DETECTION OF INTERDISC FAULT IN THE WINDINGS OF POWER TRANSFORMER WAVELET APPROACH

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Abstract:-One of the tests carried out on power transformer winding insulation after assembly is the low voltage impulse test, for assessment of the integrity of its winding insulation. The existing transfer function method used for diagnosis lacks sensitivity in detecting minor faults. Hence, a new approach using wavelets is developed to analyze the recorded neutral current waveforms to identify the existence of fault. Comparison of recorded neutral currents is a standard technique used for the detection of fault in the power transformer winding insulation during Impulse test. Any shift in the waveforms indicate fault in the windings. Hence, proper analysis of neutral current waveforms is necessary to assess the condition of insulation of transformer winding. In order to carry out wave shape analysis, a 61MVA, 11.5/230kV generator transformer is considered and faults are created in the discs of High Voltage windings at particular locations. Noise inherent in the neutral current during recordings was isolated using Daubachies wavelet and the de-noised signals were also analyzed using Daubachies wavelet for identification of fault in the winding.

Key Words: Power Transformer, Low Voltage Impulse, Neutral Current, De Noised Signal, Daubechies Wavelet.

I. INTRODUCTION

Insulation failures within Transformers are considered to be one of the most important causes of failure of Power Transformer. Impulse testing of Power Transformer after assembly is an accepted procedure for the assessment of the winding insulation strength. Manufacturing defects or inadequacy of insulation may lead to failure against impulse voltage stresses. In the conventional method, the neutral currents recorded, both at reduced and full voltages are compared and any variation found is attributed to an internal fault leading to rejection of the Power Transformer. However, the conventional method has several limitations [1]. Later, the "Transfer Function" method was used which almost eliminated all the limitations [2]. In this method, the transient admittance is calculated both at reduced and full voltages and deconvoluted into the frequency domain. Any discrepancy found after comparing them is attributed to an internal fault. Though this method is quite efficient, detection of minor faults, particularly with regard to its location, is difficult since the variation of the resulting neutral current due to such minor faults is minute [3]. As such, the purpose of the test is not fully achieved. Hence the need arises for a new method which could not only detect such minor faults but also predict the fault in the winding.

The "Wavelet Transform" approach [4] introduced here for minor fault detection supposedly fulfills the need. Stationary/Non-stationary signals can be analyzed in the time frequency domain using the wavelet transform such that it is possible to precisely locate in time all sudden variations in the signal [5]. Wavelets are widely used in areas such as singularity detection, data compression, detecting features in images, noise elimination and harmonic distortion in signals [6-8]. The principle involves choosing a wavelet which is dilated and translated to vary the frequency of oscillation and time location, superimposed on to the neutral current signal. These dilating and translating mechanisms are desirable for analyzing the waveforms containing non-stationary events. By continuously dilating the wavelet, the instant of fault occurrence is noticed on the time scale as the difference between the healthy and faulted signals abruptly change.

The present work aims at detecting and locating the disc faults of HV winding for a 61 MVA, 11.5/230 kV PT. A low voltage impulse of 100V magnitude from RSG is applied at the centre-entry lead of the HV winding. The neutral currents are recorded and noise in the signal is isolated using db3 wavelet. Isolation of noise from the recorded neutral current is important which otherwise would lead to misinterpretation of the analyzed neutral current waveforms [9, 10]. After de-noising, the signals were analyzed for fault detection using Daubechies (dB) wavelet, for different faults in the axial direction across the disc in the individual windings. Further, these analyzed waveforms were processed using plotting tools.

II. WAVELETS FOR FAULT ANALYSIS

The most interesting property of wavelet transforms is that individual wavelet functions are localized in space. This localization feature, along with wavelets localization of frequency, makes many functions and operators using wavelets 'sparse' when transformed into the wavelet domain. This sparseness, in turn, results in a number of useful applications such as data compression, detecting features in images, and removing noise from time series.

An advantage of wavelet transforms is that the windows vary. In order to isolate signal discontinuities, one would like to have some sort of basic functions. At the same time, in order to obtain detailed frequency analysis, one would like to have some very long basis functions. A way to achieve this is to have short high frequency basis functions and long low–frequency ones. This is exactly what is obtained with wavelet transforms. They have an infinite set of possible basis functions. Thus wavelet analysis provides immediate access to information that can be obscured by other time-frequency methods such as Fourier analysis.

