Turk J Elec Eng & Comp Sci, Vol.20, No.6, 2012, © TÜBİTAK
doi:10.3906/elk-0908-152

Neutral current wave shape analysis using wavelet for diagnosis of winding insulation of a transformer

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Received: 11.08.2009

Abstract

Insulation failure within the windings of a power transformer arises due to over voltages, under voltages, notches, glitches, etc. A widely used technique to detect these power transformer insulation failures during an impulse test is the comparison of neutral current waveforms. Any shift in the recorded waveforms between reduced and full voltage confirms the existence of a fault in the windings. Hence, a proper analysis of neutral current waveforms is necessary to assess the condition of the insulation of power transformer winding. In order to carry out a wave shape analysis, a 61 MVA, 11.5/230 kV generator transformer is used and faults are created in the disks of high-voltage windings at specific locations. Neutral currents are recorded by applying a 100 V, low-voltage impulse. Noise inherent in the neutral current during recordings is isolated using a biorthogonal wavelet and the denoised signals are analyzed using the Shannon wavelet for identification of a fault in the winding.

Key Words: *Power transformer, low-voltage impulse, neutral current, denoised signal, biorthogonal wavelet, Shannon wavelet*

1. Introduction

Power transformers are important components in transmission and distribution. Winding is one of the important and costliest components of power transformers. Detection of a fault in the winding results not only in lower maintenance costs, but also helps in preventing premature breakdown and/or failure, besides improving overall system reliability.

In order to detect a fault in the winding, the transfer function technique is widely used [1], which reveals the condition of the winding. However, some of the lower-order variations are difficult to recognize using this technique [2]. To overcome this, a novel technique such as the wavelet is employed [3].

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Research on winding insulation and fault diagnosis in power transformers has progressed with the application of advanced wavelet transforms. The direct consequence of this approach is the possibility of accurately locating in time all abrupt changes in the signal and estimating their frequency components [4].

In the present investigation, a low-voltage impulse of 100 V was applied at the center entry lead of the high-voltage (HV) winding. The neutral currents were recorded and noise in the signal was isolated using a biorthogonal wavelet. Isolation of the noise from the recorded neutral current is important, as it would otherwise would lead to misinterpretation of the analyzed neutral current waveforms [5,6]. After denoising, the signals were analyzed for fault detection using the Shannon wavelet for different faults in the axial direction across the disk in the individual windings. Furthermore, these analyzed waveforms were processed using plotting tools.

2. Wavelets for fault analysis

If $f(t)$ is a square integrable function, the continuous wavelet transform (CWT) of $f(t)$ with respect to a wavelet $\psi(t)$ is defined as:

$$W(a,b) \equiv \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)\psi* \left(\frac{t-b}{a}\right) dt,$$

where a and b are real and $*$ denotes the complex conjugate. Here the variable b represents time shift or translation and a represents the scale or dilation variable [4]. The function $\psi(t)$is a mother wavelet that satisfies the necessary conditions:

$$\int_{-\infty}^{\infty} \psi\,(t)\,dt = 0.$$

In other words, the function integrates to zero and:

$$\int_{-\infty}^{\infty} |\psi\,(t)|^2 dt < 0;$$

i.e. the function has finite energy.

The admissibility condition for $\psi(t)$ to be called a wavelet is that it should be oscillatory [7] because of its additional feature of providing resolution levels by dilation and translation functions; these are preferred to Fourier transform [8].

In biorthogonal wavelets, 2 wavelets are introduced. One, Φ, is used in the analysis, and the other, Ψ, is used for synthesis, as they appear in Eqs. (1) and (2), respectively, as shown in Figure 1.

$$C_{j,k} = \int s(x)\phi_{j,k}(x)dx \tag{1}$$

$$S = \sum\nolimits_{j,k} C_{j,k}\Psi_{j,k} \tag{2}$$

where S is a signal and j and k are integers.

In this study, a biorthogonal 1.3 wavelet was used for denoising the neutral current signal, as a biorthogonal wavelet has the following properties that are suitable for denoising neutral current signals.

The important properties of biorthogonal wavelets are as follows:

1. The functions defined above for decomposition and reconstruction are compactly supported.
2. The functions for decomposition also have vanishing moments.
3. The functions for reconstruction have known regularity.
4. These functions are symmetric, which is a desirable property for decomposition and reconstruction, and split and nice allocation are possible.

