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Wavelet-Based Transmission Line Fault Analysis

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Abstract*—this paper focused on identification of simple power system faults using wavelet based analysis of transmission line parameter disturbances. The major faults in transmission lines are line to ground fault, line to line fault and three phase faults. These faults can be identified and classified using discrete wavelet transform. 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. The maximum detail coefficient, energy of the signal and the ratio of energy change of each phase currents are calculated from the transients produced by each phases due to faults using discrete wavelet transform (DWT) and thus detecting and classifying transmission system faults. MATLAB Simulation results presented here validates the component models and the chosen fault detection scheme.

Index Terms—**Transmission line faults, fault detection, zero sequence current, discrete wavelet transform.**

I. INTRODUCTION

The major faults in transmission lines are line to ground fault, line to line fault and three phase faults. These faults can be identified and classified using discrete wavelet transform. 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 [1]. Analyzing the transients in each phase currents and zero sequence currents and identifying which fault is occurred. After wavelet transform calculating the energy of transients associated with each phase and ground and thus the fault involving phase is identified. The zero sequence current for ground fault analysis can be generated using Clark's transformation (abc to dq0). Electromagnetic transients in power systems result from a variety of disturbances on transmission lines, such as faults, are extremely important. A fault occurs when two or more conductors come in contact with each other or ground in three phase systems, faults are classified as Single line-to-ground faults, Line-to-line faults, double line to ground faults, and three phase faults. For it is at such times that the power system components are subjected to the greatest stresses from excessive currents These faults give rise to serious damage on power system equipment. Fault which occurs on transmission lines not only effects the equipment but also the power quality. So, it is necessary to determine the fault type and location on the line and clear the fault as soon as possible in order not to cause such damages. Flash over, lightning strikes, birds, wind, snow and ice-load lead to short circuits. Deformation of insulator materials also leads to short circuit faults. It is essential to detect the fault quickly and separate the faulty section of the transmission line. Locating ground faults quickly is very important for safety, economy and power quality. In this wavelet based fault analysis, analyzing the energy levels of wavelets of each phase and zero sequence currents and thus detecting and classifying the faults. Figure 1 shows the block diagram of discrete wavelet transform based transmission line fault analysis.

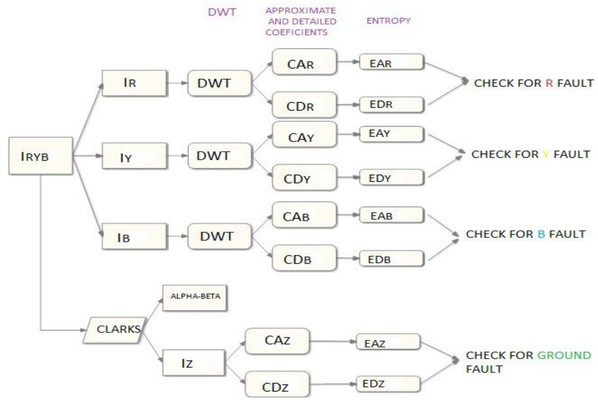

Fig.1. Block diagram of DWT based fault analysis

A. Discrete Wavelet Transform

Wavelet theory is the mathematics, which deals with building a model for non-stationary signals, using a set of components that look like small waves, called wavelets. It has become a well-known useful tool since its introduction, especially in signal and image processing. The DWT is easier to implement than Continuous Wavelet Transform CWT because CWT is computed by changing the scale of the analysis window, shifting the window in time, multiplying the signal and the information of interest is often a combination of features that are well localized temporally or spatially This requires the use of analysis methods sufficiently, which are versatile to handle signals in terms of their time-frequency localization. Frequency based analysis has been common since Fourier's time; however frequency analysis is not ideally suited for transient analysis, because Fourier based analysis is based on the sine and cosine functions, which are not transients [2]. These results in a very wide frequency spectrum in the analysis of transients Fourier techniques cannot simultaneously achieve good localization in both time and frequency for a transient signal. The main advantage of WT over Fourier Transform is that the size of analysis window varies in proportion to the frequency analysis. WT can hence offer a better compromise in terms of localization. The wavelet transform decomposes transients into a series of wavelet components [4], each of which corresponds to a time domain signal that covers a specific octave frequency band

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containing more detailed information [11]. Such wavelet components appear to be useful for detecting, localizing, and classifying the sources of transients. Hence, the wavelet transform is feasible and practical for analyzing power system transients. Figure 2 shows the high frequency and low frequency splitting of transient signal.

