sin(\omega t)) \quad (1)$$

$$i(t) = I_m(\sin(\omega t)) \quad (2)$$

The above equations are all related to linear time invariant systems and hence as a result mathematical modelling can be easily be carried out. However, generally analysing the system as such is very difficult, especially when we have to analyse the harmonics and hence we used Fourier analysis to express the functions in terms of their frequency components for the ease of analysis as shown.

$$I(t)=I_0+I_1(\sin(\omega t+\Phi))+I_2(\sin(2\omega t+\Phi))+..+I_n(\sin(n\omega t+\Phi)) \quad (3)$$

$$V(t)=V_0+V_1(\sin(\omega t+\Phi))+V_2(\sin(2\omega t+\Phi))+..+V_n(\sin(n\omega t+\Phi)) \quad (4)$$

The above equations are expressed in terms of their harmonic values with I_0 being dc component, ω being fundamental frequency, 2ω second harmonic frequency and so on. Generally in a power system, it is observed that the most significant harmonics which are heavily affected by the fault are odd harmonics especially the third harmonic which is of the prime importance. Therefore, in our analysis, we will extract the data of frequency components via the FFT (an algorithm to implement Fourier Transform. This will be later used for a periodic signals) in each fault condition under loaded and unloaded conditions. It shall save it in an indexed table from where they can be referred and used in evaluation of real time signals of transformers.

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-iwt}dt \quad (5)$$

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(w)e^{jwt}dw \quad (6)$$

The correlation equation is used to establish the strength of relationship, the greater the positive value, the stronger will the relationship be between the indexed table data and the current real-time data present. Generally a cut-off of $|r|>0.7$ signifies that the relationship is sufficiently strong and that a fault of the indexed table is present in the obtained real-time data of the transformer.

ii. Actual Methodology

The methodology followed is based upon modelling the transformer as well as all of its constraints for determining the winding faults in transformer and its subsequent comparison with real time data obtained via NI Labview. There are broadly three steps in the diagnostic methods that we propose: First the harmonic and frequency content of healthy transformer is recorded as a reference point. Subsequently faults are then introduced in the transformer to establish the changes that it causes in the transformers current or voltage signature and the harmonics which are recorded. Finally, a database is created of all the faults and their respective signatures to be stored in the embedded device for checking of the respective fault present. For this purpose, a test-bench is being setup which will contain transformer testing mechanism. To begin with our methodology, a prototype test-bench has been setup which contains an air-cooled transformer. The transformer that we are using is rated at 5kVA 420/400V with 3-phase Δ-Y winding. Core is made up of laminated steel. Different type of sensors shall be incorporated to record current, voltage, temperature and vibration readings. All the sensors data will be fed to an embedded system for the signal analysis. Setup is designed in such a way that it can be used for induction of precise pattern of faults in transformers, which can then be used to devise a system for the further development in the future. There are two tests which we will carry out on the transformer namely: no-load test and load test. The parameters recorded are Primary current, Primary voltage and Secondary voltage in no-load test, whereas, Primary current, Primary voltage, Secondary voltage and Secondary current are recorded for load test. Loads used in the load test are resistive, each rated 500W, combining up to 9 loads (3 for each phase). These tests will be carried out in fault conditions. There are broadly five fault conditions which we will induce in the transformers:

1. Phase to Phase primary winding fault
2. Phase to Phase secondary winding fault
3. Phase to Neutral secondary winding fault
4. Core Displacement fault
5. Insulation breakdown fault.

During the establishment of our fault detection test-bench, we shall ensure that the faults are induced only when the transformer is in a stable condition (i.e. after several sinusoidal cycles have passed) to ensure repetition and proper simulation of results. Also another aspect that is taken into consideration in our simulation model is the span of the wave on which the faults are induced meaning the step size and time would be such that not only it covers the zero crossing and peak but it also caters for intermediate values in the sinusoidal wave. The last step in our methodology is indexing the tables of fault data generated to be used in real-life online monitoring and creation of a regression and correlation function for the comparison of both data sets. Hence an algorithm will be devised that extracts odd indexed harmonics from the real-time and indexed data (since most of the faults are likely to appear in odd indexed harmonics) by means of regression and correlation to establish the pattern. Finally, an algorithm will be developed for the embedded platform in which it is to run the electromagnetically and electro-statically shielded embedded platform that is considered, decided on its real time response and ease of algorithm implementation and modification. Hence, the candidates that we have considered for this task are Microcontrollers (Arduino), Single Board Computer (Raspberry Pi) and Field Programmable Gate Arrays (Spartan-6, for they have modifiable hardware architecture, and their processing speeds can be altered via hardware changes). Fig. 1 shows the block diagram of the test-bench that has been setup