2.1 CONTINUOUS TIME WAVELETS

A real or complex valued continuous time varying function '$\Psi(t)$ ' satisfying the admissibility conditions:

$$\int_{-\infty}^{\infty} \psi(t)dt = 0 \qquad \text{---- (1)}$$

And

$$\int_{\infty}^{-\infty} |\psi(t)|^2 dt < \infty \qquad \text{---- (2)}$$

is called a mother wavelet and is useful in formulating a sample inverse wavelet transform.

The first admissibility condition implies that the function is oscillatory [11, 12] and the second admissibility condition indicates that most of the energy in '$\Psi(t)$' is confined to a finite duration. Thus they suffice the reason for calling the function a 'small wave' or 'wavelet'. The two properties defined are satisfied easily and there are many functions that qualify as mother wavelets.

Let '$\Psi \in L^2 (R)$' a square integrable real valued function, the continuous wavelet transform of $f(t)$ with respect to a mother wavelet '$\Psi (t)$' is defined as

$$W(b,a) \equiv (1/\surd a) \int_{-\infty}^{\infty} f(t)\, \Psi^*((t-b)/a)\, dt \qquad \text{---- (3)}$$

Where 'a' & 'b' are real and '*' denotes complex conjugation. Here the variable 'b' represents time shift or translation and 'a' represents the scale or dilation variable [5].

The wavelets may be supported compactly or may be of infinite duration. Daubechies3 wavelet is used in the present work which is shown in figure 1.

In the present work dB3 wavelet is used to de-noise the signal and is given by the following equation

$$Let \quad p(y) = \sum^{n-1}_{k=0} C_k^{N-1+k} y^k \qquad \text{---- (4)}$$

Where C_k^{N-1+k} denotes the binomial coefficient,

Then

$$|m_0(\omega)|^2 = [cos^2(\omega/2)]P[sin^2(\omega/2)^N] \qquad \text{----- (5)}$$

Where

$$|m_0(\omega)| = (1/\surd 2) \sum^{2N-1}_{k=0} h_k e^{-ik\omega} \qquad \text{------ (6)}$$

The support length of 'Ψ' is 2N-1. The number of vanishing moments of 'Ψ' is N [13, 14].

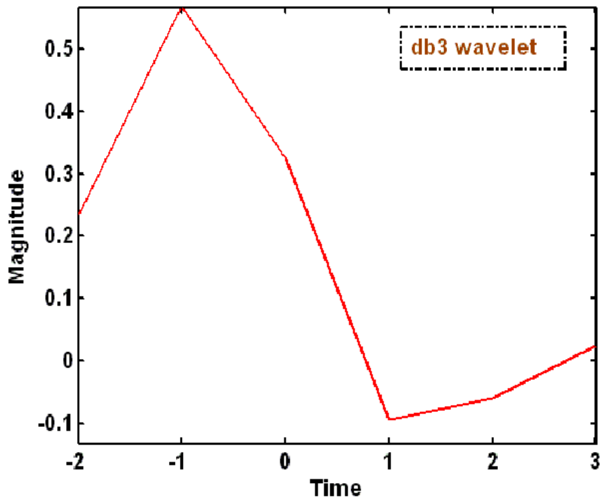

Figure1. Daubachies3 wavelet.

III. EXPERIMENTAL RECORDINGS OF NEUTRAL CURRENT WAVEFORMS

The experimental studies were carried out on a Generator Transformer of 61 MVA power rating and 11.5/230kV voltage rating as shown in Fig.2.

Figure 2: Experimental Setup

Figure 3: Shorting of discs in HV winding.

The HV winding is of two group construction with centre-entry type, having a total of 112 discs with 22 turns in each disc. The HV winding is symmetrical about the centre-entry with 56 discs in each half. The Tapping Winding consists of 40 plain discs of 4 turns each. In the present work, tapping winding was isolated and only HV winding was considered for experimental analysis. The equivalent network of HV winding of PT is shown in Fig.4. A portion of pressboard cylinder is removed to have an easy accessibility to the high voltage discs; such removal facilitates shorting of any conductor with other conductor or discs as shown in fig. 3. The paper insulation of the outer turn of large number of discs in axial direction is removed to have an access to bare conductor. These bare portions of the conductor were physically shortened to create short circuits and hence the disc faults.

