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Transmission Line Fault Detection Using Wavelet Transform

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Abstract— Proper detection of various faults occurring on the transmission line is very essential. In this paper, detection and classification of some these faults is done based on the information conveyed by the wavelet analysis of power systems transients. Maximum norm values, maximum detail coefficient, energy of the current signals are calculated from the Wavelet Toolbox in MATLAB/Simulink. Maximum norm value and energy of the signals detects the fault and threshold detail coefficient classifies the fault into different types such as L-G, L-L-G, L-L-L.

Keywords*—Fault detection, Multiresolution analysis (MRA), Power systems, Wavelet Transform (WT), Signal energy, Dabauchies Wavelet.*

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I. INTRODUCTION:

Large number of faults occurs on the transmission line. These faults cause irregularities in the power flow through the line. Basically, a fault occurs when two or more conductors come in contact with each other or ground. In three phase systems transmission line faults are classified as Single line-to-ground faults, Line-to-line faults, Double line-to-ground faults, and three phase faults [1]. 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 hazardous damage of power system equipment and also the power quality. To carry on the regular power flow in the system, these faults are to be detected. Recently, distance relays have experienced much improvement in the field of fault detection due to the adoption of digital relaying. Signal processing is one of the most important parts of the operation for fault detection. Until recently, Fourier analysis and Kalman filtering methods were the main tools in signal processing for fault detection.

Wavelets are a recently developed mathematical tool for signal processing. Compared to Fourier analysis, which relies on a single basis function, a number of basis functions of a rather wide functional form are available in wavelet analysis [2]-[3]. The basic concept in wavelet transform (WT) is to select an appropriate wavelet function "mother wavelet" and then perform analysis using shifted and dilated versions of this wavelet. Wavelet can be chosen with very desirable frequency and time characteristics as compared to Fourier techniques. The basic difference is that, in contrast to the short time Fourier transform which uses a single analysis window, the WT uses short windows at high frequencies and long windows at low frequencies. The basic functions in WT employ time compression or dilation rather than a variation in time frequency of the modulated signal.

II. WAVELET THEORY:

Wavelet theory is very new (about 25 years old) but has already proved useful in many contexts. Wavelet may be seen as a complement to classical Fourier decomposition method.

Wavelet calculations are based on two fundamental equations: the scaling function $\varphi(t)$ and the wavelet function $\psi(t)$ [4].

$$\varphi(t) = \sum_k h_k \varphi(2t-k) \qquad (1)$$

$$\psi(t) = \sum_k g_k \psi(2t-k) \qquad (2)$$

These functions are based on the chosen scaling function $\varphi(t)$ (mother wavelet) which satisfies the following conditions:

$$\left.\begin{array}{ll} \sum_{k=1}^{N} h_k = \sqrt{2} & \\ \sum_{k=1}^{N} h_k . h_{k+2l} = 1 & \text{if } l=0 \\ \qquad\qquad\quad \mathbf{= 0} & \text{if } l \in Z,\ l \neq 0 \end{array}\right\} \qquad (3)$$

The discrete sequences h_k and g_k represent discrete filters that solve each equation, where $g_k = (-1)^k h_{N-1-k}$. The scaling and wavelet functions are the prototype of a class of orthonormal basis functions of the form

$$\varphi_{j,k}(t) = 2^{j/2} . \varphi(2^j t - k) \qquad ; j,k \in Z \qquad (4)$$

$$\psi_{j,k}(t) = 2^{j/2} . \psi(2^j t - k) \qquad ; j,k \in Z \qquad (5)$$

Where, the parameter j controls the dilation or compression of the function in time scale and amplitude.

The parameter k controls the translation of the function in time. Z is the set of integers.