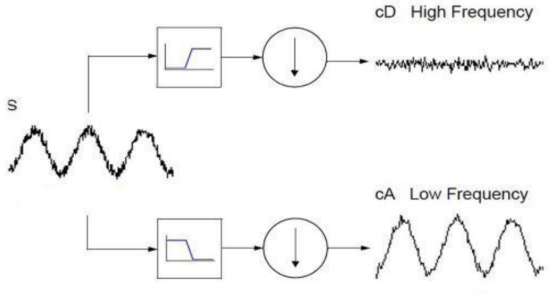

Fig.2. Analysis of signal using wavelet transforms

The discrete wavelet transform (DWT) is normally implemented by Mallats algorithm its formulation is related to filter bank theory. Wavelet transform is largely due to this technique, which can be efficiently implemented by using only two filters, one high pass (HP) and one low pass (LP) at level (k). The results are down-sampled by a factor two and the same two filters are applied to the output of the low pass filter from the previous stage. The high pass filter is derived from the wavelet function (mother wavelet) and measures the details in a certain input [3]. The low pass filter on the other hand delivers a smoothed version of the input signal and is derived from a scaling function, associated to the mother wavelet. The idea is illustrated in Figure which mathematically expressed as

$$Y\ high[k] = x[n] * H\ [2k - n] \quad (1)$$

$$Y\ low[k] = x[n] * L\ [2k - n] \quad (2)$$

In this analysis, results are carried out by using the db4 as mother wavelet for signal analysis .The wavelet energy is the sum of square of detailed wavelet transform coefficients. The energy of wavelet coefficient is varying over different scales depending on the input signals which contain energy of signal is contained mostly in the approximation part and little in the detail part-as the approximation coefficient at the first level having much more energy than the other coefficients at the same level of the decomposition tree-but because the faulty signals have high frequency dc components and harmonics, it is more distinctive to use energy of detail coefficients. The basic algorithm for the DWT is not limited to dyadic length and is based on a simple scheme down sampling and convolution. Figure 3 shows the discrete wavelet transform framework. DWT down samples the signal into detailed and approximate coefficients. Approximate coefficients again down samples into detailed and approximate coefficients.

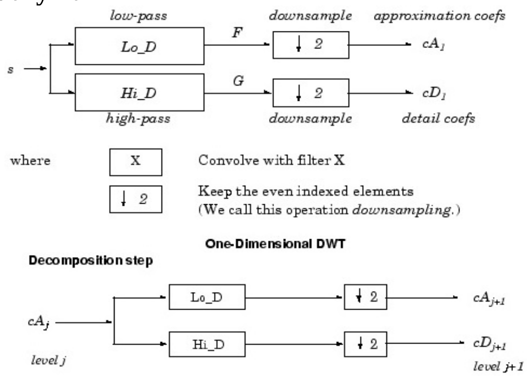

Fig.3. DWT framework

In this work the extension of DWT is Daubechies (db) this method assumes that signals can be recovered outside their original support by symmetric boundary value although Symmetrization has the disadvantage of artificially creating discontinuities of the first derivative at the border which is very small effect in calculation so the detail coefficients figured here show the signal end effects are present, but the discontinuities are very well cleared detected. The fundamental voltage and current phasors are estimated using Discrete Fourier Transform based algorithm which mitigates the effects of exponentially decaying DC offsets. The scheme is tested for different types of fault varying fault incidence angles and fault resistances using typical transmission line model. The DFT have some disadvantages that overcome by using DWT [7]. The system is modeled in MATLAB Simpowersystem environment. Results indicate that the proposed scheme is reliable, fast and highly accurate.

II. DISCRETE WAVELET TRANSFORM FOR FAULT ANALYSIS

A. Wavelet transformation and entropy calculation

Lots of fault information is included in the transient components. So it can be used to identify the fault or abnormality of equipments or power system. It can also be used to deal with the fault and analyze its reason. This way the reliability of the power system will be considerably improved. Transient signals have some characteristics such as high frequency and instant break. Wavelet transform is capable of revealing aspects of data that other signal analysis techniques miss and it satisfies the analysis need of electric transient signals. Usually, wavelet transform of transient signal is expressed by multi revolution decomposition fast algorithm which utilizes the orthogonal wavelet bases to decompose the signal to components under different scales. It is equal to recursively filtering the signal with a high pass and low pass filter pair. The approximations are the high scale, low frequency components of the signal produced by filtering the signal by a low pass filter. The details are the low scale, high frequency components of the signal produced by filtering the signal by a high pass filter. The band width of these two filters is equal. Figure 4 shows the wavelet decomposition of signal into high frequency detailed coefficients and low frequency approximate coefficients.

