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WAVELETS FOR IDENTIFY, CLASSIFY & ANALYSIS OF FAULTS IN POWER SYSTEM

P.M.SINDHU, UG Student
Deptartment of Electrical and Electronics Engineering
St. Johns College of engineering & technology
Yerrakota, Yemmiganur, Kurnool (D), A.P, INDIA
pm.sindhu1996@gmail.com

K.SUREKHA, UG Student
Deptartment of Electrical and Electronics Engineering
St.Johns College of engineering & technology
Yerrakota, Yemmiganur, Kurnool (D), A.P, INDIA
Surekhareddy931@gmail.com

B.GURURAJ, Assistant Professor
Deptartment of Electrical and Electronics Engineering
St.Johns College of engineering & technology
Yerrakota, Yemmiganur, Kurnool (D), A.P, INDIA
anilgururaj009@gmail.com

Abstract

Wavelet transform based analysis to determine line fault identification and classification, it is found wavelet is an excellent discriminant for identifying the travelling wave reflection from the faults irrespective of the faults type and impedance. Wavelet is used for analyzing power system fault transient in order to determine the fault location. The analysis involves representing signals in terms of simpler, fixed building blocks at different scales and positions. It introduces new classes of basic functions for time frequency signals analysis and have properties particularly suited to transient's components and discontinuities evident in power systems disturbances. MATLAB simulations are used to test and validate the proposed fault location approach for typical power system faults.

Keywords: Power system faults, wavelet transform, Travelling waves, Transients, Disturbances, MATLAB Simulink.

I. INTRODUCTION

Disturbances in Transmission Line (TL) results in an Electromagnetic transients and the analysis of them is very important to detect the fault [1]. A fault occurs when conductors come in contact with each other or with ground. In three phase systems, faults are classified as Single line-to- ground faults (LG Fault), double line-to-ground faults (LLG Fault), three phase-to-ground faults (LLLG Fault), Line-to- line faults (LL Fault), and Three phase faults (LLL Fault). Power system components are subjected to the greatest stresses from excessive currents at such times and may cause serious damage on power system equipment. Fault occurring on transmission lines cause degradation of power quality. So, it is necessary to determine the fault type and location on the line and clear the fault as soon as possible.

The few causes of faults in TL are lightning strikes, flashover, weather conditions, deformation of insulator materials etc. There are various techniques for fault detection and classification. Some of the techniques are based on Fuzzy logic [2-3], some use Artificial Neural Network (ANN) [4-5] while others Wavelet Transforms [6-8, 9-11]. Although, the Fuzzy and neural-network-based approaches have been quite successful in determining the correct fault type but they require considerable amount of training effort for good performance. The wavelet transform based approaches have been quite successful in fault detection and classification due to its ability to express faulted signal both in frequency and time domain. During the occurrence of faults, the grid current and voltages undergoes transients. These transients can be analyzed using discrete wavelet transform and the fault can be classified [12]. Some authors have also combined various techniques [13-18] to get better result. The authors in [16] presented an algorithm based on wavelet transform and ANN that can be used for fault classification. Daubechies wavelet filter coefficient (Db 4) has been used as mother wavelet. Youssef [15] has presented an online application of a wavelet based fuzzy-logic approach for fault classification. He introduced a fault-classification algorithm that was able to differentiate the appearance of a fault from the step up transformer magnetizing inrush current. Level 1 and level 4 approximation coefficients of fault signal was used for analysis. The authors in [13] have used fuzzy logic systems for which the discrete wavelet coefficients of current signals are given as input, to classify the faults in a transmission line possessing series compensation. To classify and identify the fault the authors have used Meyer wavelet as mother wavelet to obtain level 1 and level 2 details and approximation to extract the information from the current signals which are sampled at a rate of 10kHz. Using more than one technique gives better result, but at the cost of computational time andresource.

Wavelet transform [19] possesses excellent feature of being of short duration with finite energy which integrates to zero. Wavelet is well suited to wide band signals that are not periodic and may contain both sinusoidal and impulse components as it is typical for power system transients. Any random signal can be represented as sum of wavelet functions. Wavelet transform transforms the time-amplitude information into time-scale information. The advantage of this technique is that, both time and frequency domain information can be obtained. Using wavelet transforms the waveforms that occur during switching operations, transients, faults etc., can be analyzed so that more accurate analysis can be obtained. Wavelet transforms are practically realized using filter banks. In this paper, a new scheme is proposed for reliable fault classification. The proposed method uses the mean of the approximate coefficients, calculated from the DWT of each phase current at Scale 1, to define the wavelet-based classification scheme. Various faults are modeled and the performance of the proposed scheme is evaluated using various fault types.

