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Wavelet Transform Technique for Fault Detection on Power System Transmission Line

V. C. OGBOH[1], E. A. EZEAKUDO[2], E. C. NWANGUGU[3]
[1,2,3] *Department of Electrical of Engineering, Nnamdi Azikiwe University Awka. Anambra State Nigeria*

Abstract - This paper presents a discrete wavelet transform and neural network approach to fault detection and classification in transmission line faults. The detection is carried out by the analysis of the detail's coefficients energy of the phase signals, and as an input to neural network to classify the faults on transmission lines. Neural network performs well when faced with different fault conditions and system parameters. In this paper, WT has been applied to the output phase A unbalance fault voltage and current signals of a typical transmission line modeled with MATLAB/SIMULINK 2016. The Phase A were simulated on the line and their pre – fault and fault voltage and current per – unit output values were generated and produced waveforms of pre – fault and fault signals. The results of the MRA fault detection analysis show that the wavelet transform method is more accurate in detecting the various faults of a transmission line than any other signal analysis techniques.

Indexed Terms: Wavelet Transform, Fault detection, Transmission line, Multi resolution analysis, Transient energy.

I. INTRODUCTION

In recent years power demand has been increased due the population of the power consumers. This increase in the population of the power consumers brought about the increase in the equipment use for the generation and transmission of this power.

Due to the robustness of the entire power system and weight of the load demand of it, it became obvious that the system is exposed to inevitable disturbances which are referred as faults.

These faults which are classified as balanced and unbalanced fault when occurs on transmission lines, causes a lot of damages. Thought classified as severe and un-severe but still can cause serious damages to the entire power system if not cleared of the system.
When the fault occurs on the transmission line, it needs to be detected and cleared within a very short time to avoid damage of the power system equipment or even causing economic loss to the community.
In last decade several techniques have been employed for the detection of the faults on the transmission line. These include impedance, bus impedance, symmetrical component techniques etc. other techniques include the expert systems (machine language, artificial intelligence etc.) and signal analysis techniques.
The signal analysis techniques are the Fourier series, Fourier Transform (FT), Fast Fourier Transforms (FFT), S – Transform (ST) and Wavelet Transform (WT) [1] [2].

II. METHODOLOGY

A. Detection of Fault Using WT

This section dwells on the application of the wavelet transform algorithm called Multiresolution Analysis (MRA) in diagnosis of fault on the 132kv Onitsha– Awka– Enugu transmission line.

Overcurrent and overvoltage or under voltage which are regarded as transient occurs very often on the transmission line. Persistence of these fault causes severe damage or problems can cause damage to the power system, therefore, the transmission line should be protected against persistence of these faults using all the possible transmission line protection schemes.

In this section, we are going to apply the second signal analysis method called Wavelet Transform (WT) for the diagnosis of fault on the 132kv Onitsha – Awka – Enugu transmission line.

Negative effects of faults are the presence of high frequency components of voltage and current fault signals [3] [4].

III. MODELING THE POWER SYSTEM TRANSMISSION LINE

The figure 1 is Wavelet Transform transmission line diagram modeled using Matlab 2016 specifically modeled for WT, for the detection of fault on the said transmission line.

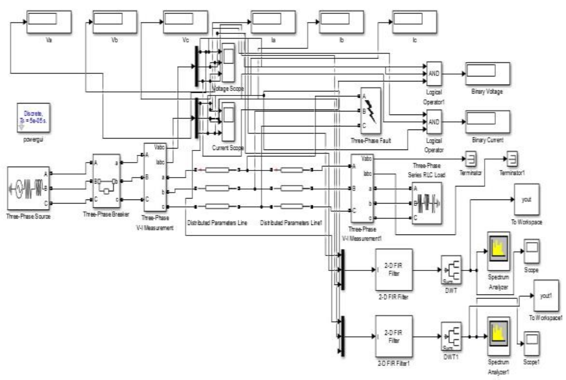

Figure 1: A wavelet transform model of transmission line for fault diagnosis of 330/132kv Onitsha – Awka – Enugu transmission line [3]

IV. DECOMPOSITION OF FAULT SIGNAL USING MULTI - RESOLUTION ANALYSIS (MRA) WAVELET TRANSFORM (WT) ALGORITHM

WT is a tool which analyzes the faulty signals obtained from the transmission line in the time as well as frequency domains effectively. It provides a non – uniform division of frequency domain which uses short window at high frequency and long window at low frequency. Using the multiresolution analysis (MRA) algorithm, a particular band of frequencies present in the fault signal can be analyzed.

Transient voltages and currents signals during the fault carry high frequency components which carry important information regarding detection, classification and location of faults on the transmission line.