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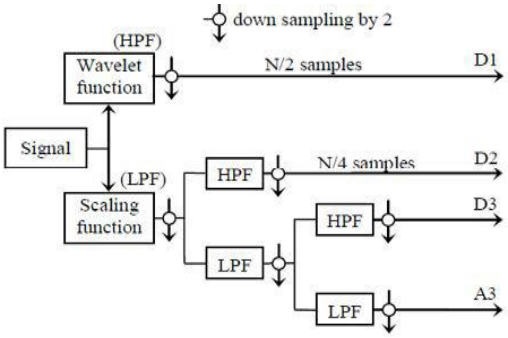

Fig.4. Wavelet decomposition

After each level of decomposition, the sampling frequency is reduced by half. Then recursively decompose the low-pass filter outputs (approximations) to produce the components of the next stage. Given a discrete signal x (n), being fast transformed at instant k and scale j, it has a high-frequency component coefficient Dj (k) and a low-frequency component coefficient Aj (k). The frequency band of the information contained in signal components Dj (k) and Aj (k), obtained by reconstruction are as follows.

$$Dj\ (k)\ :\ \left[2^{-(j+1)}\ fs,\ 2^{-j}\ fs\right] \quad \ldots\ldots\ (3)$$

$$Aj\ (k)\ :\ \left[0, 2^{-(j+1)}\ fs\right] \quad \ldots\ldots\ (4)$$

Where j= (1, 2, 3.....m), and fs is the sampling frequency the original signal sequence x (n) can be represented by the sum of all components as follows

x (n) = D1 (n) + A1 (n) = D1 (n) + D2 (n) + D3 (n) + A3 (n)... (5)

i.e.; x (n) = D1 (n) + D2 (n) + ……. + DJ (n) + AJ (n)……. (6)

Various wavelet entropy measures were defined here; the non normalized Shannon entropy will be used. The definition of non normalized Shannon entropy is as follows.

$$Ej = -\sum Ejk\ logEjk \quad \ldots\ldots\ldots\ (7)$$

Where Ejk is the wavelet energy spectrum at scale j and instant k and it is defined as follows.

$$Ejk = (Djk)^2 \quad \ldots\ldots\ldots\ (8)$$

The wavelet decomposition and entropy calculations are done on each phase to identify the faults in each phase and presence of ground fault can be identified based on the wavelet transform and entropy calculation on zero sequence currents. The modal transformation resolves three-phase signals in a coupled network into three uncoupled modal components, namely, 1) the ground mode; 2) aerial mode-1; and 3) aerial mode- 2 components. For non transposed multi phase systems, an eigenvector-based frequency dependent transformation matrix is required to convert the quantities from phase domain to modal domain. For balanced and ideally transposed lines, a frequency independent, real transformation matrix, such as Clarke transformation, can be used. Although practical distribution systems do not satisfy the aforementioned conditions, a frequency-independent real transformation matrix can be used to obtain somewhat decoupled signals that can be advantageous in transient based fault location.

B. System study and work process

Three phase current signals at normal condition were recorded and decomposed using DWT (db4 level 1) to get there maximum details coefficient, energy of these signals and then making compression of these signals and take the ratio of energy change from the first level with keeping approximation with no change because fault inception have great effect on detail coefficient as it generate a high frequency component to signal [6]. First Faults were created at a line for one cycle and analysis these signals before the realizing and switching of the circuit breaker. Different types of faults were simulated using MATLAB simulation and after recorded transient signals they were decomposed using wavelet toolbox to get there maximum details coefficient, energy of these signals and then making compression to these signals to get the ratio of energy change from the first level and how faults make changes to the energy of these signals. Figure 5 shows Matlab/Simulink simulation model for the transmission line fault analysis.