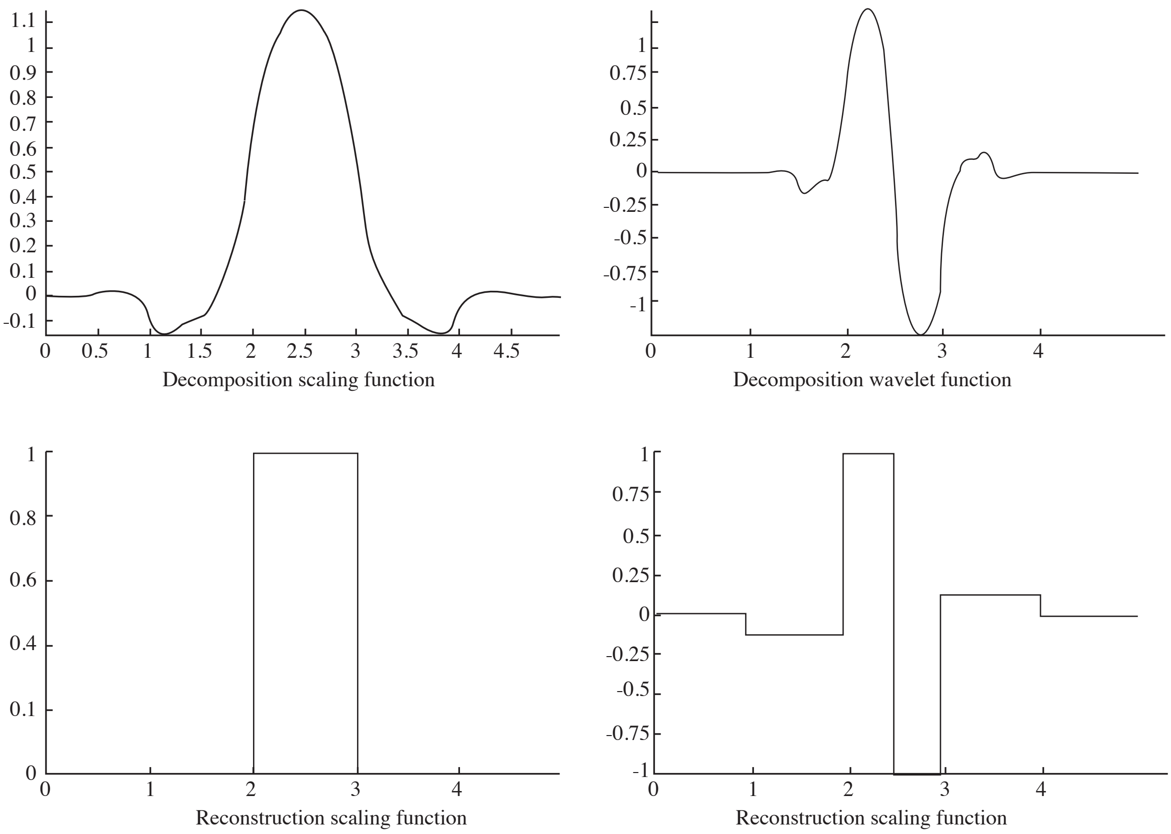

Figure 1. The Φ and Ψ functions of a biorthogonal wavelet.

In this study, a Shannon 1-1.5 wavelet was used to analyze the neutral current waveforms for the identification of the fault, which is given as follows:

$$\psi(x) = \sqrt{f_b}\,\{\sin c(f_b x)\}\, e^{2\pi i f_c x},$$

where f_b is the band width and f_c is the central frequency parameter.

The Shannon wavelet is complex and symmetrical, and it has a slow decay in the time domain but a sharp compact support in the frequency domain; hence, it is easy to compute expansion coefficients [9,10].

3. Experimental recordings of neutral current waveforms

The experimental studies were carried out on a generator transformer with a 61 MVA power rating and 11.5/230k V voltage rating, as shown in Figure 2. A low-voltage impulse at a magnitude of 100 V was applied from a recurrent surge generator (RSG) at the center entry of a HV winding of a transformer.