II. WAVELET TRANSFORM

Wavelet transform (WT) is a mathematical technique used for many application of signal processing. Wavelet is much more powerful than conventional method in processing the stochastic signal because of analyzing the waveform in time scale region. In wavelet transform the band of analysis can be adjusted so that low frequency and high frequency components can be windowing by different scale factors. It allows time localization of different frequency components of a given signal. Windowed Fourier transform also partially achieves this same goal, but with a limitation of using a fixed width windowing function.

In the case of the wavelet transform, the analyzing functions, which are called wavelets, will adjust their time-widths to their frequency in such a way that, higher frequency wavelets will be very narrow and lower frequency ones will be broader.

This property of multi resolution is particularly useful for analyzing fault transients which contain localized high frequency components superposed on power frequency signals. Thus, wavelet transform is better suited for analysis of signals containing short lived high frequency disturbances superposed on lower frequency continuous waveforms by virtue of this zoom-in capability. The wavelet transform of a signal *f (t)* € $L^2(R)$ is defined by the inner-product between Ψ_{ab} *(t)* and *f (t) as:*

$$WT(f,a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} f(t)\varphi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where, a and b are the scaling (dilation) and translation (time shift) constants respectively, and Ψ is the wavelet function which may not be real as assumed in the above equation for simplicity. The choice of the wavelet function (mother wavelet) is flexible provided that it satisfies the so called admissibility conditions [20].

A. SINGLE ENDED RECORDING

A more robust configuration that does not require remote end synchronization is when the fault location is determined based solely on the recorded signals at one end of the line. However, in such a case, due to the lack of any other time reference, all time measurements will be with respect to the instant when the fault is first detected. Therefore, fault location calculations will be based on the reflection times of the travelling waves from the fault point. Unfortunately, for faults involving a ground connection, not only those reflections from the fault point, but also from the remote end bus will be observed at the sending end of the line. Proper algorithms should therefore be devised in order to distinguish between close-in and remote faults which may produce similar reflection patterns for the grounded faults. The following sections describe our proposed approach to accomplish this task.

B. APPROACH I: UNGROUNDED FAULTS

It has long been observed that ungrounded faults such as line-to line or ungrounded three-phase, do not cause significant reflections from the remote end bus during the fault transients. Thus, by measuring the time delay between the two consecutive peaks in the wavelet transform coefficients of the recorded fault signal at scale **1,** and taking the product of the wave velocity and half of this time delay, the distance to the fault can easily be calculated for these kinds of faults. The fault distance will be given by the equation:

$$x = \frac{v.td}{2} \text{ Eq} \qquad (2)$$

where, x is the distance to the fault, v is the wave velocity (for the mode used), and t_d is the time difference between two consecutive peaks of the wavelet transform coefficients.

C. APPROACH II: GROUNDED FAULT

When the fault involves a connection to ground, then sending end signals may contain significant reflections from the remote end bus in addition to the ones from the fault point. Also, depending on the location of the fault, the reflections from the remote end may arrive before or after those reflected from the fault point.

It can be easily verified by using the Lattice diagram method that the remote end reflections will arrive later than the fault reflections if the fault occurs within half the length of the line, close to the relay location. The opposite will be true if the fault is situated in the second half of the line. It is observed that, in the former case the *ground mode* wavelet transform coefficient (WTC) for scale 1, shows significant peaks, while the latter case ground *mode* WTC for scale 1 remains insignificant below the chosen detection threshold. Therefore, first a decision is made on whether or not the b fault is ground based on scale 2 WTC's of the ground mode signals. If these coefficients are found significant, then the fault will be assumed to be a ground fault. Next decision will be made on which half of the line the fault is actually located. This is done by observing scale 1 WTC's of the ground mode signals. Insignificant coefficients will imply that the fault is in the remote half of the line, and vice versa. If the fault is determined to be in the near half of the line, then ***td*** in Eq.(2) will simply be the time interval between the first two peaks of the scale **1** WTC's for the aerial mode. If the fault is suspected to be in the second half of the line, then ***td*** in Eq.(2**)** will be replaced by:

$$t_d = 2t - t_x - \qquad Eq\ (3)$$

Where:
t is the travel time for the entire line length, and
e, is the time interval between the first two peaks of aerial mode WTC's in scale 1.
Figure 1 shows the flowchart for the proposed fault location algorithm based on the wavelet transform coefficients. Next section contains results of simulations used to test this proposed algorithm for various fault types and line configurations.