MRA is a WT algorithm which decomposes the original fault signals to low frequency fault signal called approximations and high frequency fault signal called details. The approximations are denoted by the letter A_1 to A_n and details denoted by the letter D_1 to D_n. Where n = 1, 2, 3 …k.

The approximation and detail are decomposition output levels of a signal after decomposition and processed.

Let A_0 (n) be the discrete time voltage or current fault signal from Onitsha transmission line station or generated from the transmission line Simulink block model. These fault signals are to be decomposed into the detail and approximation. From the MRA algorithm, the decomposed fault signals at scale 1 are A_1 (n) and D_1 (n). where A_1 (n) is the version of the original fault signal (Approximation) and D_1 (n) fault signal (detail) detailed representation of the original fault signal A_0 (n) inform of wavelet transform coefficient [5].

$$A_1(n) = \sum_k h(k - 2n)\, A_0(k) \quad (1)$$

$$D_1(n) = \sum_k g(k - 2n)\, A_0(k) \quad (2)$$

Where h(n) and g(n) are the associated filter coefficient that decomposes A_0 (n) into A_1 (n) and D_1 (n) respectively.

This means in the first stage decomposition, the original fault signal is divided it two Halves of the frequency band. The next higher scale decomposition is now based on the fault signal $A_1(n)$. The decomposed fault signal at scale two is given by;

$$A_2(n) = \sum_k h(k - 2n)\, A_1(k) \quad (3)$$

$$D_2(n) = \sum_k g(k - 2n)\, A_1(k) \quad (4)$$

In the first decomposition, the fault signal is decomposed into D_1 component of high frequency band and A_1 component of low frequency band. The frequency band of D_1 component is $\left(\frac{f_s}{2} - \frac{f_s}{4}\right)$Hz and A_1 component is $\left(\frac{f_s}{2} - 0\right)$ Hz. Where f_S is the sampling frequency.

In the second decomposition steps, A_1 component extracted from the first decomposition steps is again decomposed, thereby producing D_2 component of high frequency band and A_2 component of low frequency band. However, frequency of D_2 component becomes $\left(\frac{f_s}{4} - \frac{f_s}{8}\right)$ Hz and A2 component becomes $\left(\frac{f_s}{2} - 0\right)$ Hz.

Figure 2 shows the multiple level decomposition (MRA steps) of the fault signals using DWT.

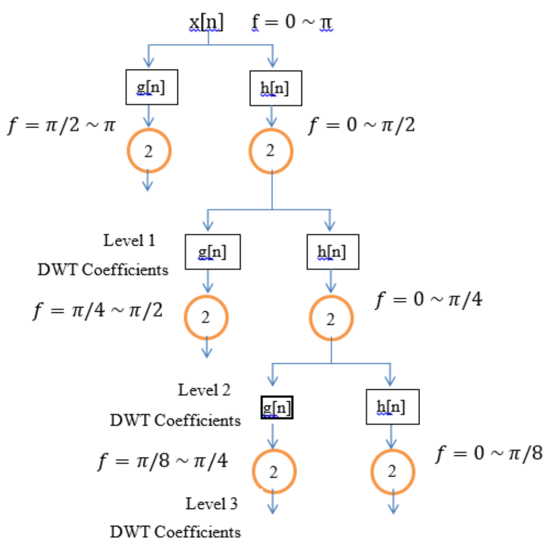

Figure 2: The Decomposition steps of fault signals (Sub-band Coding Algorithm)

From figure 2: The fault signals of the desired component is extracted through repetitive decomposition process. Thus, number of decomposition steps is chosen by comparing the scale of sampling frequency after each decomposition with that of frequency component of desired fault signal. The fault signals of voltage and current are sampled at 1 kHz which gives 2001 samples per cycle.
Daubechies (db5) among other mother wavelets was chosen since it has the ability of giving clear and accurate analysis result more than other mother wavelets.

The energy of detail coefficients for a k^{th} window is given as;

$$E_d\ (k) = \sum_{i=1}^{N} D_1^2\ (i) \qquad (5)$$

Where k = window number, i = level of DWT, N = length of detail, D coefficient at level 1. However, for accurate detection of fault, the difference between the two consecutive energies of the moving window can be obtained using;

$$F.\ D(k) = F.\ D(k-1) + [\ E_d^2\ (k) - E_d^2\ (k-2001)] \qquad (6)$$

Where F is the energy difference of two consecutive decomposed signals. D is the detail coefficient at level1 with k as the window number at that point. E_d is energy of the decomposed signal with D coefficient at level1. Total data sample is 2001 [4] [5].