The construction of disc of HV winding is as shown in Fig 5A. The HV winding itself is made of interleaved connection to provide a high value of series capacitance. This prevents swings in voltage distribution and makes it almost linear with time along the whole length of winding. A typical conductor cross section of a turn with paper insulation is shown in Fig 5B. The removed paper provides access to the bare portion of conductor. A thin copper wire is soldered to the respective bare conductor. The turn shorting is carried out by connecting the two wires before the application of voltage.

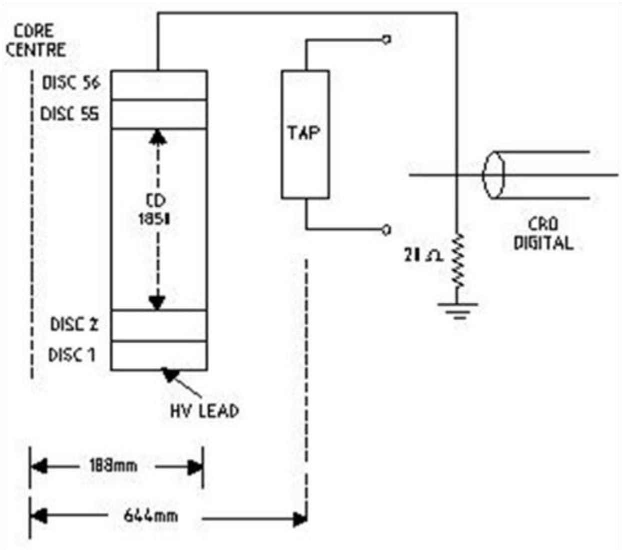

Figure 4: Schematic diagram of HV Winding configuration of the Transformer.

A low voltage impulse of 100V magnitude is applied from RSG and the neutral currents are recorded on the digital oscilloscope (Type Nicolet Power Pro 610) across a 20Ω non – inductive shunt.

Neutral currents are recorded for healthy winding as well as for each shorted disc. The sequence of measurements is as follows. First 2nd disc is shorted to 4th disc by the method suggested in Fig 5B. The voltage is then applied to HV terminal as shown in Fig 5A. The neutral current is passed through a 75Ω surge impedance cable and recorded on digital CRO. The shorting terminal is changed for 2nd disc to 6th disc. The measuring process is continued until 16th

disc is shorted. The transient current is then recorded for every short. The list of shorted discs is given below:

- Healthy winding
- 2 to 4 disc shorted
- 2 to 6 disc shorted
- 2 to 8 disc shorted
- 2 to 10 disc shorted
- 2 to 12 disc shorted
- 2 to 14 disc shorted
- 2 to 16 disc shorted

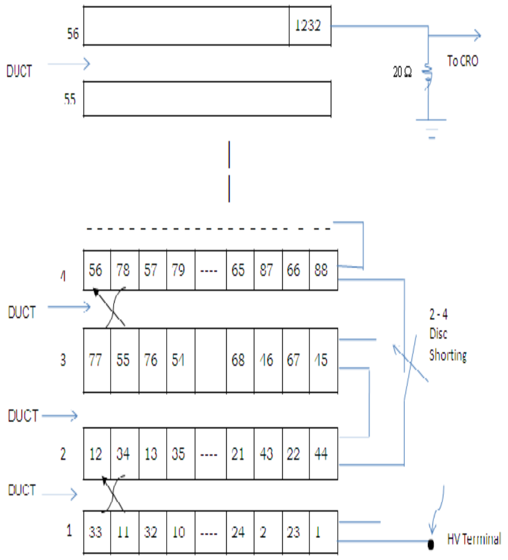

Figure 5A. Schematic diagram of an interleaved disc.

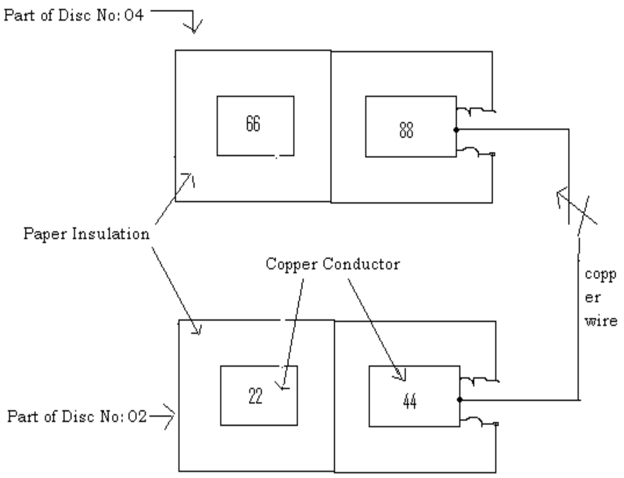

Figure 5B. Schematic diagram showing 44-88 shorting.