The HV winding is of 2-group construction with a center entry type having a total of 112 disks, with 22 turns in each disk. The HV winding is symmetrical at the center entry, with 56 disks in each half. The tapping winding consists of 40 plain disks of 4 turns each. The transformer with removed insulation is shown in Figure 3. In the present study, tapping winding was isolated and only HV winding was considered for experimental analysis. The schematic diagram used for the experimental studies is shown in Figure 4. A portion of pressboard cylinder was removed to allow easy accessibility to the HV disks; such removal facilitates the shorting of any conductor with other conductors or disks. The paper insulation of the outer turn of a large number of disks in the axial direction was removed to allow access to the bare conductor. These bare portions of the conductors were physically shortened to create short circuits, and hence the disk faults.

The construction of disks of HV winding was done as shown in Figure 5. The HV winding is made of an 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 the winding.

Figure 2. Experimental setup of a generator transformer.

Figure 3. The schematic diagram of HV winding.

A low-impulse voltage of 100 V, as mentioned above, was applied from the RSG and the neutral currents were recorded on the digital oscilloscope (Type Nicolet Power Pro 610) across a 10 Ω noninductive shunt.

Neutral currents were recorded for the healthy winding as well as for each shorted disk, as follows:

Healthy winding

2 to 4 disks shorted

2 to 6 disks shorted

2 to 8 disks shorted

2 to 10 disks shorted

2 to 12 disks shorted

2 to 14 disks shorted

2 to 16 disks shorted

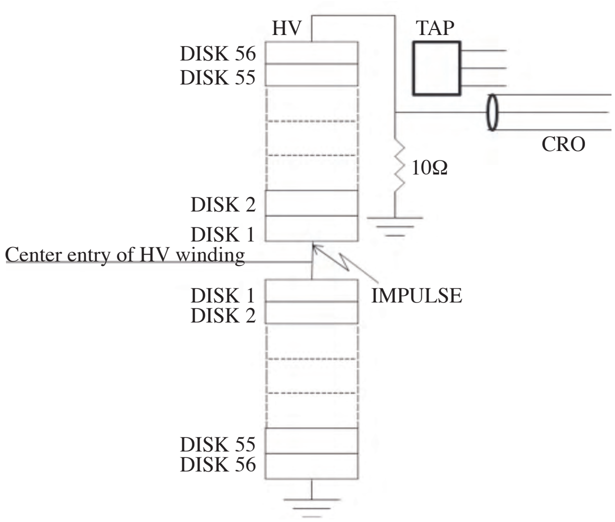

Figure 4. Schematic diagram of the transformer HV winding for the experimental studies.

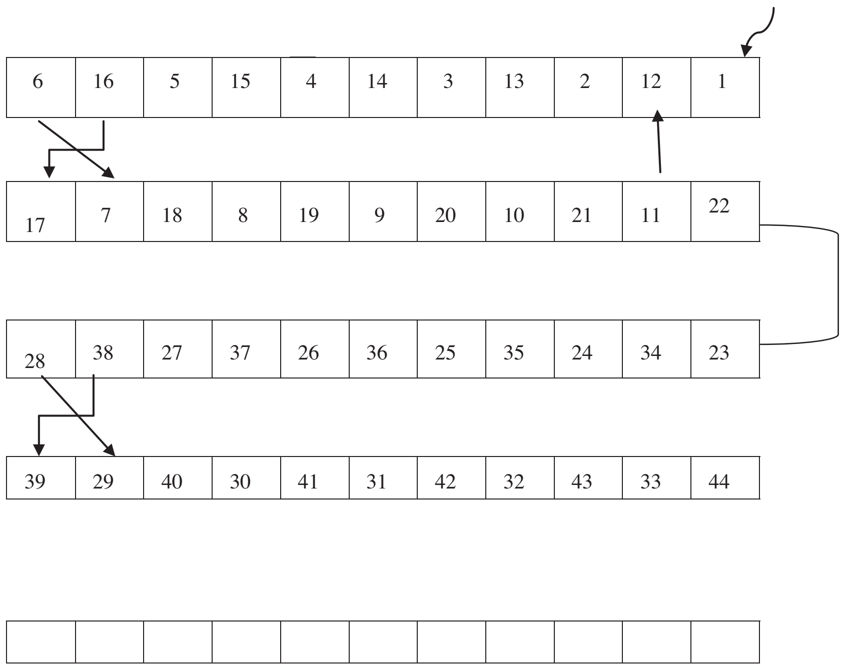

Figure 5. Schematic diagram of interleaved winding.