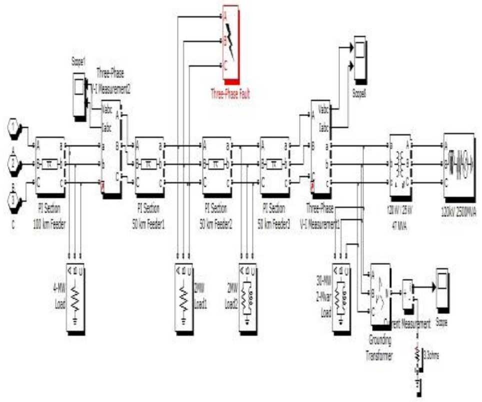

Fig.5. Power system simulation model

Simulation was carried out for all different single phase to ground fault, different double Phase with or without ground, and three phase faults with or without ground faults are simulated and analyzed. Making compression of current signals using threshold energy ratio with the first energy level for all current signals with keeping approximation with no change to compute the threshold of energy ratio change which if any energy ratio exceed this ratio level this means that there is a faulty condition to that phase. In this work if the energy ratio was exceed the energy ratio level corresponding to the normal condition, and then this phase is a faulty phase. Secondly to decide if this double phase or double phase to ground fault it was very cleared that if the fault is double phase the energy ratio will be the same for these two faulty phases with comparison with the energy ratio of double faulty phases when there is double phase to ground fault these ratio were not same and were some different. After the Clarke's

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transformation the energy level corresponds to the zero current. This energy level determines whether there is ground fault or not.

III. SIMULATION RESULTS

A. Without fault

The figure shows grid voltage and current. The energy associated with approximate and detailed coefficients are tabulated below. These energies are the reference parameters. If there is any change in these parameters, the phase is considered as faulty.

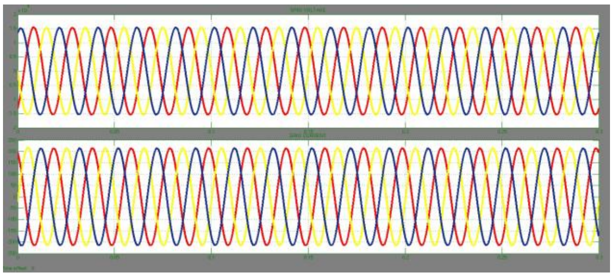

Fig.6. without fault

The energy of approximate coefficients and detailed coefficients of each phase and zero currents for without fault condition are given below.

Phase	R	Y	B	Zero
E_{CA}	99.997	99.997	99.997	99.995
$E_{CD}(wf)$	.002	.002	.002	.005

B. L-G faults

The L-G faults occur in transmission system are R-G, Y-G and B-G faults. For an example R-G fault is considered here. The figure shows the voltage and current waveforms of RG fault system. The R phase signals having more transients than other phases.

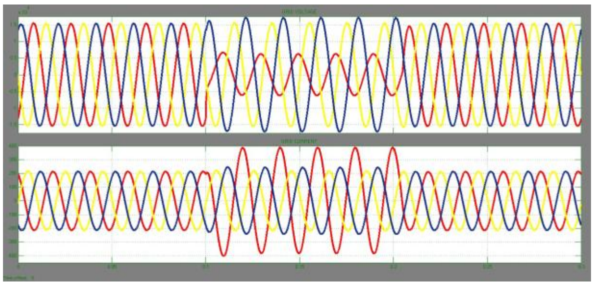

Fig.7. R-G fault

The approximate and detailed coefficients are calculated and energy associated with each phase and ground is tabulated. From the table it is clear that the energy associated with detailed coefficients of R phase and ground are changed and thus this is an R-G fault system.

Phase	R	Y	B	Zero
E_{CA}	99.992	99.997	99.997	99.999
$E_{CD}(wf)$	.002	.002	.002	.005
$E_{CD}(R-G)$	**.008**	.002	.002	**.001**

C. L-L faults

The L-L fault occur in transmission system are R-Y fault, RB fault and Y-B fault. For an example Y-B fault is considered here. The figure shows the voltage and current waveforms of Y-B fault system. The Y and B phase signals having more transients than other phases.

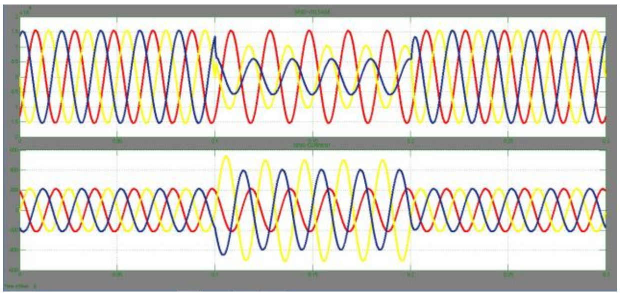

Fig.8. Y-B fault

The approximate and detailed coefficients are calculated and energy associated with each phase and ground is tabulated below. From the table it is clear that the energy associated with detailed coefficients of Y phase and B phase are changed and thus this is a Y-B fault system.