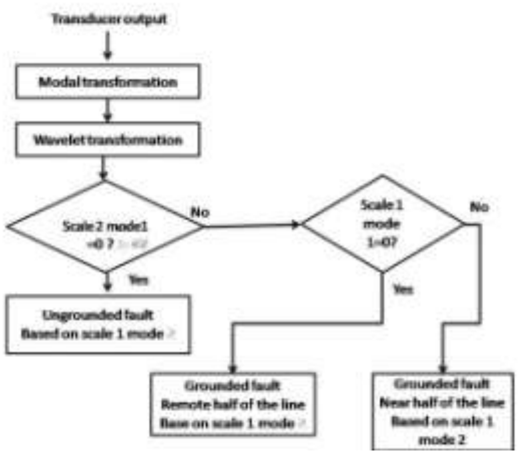

Figure1: Flowchart of the proposed fault location

III. FAULT CLASSIFICATION ALGORITHM

The types of faults considered in the analysis are LG, LLG, LLLG, LL and LLL. As three phase system is considered, there are altogether 11 faults possible. The faults are first simulated in MATLAB Simulink; the phase current values of each phase are collected. Daub4 discrete wavelet transform is applied to each phase at scale 1. The mean of the approximate coefficients of each phase is calculated. The parameter for the classification of faults is the mean of the approximate coefficient part of the Daub4 wavelet transform for each phase.

Let M_A= mean of the approximate coefficient part of the phase 'A' current at scale 1
M_B= mean of the approximate coefficient part of the phase 'B' current at scale 1
M_C= mean of the approximate coefficient part of the phase 'C' current at scale 1

1) *LG fault*

a) *Phase 'A'-to-ground (A-g) fault then,*

$|M_A| > |M_B|$ & $|M_C|$ and $|M_B| = |M_C|$

b) *Phase 'B'-to-ground (B-g) fault then,*

$|M_B| > |M_A|$ & $|M_C|$ and $|M_A| = |M_C|$

c) *Phase 'C'-to-ground (C-g) fault then,*

$|M_C| > |M_A|$ & $|M_B|$ and $|M_A| = |M_B|$

2) *LLG fault*

a) *Phase 'AB'-to-ground (AB-g) fault then,*

$|M_A| > |M_C|$ & $|M_B| > |M_C|$ and $|M_A + M_B| \neq |2 * M_C|$

b) *Phase 'BC'-to-ground (BC-g) fault then,*

$|M_B| > |M_A|$ & $|M_C| > |M_A|$ and $|M_B + M_C| \neq |2 * M_A|$

c) *Phase 'AC'-to-ground (AC-g) fault then,*

$|M_A| > |M_B|$ & $|M_C| > |M_B|$ and $|M_A + M_C| \neq |2 * M_B|$

3) *LLLG fault*

Phase 'ABC'-to-ground (ABC-g) fault then

$|M_A| \neq |M_B| \neq |M_C|$ and $|M_A + M_B| \neq |M_C|$, $|M_B + M_C| \neq |M_A|$,
$|M_A + M_C| \neq |M_B|$

4) *LL fault*

a) *Phase 'AB'(AB) fault then,*

$|M_A| > |M_C|$ & $|M_B| > |M_C|$ and $|M_A| = |M_B|$

b) *Phase 'BC'(BC) fault then,*

$|M_B| > |M_A|$ & $|M_C| > |M_A|$ and $|M_B| = |M_C|$

c) *Phase 'AC' (AC) fault then,*

$|M_A| > |M_B|$ & $|M_C| > |M_B|$ and $|M_A| = |M_C|$

5) *LLL fault*

Phase 'ABC' (ABC) fault then,

$M_A| \neq |M_B| \neq |M_C|$ and $|M_A + M_B| = |M_C|$, $|M_B + M_C| = |M_A|$, $|M_A + M_C| = |M_B|$

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Figure 2: Flowchart of fault classification.