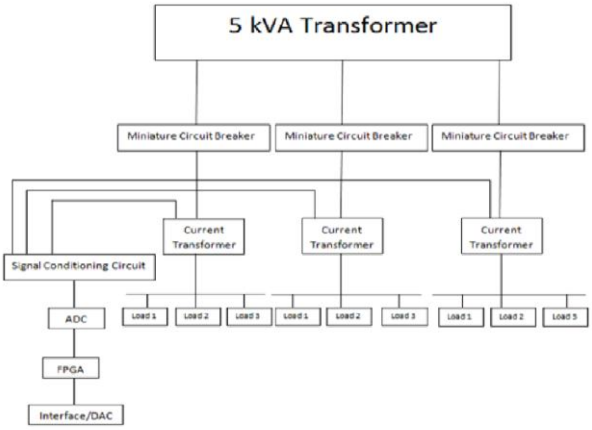

Fig.1 Block diagram of transformer fault analysis test-bench

iii. Plan Execution

Ample amount of brainstorming has been carried out regarding the plan of action. Keeping in mind the safety precautions we first designed a small scale setup (with small 220/12V transformers) in which phase to phase winding fault test was carried out as per the simulation circuit shown in Fig. 2, the following current readings were recorded as shown in Table 1. Table 2 shows the readings before the fault was induced. A change in current readings can be observed.

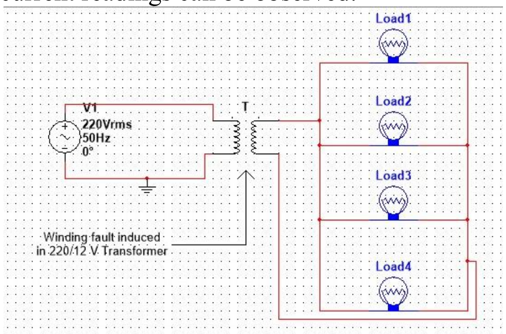

Fig. 2 Winding fault test simulation circuit

TABLE I
CURRENT READINGS OF AFTER WINDING FAULT WAS INDUCED

S. No.	I/(A)
1	1.392
2	1.394
3	1.395
4	1.401
5	1.409

TABLE II
CURRENT READINGS BEFORE WINDING FAULT WAS INDUCED

S. No.	I/(A)
1	1.695
2	1.694
3	1.696
4	1.702
5	1.708

To increase the probability of successful diagnosis multiple factors for real-time analysis (processed data via Image processing, Wavelet Analysis, Temperature Signature Analysis, Machine Current Signature analysis etc.) shall be utilized.

iv. Signal Conditioning Circuitry for feeding the signal into the FPGA

The instrumentation which is being used for monitoring the current signature is 60:5 ampere current transformer, whereas the ADC which we are utilizing reads only the values between 3.3 – 0 V. This calls for a signal conditioning circuit which we have made and simulated as shown in Fig. 3.

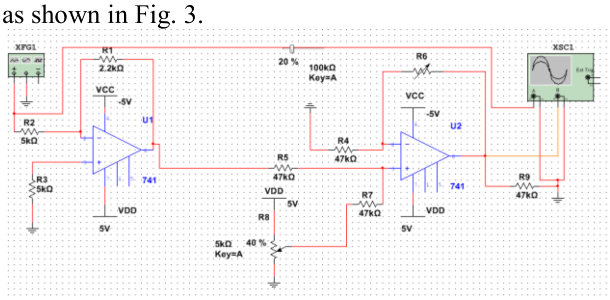

Fig. 3 Signal conditioning simulation circuit

The configuration comprises of a secondary CT of 1:1800 turns followed by an inverting amplifier with a variable gain to reduce the voltage and vary it as per the need. The last step of the circuitry, shown above, is to add a DC offset to it which is achieved via the use of non-inverting summing configuration. The final waveform which we get is a signal of 180^{o} out of phase with the inbound wave at the minor CT with a DC offset. The high pass filtering for a particular instance of time on an inbound signal simulated via MATLAB as shown in Fig. 4