V. OPERATIONAL PROCEEDURE OF THE WAVELET TRANSFORM TOOLBOX FOR THE DETECTION OF FAULT ON THE TRANSMISSION LINE

The pre – fault and fault voltage and current signal values are the inputs of the wavelet transform toolbox at point t = 0. The wavelet function picks s = 1 and multiplies by the selected signal value and then interpret the over result over times. The result of the interpretation is then multiply by the constant number; $\frac{1}{\sqrt{s}}$. This multiplication is for the normalization of the energy of the signal so that the transformed signal will have the same energy correspond to the highest frequency in the plot.

Considering the MRA (sub-coding pyramid), the original signal voltage and current are represented as x (n) and has 2001 samples existing with a frequency band of zero to frad/s. At the first decomposition level, the signal is passed through the high pass and low pass filters followed by subsampling by 2. The output of the high pass filter is then divided by 2 (ie $\frac{2001}{2}$) giving 1000.5 output sample or approximately 1000 samples. This 1000 samples carries the frequency band f/2 to frad/s which is double the frequency resolution and contributes the first level of DWT Coefficients.

This process continues until two samples are left. It will continue as decomposition process up to level 5 as has decided as our last decomposition level since the result obtained after level 5 did not reflect a good background for the analysis of the fault voltage and current signals used in this work.

The prominent frequencies in the output wavelet transform waveform corresponds to the fault point in the original signal and appeared as high amplitude or magnitude frequency component signals in the waveform. [4] [5]

VI. RESULT ANALYSIS

A. Fault detection

Wavelet transformations are applied to the transmission line fault voltage and current signals to obtain further information from them that is not readily available in their raw signal. Figure 4.3 to figure 4.24 show the three phase fault voltage and current waveforms for all the fault type simulated.

Energy of the voltage and current signals from D1 to D5 for data window of each fault signal were calculated and shown on tables 3, 4, 5 and 6 for real and simulated data respectively.

Figure 41 show the relationship between the energies of the faulted signal and their corresponding fault currents for both real and simulated data.

The actual energy value from the first data window (D1 to D5) to the last data window can be obtained using the graph of the data multiplied by the number of sample 2001.

[4] [5] [6].