Phase	R	Y	B	Zero
E_{CA}	99.998	99.996	99.993	99.999
$E_{CD}(wf)$	.002	.002	.002	.005
$E_{CD}(Y-B)$	.002	**.004**	**.007**	.005

D. L-L-G faults

The figure shows the voltage and current waveforms of RB-G fault system. The R, B and zero signals having more transients than other phases.

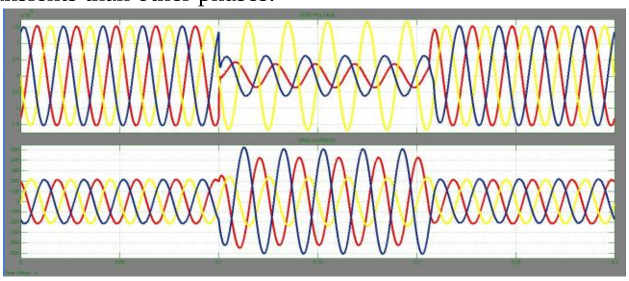

Fig.9. R-B-G fault

The approximate and detailed coefficients are calculated and energy associated with each phase and ground is tabulated below. From the table, it is clear that the energy associated with detailed coefficients of R B phases and ground is changed and thus this is an R-B-G fault system.

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Phase	R	Y	B	Zero
E_{CA}	99.99	99.998	99.993	99.999
$E_{CD}(wf)$	.002	.002	.002	.005
$E_{CD}(R-B-G)$	**.01**	.002	**.007**	**.001**

D. Three phase faults

Three phase faults occurs in transmission system are RYB faults and R-Y-B-G faults. Simulation results of both fault conditions are discussed. The figure shows the voltage and current waveforms of R-Y-B fault system. The R, Y and B phase signals having more transients than other phases

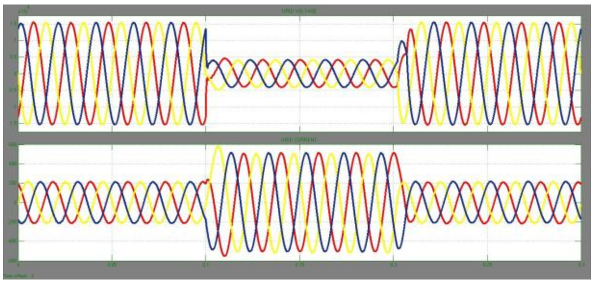

Fig.10. R-Y-B fault

The approximate and detailed coefficients are calculated and energy associated with each phase and ground is tabulated below. From the table it is clear that the energy associated with detailed coefficients of R, Y and B phases changed and thus this is an R-Y-B fault system.

Phase	R	Y	B	Zero
E_{CA}	99.99	99.992	99.991	99.995
$E_{CD}(wf)$	.002	.002	.002	.005
$E_{CD}(R-Y-B)$	**.01**	**.008**	**.009**	.005

The figure shows the voltage and current waveforms of RYB-G fault system. The R, B and B phase and ground signals having more transients than other phases.

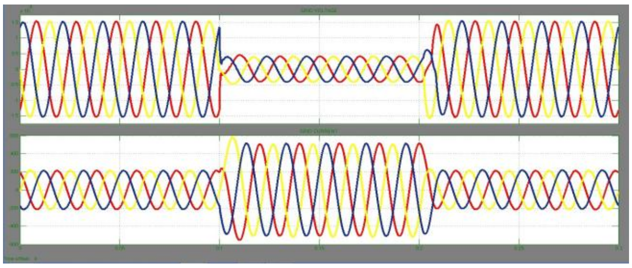

Fig.11. R-Y-B-G fault

The approximate and detailed coefficients are calculated and energy associated with each phase and ground is tabulated below. From the table it is clear that the energy associated with detailed coefficients of R, Y and B phases and ground are changed and thus this is an R-Y-B-G fault system.

Phase	R	Y	B	Zero
E_{CA}	99.99	99.992	99.992	99.999
$E_{CD}(wf)$	.002	.002	.002	.005
$E_{CD}(RYB-G)$	**.01**	**.008**	**.008**	**.001**

IV. CONCLUSION

This paper proposed a detection and classification method for the transmission line faults. For the fault detection and classification, a wavelet based current signature analysis technique is used. In this method of discrete wavelet based analysis of transmission line parameters for the fault detection took the advantages of the time and frequency localization of the DWT applied to the high-frequency components of transmission line parameter disturbances. A theoretical analysis, the complete design process, and the obtained results, in simulation, have been given in this paper. The proposed method, which has been validated in the presence of distorted grid voltages and classifying the faults in each category of faults.

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