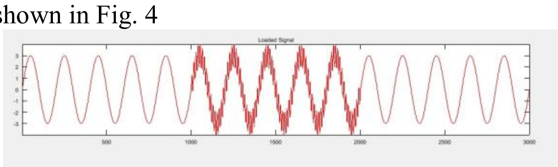

Fig. 4 MATLAB simulation of Highpass filter

v. FIR Filter Bank for Hardware Realization of Discrete Wavelet Transform

The Feature extraction of the current signature which is to be eventually be classified takes place via use of the discrete wavelet transform. In our case, we have utilized the debauchies 4 transform with level of refinement 2 to split or bifurcate the incoming stream into its constituent frequencies which can be later better be distinguised and classified and their features studied.
The filter used is this realization is an 8 tap FIR filter with its coefficients scaled to a 1024 bit register x 8 array in a 2's complement form. FIR filter block diagram is being dsiplayed in Fig. 5.

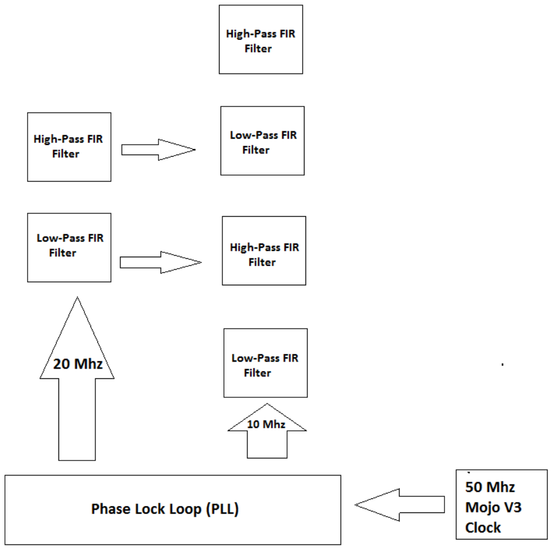

Fig. 5 Block Diagram for the FIR filter operation

We shall try to bring this system in conjunction with the existing mechanical systems being currently used for the fault diagnosis so that the efficiency of the system is further increased. An online data logging scheme (like ThingsSpeak which comes with MATLAB as an add-on) for statistical analysis of transformer data trends to better predict and monitor condition of the transformer.

VI. RISK ASSESSMENT

The setup which involves transformer fault diagnosis poses great risks. Some of the associated risks are as follows;

- The setup focuses on internal faults of the transformer since most of the signals acquired focus on internal faults of the transformer and hence it would be a challenge to isolate and account for any external factor affecting the system.
- The system installed require complete over-hauling of current mechanism, the workforce will have to be re-trained in dealing with new

equipment and also the mechanical system would have to be changed to take into account the new system.

- Any external noise or distortion caused by any external unwanted signal may interfere with the signal processing being carried out by the system.
- There has to be a proper electromagnetic shielding of the electronic equipment alongside its protection from static charges.

- Caution has to be taken to ensure that the personnel as well as the equipment remains safe as there will be high voltage which may damage the system. There has to be a proper heat-sink as well as cooling mechanism for the embedded or electronic setup to ensure that its functioning remains efficient.

Thus so far whatever risks or challenges that could have been contemplated, have been addressed and the plans are devised to resolve those problems. The operating mechanism is ready to encounter and eradicate the risk that could be encountered.

VII CONCLUSION

In the Transformer fault detection system, continuous fault diagnosis of the transformer faults is conducted. This is the technique considered as part of Condition Based Maintenance (CBM) approach where the hardware's current working condition is continuously monitored to detect any type of faults. Current and noise based detection and classification method is developed which is installed on site using an embedded system.

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