Once a wavelet system is created, it can be used to expand a function $f(t)$ in terms of the basis functions.

$$w(t) = \sum_{l \in Z} c(l) \varphi(t) + \sum_{j=0}^{J-1} . \sum_{k \in Z} d(j,k) \psi_{j,k}(t) \qquad (6)$$

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Where, the coefficients *c(l)* and *d(j,k)* are calculated by inner product as

$$c(l) = \int f(t)\varphi_l(t)dt \qquad (7)$$

$$d(j,k) = \int f(t)\psi_{j,k}(t)dt \qquad (8)$$

Here, the expansion coefficients *c(l)* and *d(j,k)* represents the approximation and details of the original signal *f(t).*

The wavelet transform decomposes transients into a series of wavelet components having each of which corresponds to a time domain signal that covers a specific octave frequency band containing more detailed information. Such wavelet components appear to be useful for detecting and classifying the sources of surges. Hence, the WT is feasible and practical for analyzing power system transients and disturbances.

Wavelet transform is largely due to the use of Multiresolution Analysis [5], which can be efficiently implemented with the help of two filters, one of which is high pass (HP) and another low pass (LP) at level (k) where fundamental components generate. These 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 of the signal. The high pass filter is derived from the wavelet function (mother wavelet) and measures the details in a certain input while 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 Fig.1.

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. Energy of signal is contained mostly in the approximation part and little in the detail part-as the approximation coefficient at the first level have 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 [7]-[8]. The basic algorithm for the DWT is not limited to dyadic length and is based on a simple scheme: down sampling and convolution. As usual, when a convolution is performed on finite-length signals of border, distortions arise. 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 in effect in the calculation. So the detail coefficients figured here showed that the signal end effects are present, but the discontinuities are very well clearly detected [12]-[14]. The DFT have some disadvantages that are overcome by using DWT. The system is modeled in MATLAB Sim Power systems environment. Results indicate that the proposed scheme is reliable, fast and highly accurate.

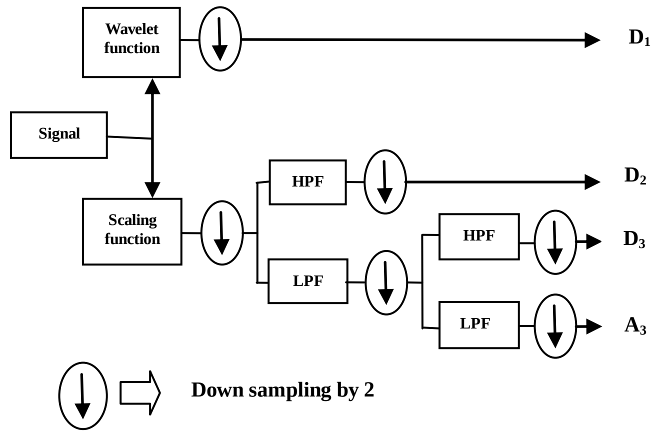

Figure 1. Multiresolution Analysis

III. Model Description:

The single line diagram of the simulated power network is shown in fig. below.

Figure 2. Single line diagram of the power system

Power system described in this paper consists of two sources A and B with buses 1 and 2 separated by a 300 km long transmission line. Various parameters are described in the table 1.

When fault occurs within the power network, the transient voltage and current signal in the fault section contain predominant high frequency components. This is due to superimposed reflection of the fault signals at the fault point. The energy of these high frequency signals is used as indicator of the fault occurrence in circuit. The fault detection rules are established by means of the analysis of the current waveforms in time domain and in the first decomposition level of the DWT. This level contains highest frequency components. In order to compute the wavelet coefficients energy, a moving data window goes through the current wavelet coefficients shifts one coefficient at a time shown in given equation.

$$E_w = \sum_{k=1}^{N_w} [d_w(k)]^2 \qquad (9)$$

Where, $d_w(k)$ is the k^{th} wavelet coefficient within the w^{th} window and N_w is the window length which computed as,

$$N_w = N_s / 2$$

Where, N_s is the number of samples within one cycle of the fundamental frequency of 50 Hz.