All the 11 types of fault for three phase transmission system (A-g fault, B-g fault, C-g fault, AB-g fault, BC-g fault, AC-g fault, ABC-g fault, AB fault, BC fault, AC fault and ABC fault) is simulated for the sample system and the values of the mean of the approximate coefficients of each phase is calculated.

IV. WAVELET ANALYSIS:

Wavelet analysis is based on the multiresolution transformation of a signal, using a wavelet scaling function with known properties, into the time - scale (frequency) domain for feature and structural analysis. Scaling functions with good compact support yield *transform coefficients* which are localized both in time and frequency.

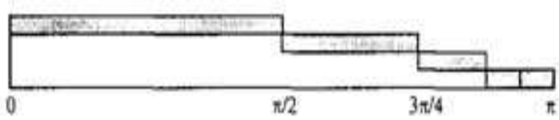

Figure 3: An arbitrary basis tree optimized for higher frequencies

This contrasts with the DFT where the sine/cosine orthogonal basis only provides frequency localization. At different scales in the wavelet domain the transform coefficients of a signal are de-correlated (linearly independent, unlike the time domain) and therefore sparse. **A** threshold criterion can be applied to the coefficients for feature extraction with the coefficients above the threshold used as an input to a neural network or Kohonen (feature) map for signal characterization [2]. Conversely, if an appropriate shrinkage criterion is applied to the coefficients, (retaining those above the threshold and rejecting those below) the signal can be compressed or de-noised, depending on the choice of criteria [3]. The resultant coefficients are inverted and the signal reconstructed.

A. WAVELET PACKET ANALYSIS

The waterfall plot in Fig. 4 illustrates the time - scale WPT analysis of the neutral current signal. The time – scale (frequency) localization of the WPT reveals the sparse coefficients at each scale (-ji) n the transform domain. The most energetic coefficients are those that best match the chosen scaling function, *q.* As the coefficients move from coarse (j = -1) to fine (j = **-8)** frequency resolution the more energetic coefficients are focused into two areas; around the fundamental and higher frequency transient. Short-term features, such as transients, are more readily localized at different scales and the WPT can be used to extract predetermined features from a signal using an appropriate scaling function and *descriptive basis.* The Fourier spectrum was computed using a normalized 512-point FFT with a rectangular window and frequency resolution of 2400 / 512 = 4.6875 Hz. The WPT PSD was computed and normalized by a squared-magnitude function described. The WPT frequency axis was linearised using the same Fourier frequency resolution.

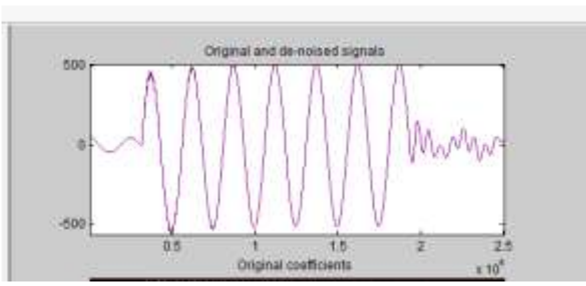

Figure4: A neural current signal from a phase to earth fault.

The plots reveal sharp spectral peaks at 50 Hz (fundamental) and gradual peaks at 1000 Hz (damped transient) with a 35 dB relative difference in amplitude. The difference can be attributed to the lower mean value of the non-energetic WPT coefficients. Also, the spectral continuity of the Fourier spectra is evident when compared to the 'jagged' appearance of the equivalent wavelet spectra. The fixed Fourier window and sinusoidal basis action mean that the contribution to a particular frequency coefficient will come from features at different scales. The Fourier transform coefficients tend to be strongly correlated unless long segments of a signal are used. This characteristic could be minimized, however, using an applied window function, such as Gaussian weighting. In contrast to the FFT, the WPT coefficients are better decorrelated and localized. This property is important for feature extraction in power system disturbances. **A** significant number of low-energy coefficients contribute little to the spectral energy of the signal hence the lower mean PSD and jagged appearance of the wavelet spectrum.