Daubachies3 wavelet is used to de-noise the recorded neutral current waveforms. These de-noised signals are compared with the original signals after reconstruction. These healthy winding currents transformed by wavelet and the faulted current transformed were analyzed using dB3 to identify the fault in the winding of the transformer.

IV. RESULTS AND DISCUSSIONS

The recorded neutral current waveforms for healthy winding, 2 disc fault, 4 disc fault and 12 disc fault are as shown in Fig.6. A careful observation between the current oscillogram of healthy winding and that obtained from 2 disc fault are almost identical. The small difference if any could be due to noise and jitter in triggering instant of the recurrent surge generator (RSG). The number of turns involved in 2 disc fault are 44. From this it can be inferred that if only two turns are associated with fault, it is extremely difficult to differentiate the current between healthy and two turn fault.

However, IEC-60076 suggests that a power transformer can be declared passed only if the neutral currents at calibration voltage and the test voltage remains identical. It is also stated that at full voltage Partial Discharges (PD) may appear which could remain dormant or non-existent at calibration voltage. The PD however is acceptable at high voltage and is not construed as failure. It is in this context that noise detection and elimination becomes important. The accuracy of noise determination may reflect on the acceptance or rejection of costly power transformers.

Using dB3 wavelet, the inherent component of noise is identified and is plotted in Fig 7. From Fig.7 it is evident that the component of noise in the recorded neutral current could have led to misinterpretation of data and hence dB3 wavelet is successful in identifying the component of noise and isolating the noise component from the recorded neutral current waveforms.

These de-noised neutral current waveforms were considered for identification and dB3 was used for the analysis. The detailed coefficients are used for comparative studies and a few of the typical waveforms are shown in Fig 8.

Using plotting tools the analyzed neutral currents are plotted and a shift in the neutral current waveforms is observed as shown in Fig 9, which confirmed the existence of fault in the windings because of physical shorting and hence wavelet technique is successful in identifying the fault in the winding of power transformer. Similar studies have been carried out for other recorded neutral currents. The results are found to be consistent with failure.

Shifting of the peak may be related to the change in winding inductance and capacitance causing a corresponding change in resonant frequency of the coil. The detection of difference in frequency may be identified by Fourier Transform and likely to be related to the shifting of peaks in current oscillograms.

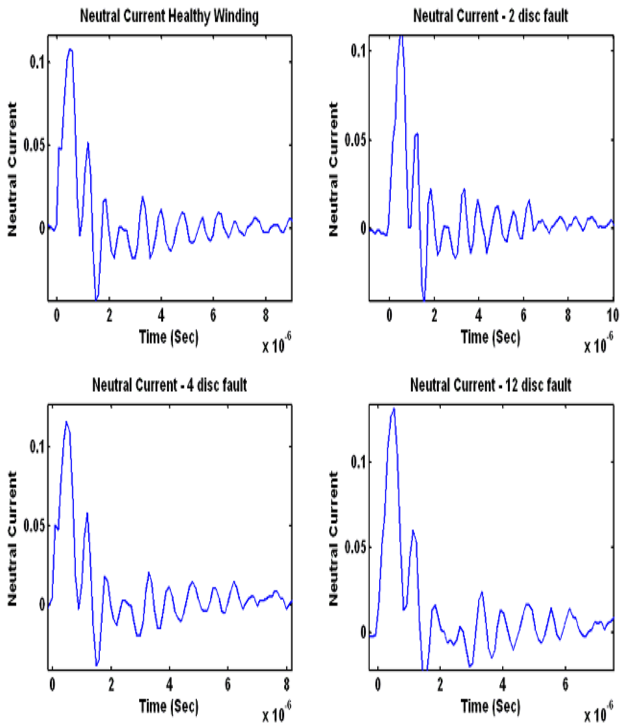

Figure 6: Recorded Neutral Current Waveforms.