TABLE 1:
PARAMETER VALUES OF THE POWER SYSTEM

Components	Parameters
Frequency	50 Hz
Sources 1 and 2	400 kV (each)
Source impedance (same for both sources)	R1= 1.31Ω R0=2.33 Ω X1=15 Ω X0=26.6 Ω
Transmission line impedance	R1= 8.25 Ω R0=82.5 Ω X1=94.5 Ω X0=308 Ω
Capacitances	C1=13nF/km C0=8.5nF/km
Line length	300 km

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 by energy ratio method keeping approximation with no change, threshold detail coefficients are calculated. Different types of faults are simulated using MATLAB simulation [6] and after recording transient signals, they were decomposed using wavelet toolbox to get there maximum details coefficient, energy of these signals and then compressed these signals to get the threshold detail coefficients from the first level and hence showed how faults make changes to the energy of these signals. Simulations are carried out for all different single phase to ground fault but only shown here is Phase-A to ground, all different double Phase with or without ground but only shown here are Phase-AB (double phase fault) and AB-G (double phase to ground fault) and three phase faults [4]. Using the Wavelet Toolbox, if the maximum norm value and energy of the signals exceeds that of the normal condition, a fault is detected. Secondly, to decide if the fault occurred is double phase or double phase to ground, it is to be done that if the fault is double phase, the threshold detail coefficient for these two faulty phases will be the same while the energy ratio of double phase to ground fault for these two faulty phases will not be same, will be some some different. These results will be very cleared in next figures and tables of paper.

IV. SIMULATION RESULTS AND ITS ANALYSIS:

A. Normal Condition

Fig. 3 and 4 shows three-phase current signals (A blue, B green and C red colours) and its detail coefficients at no fault condition.

It is seen that when there is no fault, detail coefficients for all three phases are near to reach zero and only appears is the ending effect of daubechies wavelet which is also very small. Energy of the signal, maximum norm value and threshold detail coefficient for normal condition is shown in table 2 below.

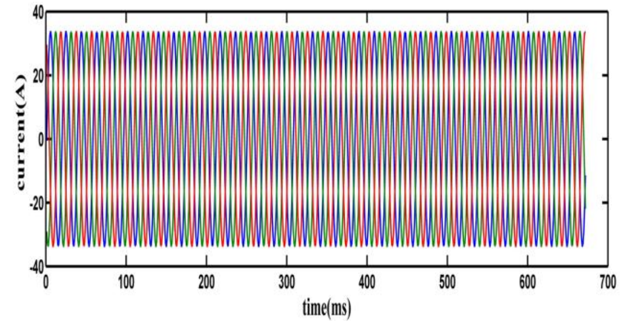

Figure 3. Three phase current signals at normal condition

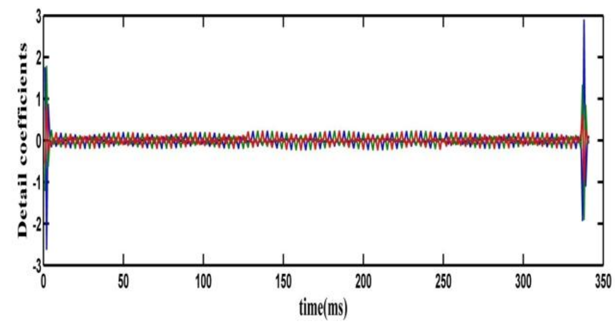

Figure 4. Detail coefficient at normal condition

TABLE 2:
MAXIMUM NORM VALUE, ENERGY AND THRESHOLD DETAIL COEFFICIENT OF THREE PHASES AT NORMAL CONDITION.

Phases	Parameters	Values
A	Maximumnorm	0.5414
	Energy of signal	3.886e005
	Thre. D coefficient	0.839
B	Maximumnorm	0.5415
	Energy of signal	3.909e005
	Thre. D coefficient	0.743
C	Maximumnorm	0.5414
	Energy of signal	3.88e005
	Thre. D coefficient	0.459

B. Single phase to ground fault

Three-phase current signals and the detail coefficients using DWT (db4 level 1) for phase A to ground fault are shown in fig. 5 and 6. From the detail coefficients, it is clear that the fault inception began at the instant fault occurred on phase A with

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other phases having no change as compared to that of phase A. Energy of the signal, maximum norm value and threshold detail coefficient for normal condition are shown in table 3 below. Since the faulty phase maximum norm value, energy of signal and threshold detail coefficients, is the highest, it is much cleared that the faulty phase has been detected on transmission line.