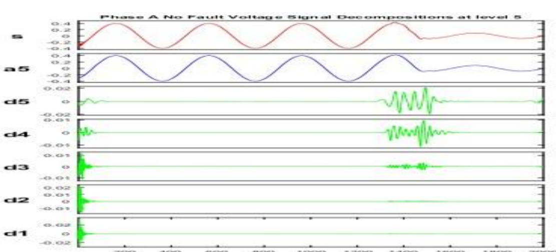

Figure 3: Decomposed No fault voltage signal waveform for phase A

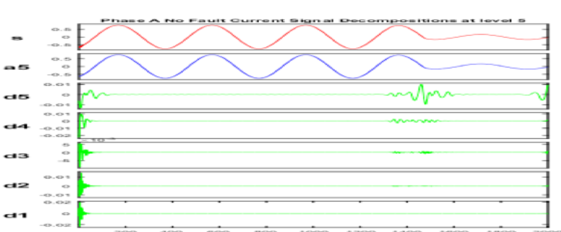

Figure 4: Decomposed No fault current signal waveform for phase A

VII. WAVELET TRANSFORM USING REAL DATA VALUE

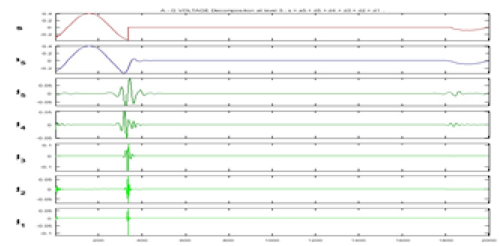

Figure 9: Decomposed voltage signal waveform for phase A – G fault

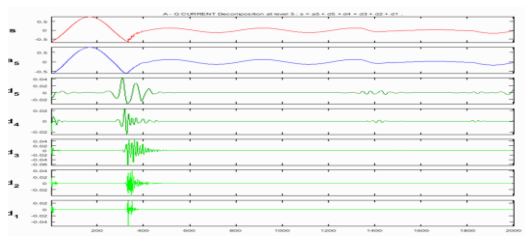

Figure 6: Decomposed current signal waveform for phase A – G fault

VIII. WAVELET TRANSFORM USING SIMULATED VALUE AT 48KM

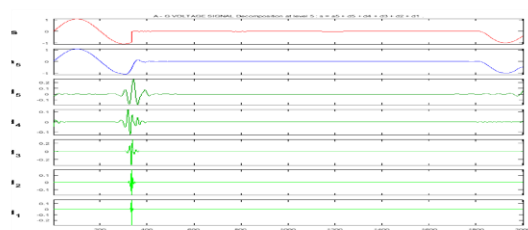

Figure 7: Decomposed phase A voltage signal waveform for phase A – G fault

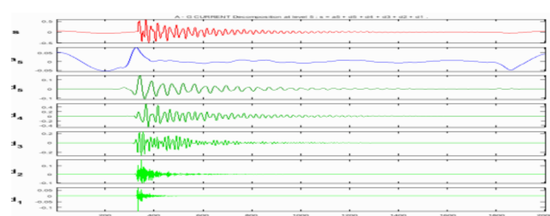

Figure 8: Decomposed phase A current signal waveform for phase A – G fault

IX. DECOMPOSITION OF THE PRE – FAULT (NO FAULT) OR FAULT VOLTAGE AND CURRENT SIGNAL

This is the continuous splitting of the signals into two equal portions in which one portion containing certain lower range frequency of that signal and referred as low pass portion because it is allowed to pass through low pass filter for the wavelet transformation processes or analysis. The other portion is called high range frequency of the same signal passing through high pass filter. Both portions can also be combine during the wavelet transformation process.

The act of decomposition is done from the level 1 to any level say 5 or 6 as the case may be. The signal decomposes from that level 1 to any level and continue to split into low pass and high pass portions. Its frequency component also continues to decompose until a predetermined level is obtained with different frequency bands.

X. MULTI – RESOLUTION ANALYSIS (MRA)

MRA is a Wavelet Transform algorithm built in the WT toolbox in Matlab software. It was used to analyses the voltage and current signals at different frequencies with different resolutions. This means that, every spectral component is not resolved equally. The MRA gives good time resolution and poor frequency resolution at high frequencies and gives good frequency resolution and poor time resolution at low frequencies.

However, once a mother wavelet (daubechies) is chosen, the computation selection of the scale value begins with s = 1 and the WT is computed for all possible values of s with a view of achieving a better computational result.

The scale ‘s’ is one of the tool that tell more about the fault existence or detection on the transmission line.

The larger the scale, the lower the frequency and corresponds to a non – detailed view of the signals, but the smaller the scale, the higher the frequency which is corresponds to detailed view of the signal and evidence of fault on the transmission line. From the wavelet transform waveforms, we can see that, the scales of all the fault types detected from the transmission line are all small, showing that, the faults detected are correct [1] [2] [3] [4] [5] [6].

Table 1: Fault Classification using Wavelet Transform using real data

S/No	Energy of the fault current signal after WT application (%)	Fault Currents (pu)	Fault Distance (Fault Location) (Km)	Fault Types
1	261.81	0.6586	232.4	A – G

Table 2: Fault Classification using Wavelet Transform using simulated data

S/No	Energy of the fault current signal after WT application (%)	Fault Currents (pu)	Fault Distance (Fault Location) (Km)	Fault Types
1	251.4	0.4423	232.4	A – G

Table 3: Energy of the fault voltage signals and the their corresponding fault types for real data

S/NO	D1	D2	D3	D4	D5	A5	E	Faults
1	0.01	0.02	0.20	0.08	0.40	99.40	40.40	A – G

Table 4: Energy of the fault current signals and the their corresponding fault types for real data

S/NO	D1	D2	D3	D4	D5	A5	E	Faults
1	0.01	0.00	0.01	0.02	0.22	98.99	261.81	A – G

Table 5: Energy of the fault voltage signals and the their corresponding fault types for simulated data

S/NO	D1	D2	D3	D4	D5	A5	E	Faults
1	0.00	0.01	0.22	0.08	0.45	99.88	50.34	A – G

Table 6: Energy of the fault current signals and the their corresponding fault types for simulated data

S/NO	D1	D2	D3	D4	D5	A5	E	Faults
1	0.00	0.00	0.00	0.00	0.02	98.99	251.4	A – G

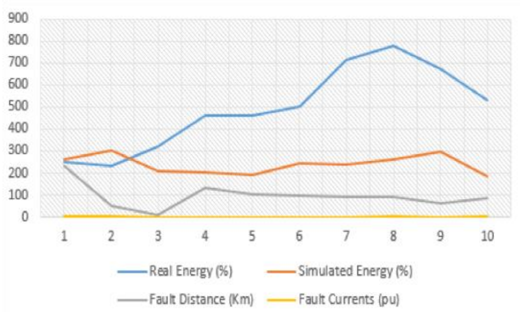

Figure 41: Wavelet transform fault location using both real and simulated data

XI. CONCLUSION

In this paper accurate fault detection was performed using WT with phase A voltage and current signals as inputs of the WT system. The high frequency components were decomposing from fault signals using WT. The ability of wavelets to decompose the signal into frequency bands in both time and frequency allows accurate fault detection.

It is found that the WT fault detection algorithm can detect fault with the very high accuracy.

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