V. MATLAB SIMULINK MODEL

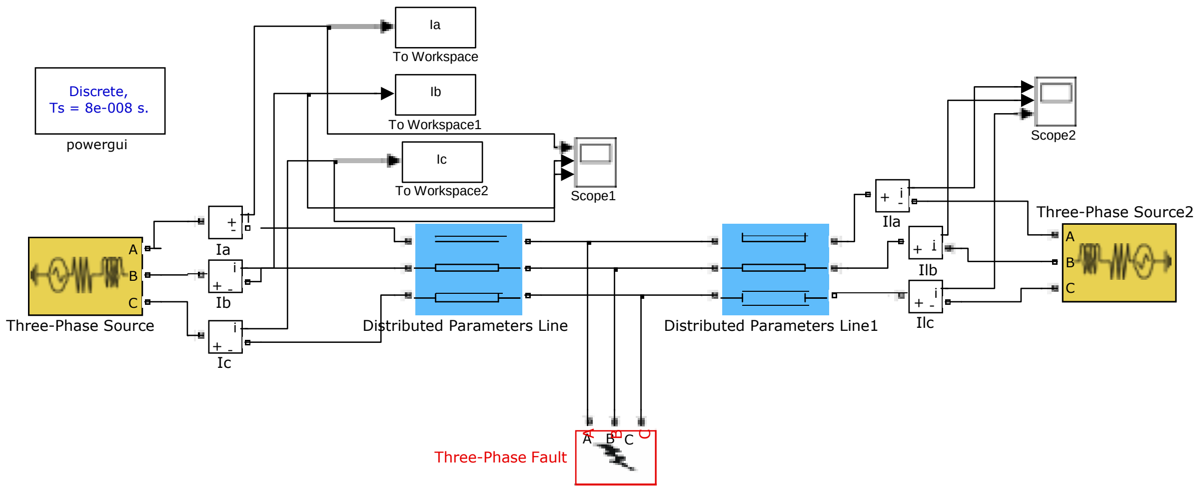

Fig.5 MATLAB/Simulink model of power System with fault analysis.

Consider a sample system. The data for the system is shown in table I. The fault occurs at a distance 50km from bus A.

TABLE I. SAMPLE SYSTEM DATA

Supply Voltage (G1 & G2)	132 Kv
Frequency	50 Hz
Sampling Time	$8*10^{-8}$
L (H/Km)	0.9337*10
C (F/Km)	12.74*10-
Length (Km)	200

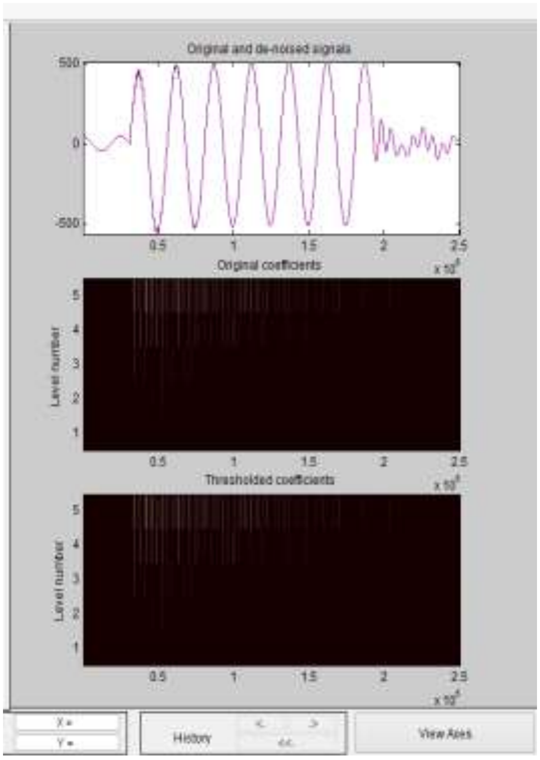

fig.8 FFT Spectrum of LG fault current waveform

VI. CONCLUSION

In this paper a new wavelet based transmission line fault identification and classification methodology, which is deterministic in nature and easy to implement .This method is thus useful to detect whether the fault is grounded or not and based on the formula for fault location . Using the travelling wave theory of transmission lines, the transient signals are first decoupled into their modal components. Model signals are then transformed from the time domain into time frequency domain by applying the wavelet transform .Simulation results are given to demonstrate the performance of the method.

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