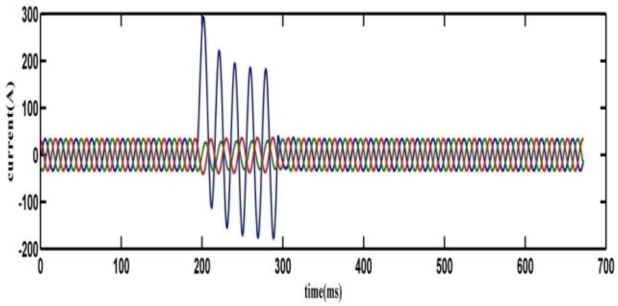

Figure 5. Three phase current signals at phase to ground fault

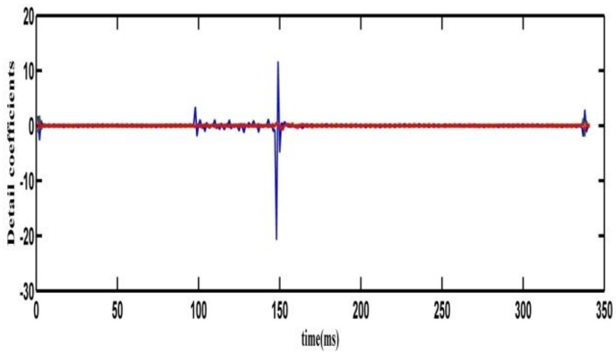

Figure 6. Detail coefficient at Single phase to ground fault

TABLE 3:
MAXIMUM NORM VALUE, ENERGY AND THRESHOLD DETAIL COEFFICIENT OF THREE PHASES AT SINGLE PHASE TO GROUND FAULT.

Fault type	Parameters	A	B	C
A-g	Max. norm	**4.755**	0.6395	0.6563
	Energy	**2.324e6**	3.833e5	4.024e5
	Thre. D coeff.	18.299	0.929	0.786
B-g	Max. norm	0.9647	**3.985**	0.9932
	Energy	4.142e5	**2.11e6**	3.956e5
	Thre. D coeff.	5.634	15.955	5.971
C-g	Max. norm	0.9467	1.295	**3.697**
	Energy	3.856e5	4.022e5	**1.951e6**
	Thre. D coeff.	8.030	8.471	16.819

C. Double phase to ground fault:

Three phase current signals with phases A-B to ground fault and its detail coefficients are shown in fig. 7 and 8. In this case, only two faulty phases at the fault inception time catch a great amount of change and high level of detail coefficient, although the healthy phase had nearly zero change. This is also described by the data included in Table 4 as the healthy phase is nearly with no change and nearby normal condition in energy and maximum norm, although faulty phases were so different which meant that these phases are in fault condition and when making compression, the threshold detail coefficients for two faulty phases are different (not in same amount). This will indicate that these faulty phases are connected to the ground of transmission line.

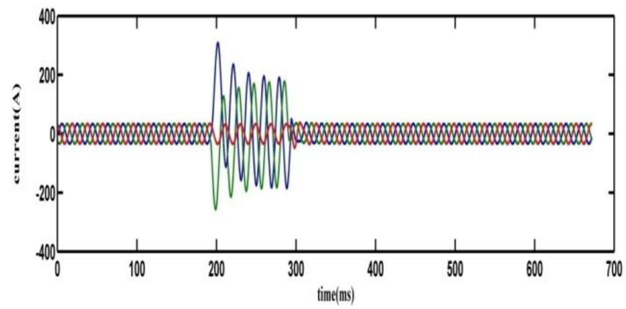

Figure 7. Three phase current signals at Double phase to ground fault

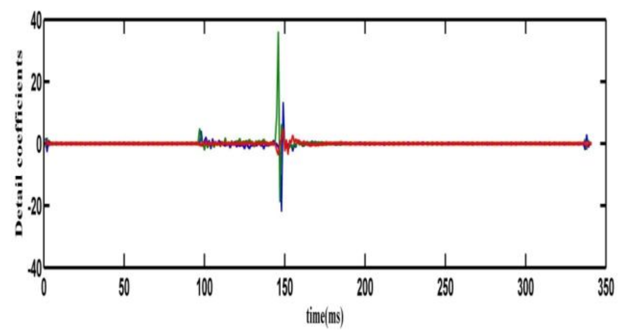

Figure 8. Detail coefficient at Double phase to ground fault

TABLE 4:
MAXIMUM NORM VALUE, ENERGY AND THRESHOLD DETAIL COEFFICIENT OF THREE PHASES AT DOUBLE PHASE TO GROUND FAULT.