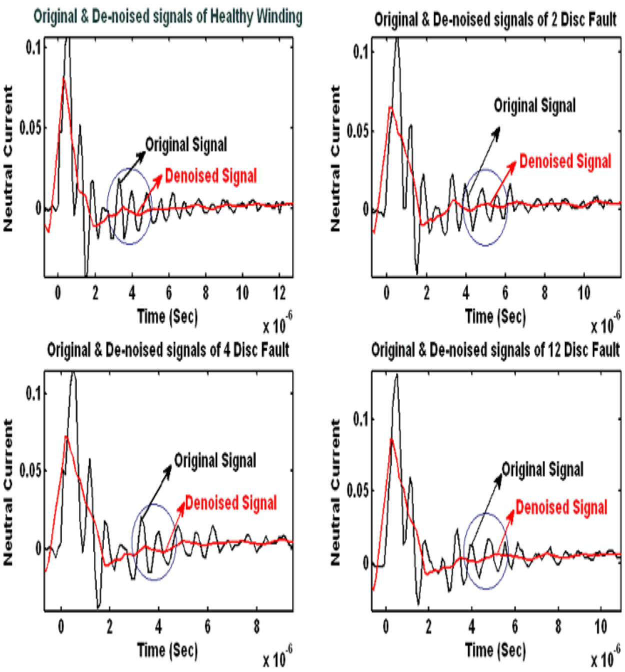

Figure 7: Comparison of original and de-noised signals

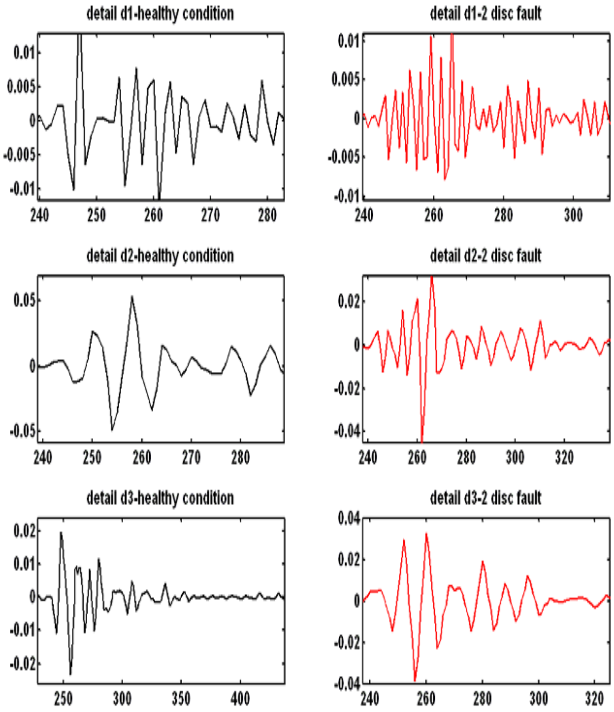

Figure 8: Comparison of Detailed coefficients of healthy & 2 Disc fault.

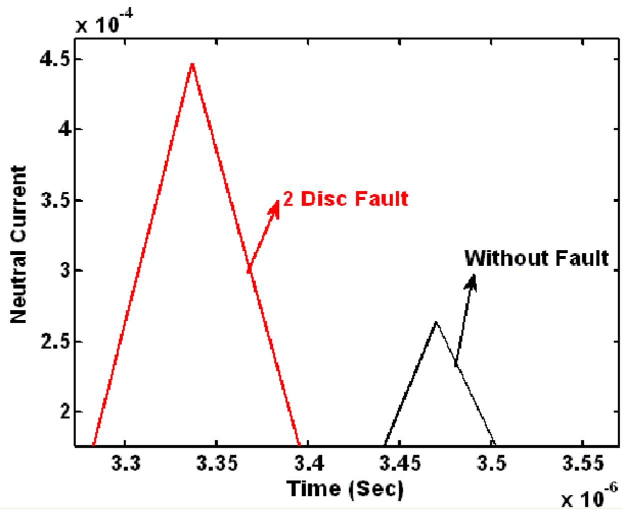

Figure 9: Shifting of peaks at different instants for different fault conditions

V. CONCLUSIONS

The neutral current wave forms recorded in high voltage winding of a generator transformer for an applied low voltage impulse were analyzed for fault diagnosis in windings using Daubachies3 wavelet. The noise component which was inherent in the signal was isolated effectively from the original signal using Daubachies3 wavelet. Thus signals have been reconstructed after de- noising and compared with the original signal. The de-noised neutral current signals were analyzed using Daubachies3 wavelet to detect the fault in the winding. Identification of fault in the winding thus can be visualized easily using wavelet technique.

VI. ACKNOWLEDGEMENT

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