A biorthogonal wavelet was used to denoise the recorded neutral current waveforms. These denoised signals were compared with the original signal after reconstruction. These healthy winding currents transformed by wavelet and the faulted current transformed were analyzed using a Shannon wavelet to identify the fault in the winding of the transformer.

4. Results and discussions

In Figure 6, the recorded neutral current waveform of the healthy winding and reconstructed denoised waveform are shown. It can be observed that the component inherent in the signal was of definite magnitude and it could have led to misinterpretation of the data, and that the biorthogonal wavelet was successful in isolating the contribution of the noise in the signal.

These recorded neutral current waveforms of the healthy winding and the windings with different disk fault after denoising and reconstruction were considered for analyzing and identifying faults using the Shannon wavelet technique.

In Figure 7, the analyzed healthy winding waveform and 2-disk faulty waveform are shown. A definite shift in the peaks can be observed, which confirms the existence of a fault in the windings, and the Shannon wavelet technique was helpful in visualizing the fault. Similar analyses for other disk faults also confirmed the existence of a fault, i.e. there was a definite peak shift, but for want of space, only the healthy condition and 2-disk faults were compared, as shown in Figure 7.

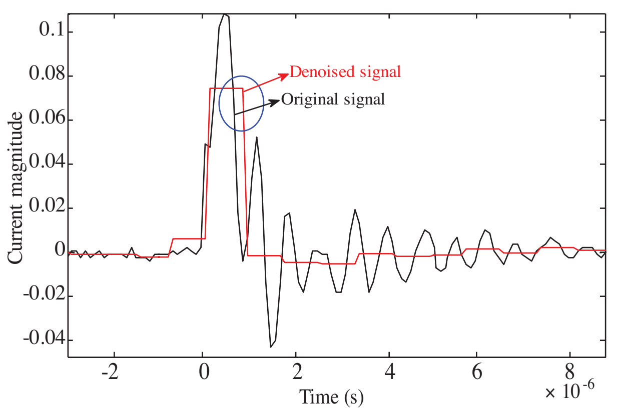

Figure 6. Comparison of the original and denoised signal.

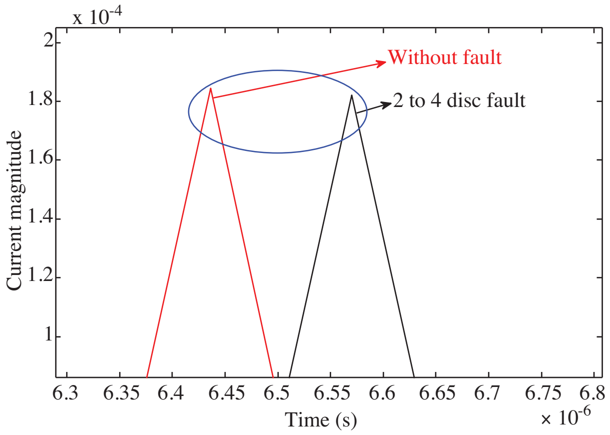

Figure 7. Shifting of the peaks at different instances for different fault conditions.

5. Conclusions

The neutral current wave forms recorded in the HV winding of a generator transformer for an applied low-voltage impulse were analyzed for fault diagnosis in the windings using the Shannon wavelet. The noise component that was inherent in the signal was isolated effectively from the original signal using a biorthogonal wavelet. Thus, the signals were reconstructed after denoising and were compared with the original signal. The denoised neutral current signals were analyzed using a Shannon wavelet to detect a fault in the winding. Identification of a fault in the winding can thus be visualized easily using the wavelet technique.

Thus, by carrying out calculations for various numbers of disk faults, it is possible to identify the extent of the fault. This can be related to the number of turns and/or the number of disks participating in the fault.

Acknowledgment

The authors would like to acknowledge the support, suggestions, and encouragement rendered by BHEL Corporate R&D, Hyderabad, in the successful completion of this paper. The authors would also like to gratefully acknowledge the constant encouragement and continuous support of the management, principal, and staff of the Institute of Aeronautical Engineering, Dundigal, Hyderabad.

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