Fault type	Parameters	A	B	C
AB-g	Max. norm	**4.937**	**4.14**	1.275
	Energy	**2.486e6**	**2.174e6**	4.045e5
	Thre. D coeff.	**12.624**	**16.456**	6.298
BC-g	Max. norm	1.424	**4.066**	**3.644**
	Energy	4.039e5	**2.23e6**	**1.967e6**
	Thre. D coeff.	16.331	**10.444**	**13.991**
CA-g	Max. norm	**4.817**	1.498	**3.914**
	Energy	**2.363e6**	4.087e5	**2.069e6**
	Thre. D coeff.	**12.498**	8.268	**16.713**

D. Three-phase fault:

Three phase current signals with three phase fault and their detail coefficients are shown in fig. 9 and 10. In this case, at fault inception time, there were great changes in all phases energy, its maximum norm values and all threshold detail coefficients of these faulty phases were higher than 0.001 and these above values are shown in Table 5 given below.

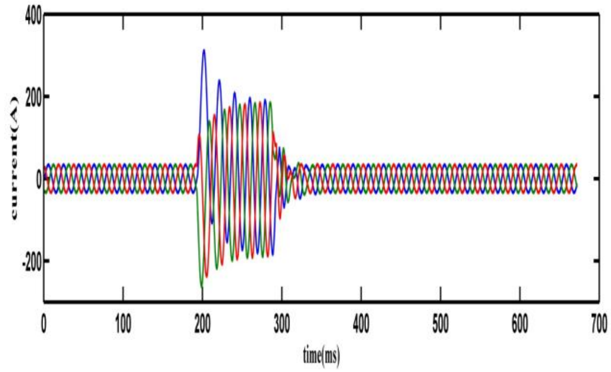

Figure 9. Three phase current signals at Three phase fault

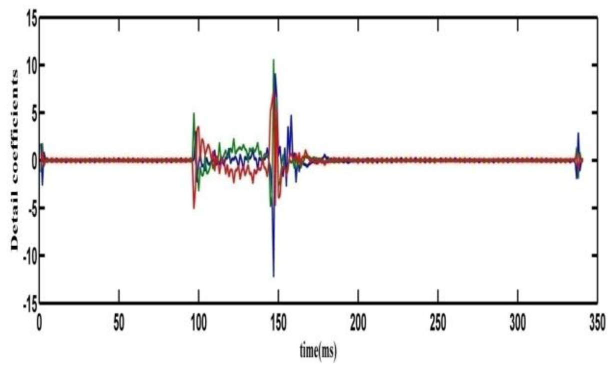

Figure 10. Detail coefficient at Three phase fault

TABLE 5: MAXIMUM NORM VALUE, ENERGY AND THRESHOLD DETAIL COEFFICIENT OF THREE PHASES AT THREE PHASE FAULT.

Fault type	Parameters	A	B	C
ABC	Max.norm	4.983	4.188	3.856
	Energy	2.601e6	2.302e6	2.089e6
	Thre. D coeff.	34.374	10.454	24.465

V. Conclusion:

WT has many applications in the field of Power system protection. One of those applications related to the detection of transmission line faults is presented here. WT has the ability to decompose current and voltage signals into both time and frequency domain which can be used for accurate fault classification. In this work, the proposed method used wavelet decomposition which provides more features about the signals. After decomposition, it is concluded that if maximum norm value of the particular current signal exceeds the value which is set for normal condition, a fault is detected. In further work, the technique which has the best performance will be used for a more complicated power system and using the logic method, fault fast detection is performed.

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