International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 6, Number 1 (2013), pp. 77-88

http://www.irphouse.com

Fault Location Technique for UHV Lines Using Wavelet Transform

G. Banu and Dr. S. Suja

EEE / Karpagam college of Engineering, Coimbatore, India
g.banusridhar@gmail.com
EEE / Coimbatore Institute of Technology, Coimbatore, India
ssujacit@yahoo.com

Abstract

The paper illustrates a procedure based on the continuous-wavelet transform (CWT) for the analysis of current transients due to line faults. Considering roundly reliability and accuracy of one terminal fault location system for transmission lines, a single-ended continuous wavelet Transform (CWT) based fault location algorithm has been presented in this paper. Wavelet transform is a powerful mathematical tool which can be employed as a fast and very effective means of analyzing power system transient signals. The modal current is decomposed by wavelet in time. The different decomposition coefficients on different scales reflecting different frequency information are used to calculate the transient characteristic of voltage and current. The transient characteristic is then utilized to obtain the transient energy of the fault that is employed to identify the fault position. MATLAB/Simulink is used to generate fault signals and verify the correctness of the algorithm

Keywords- Accuracy, Fault location, Fault currents, Continuous wavelet Transform, One end data

I. INTRODUCTION

Faults often occur in power transmission system, which cause supply interruptions, damages to equipment’s and affect the power quality. Therefore, accurate fault location estimation is very important in power transmission system in order to restore power supply as soon as possible with minimum interruption. Most of faults occurring in transmission and distribution networks are single-phase to ground faults.

Accurate location of faults on power transmission systems can save time and resources for the electric utility industry. Transmission line fault location techniques can be classified into two categories: (i) methods using data at two terminal of transmission line; and (ii) methods using data at one terminal. It is well known that techniques based on two terminal data require communication links and synchronized sampling equipment [1], [2]; more complex synchronized sampling, such as GPS method.

As the fast, accurate and reliable fault location on power system has become increasingly important issue for the utility industries, various single-ended and double-ended travelingwave (TW) based fault classification and location algorithms have been developed.

In general, transmission line fault location techniques could be divide into two broad categories based on the number of terminal data used, namely single end/terminal[3 -7].

The accuracy of identifying the faulted half of the line proposed in [8] for two terminal lines may not be reliable as the identification of the polarities of the TWs using WT will be difficult. The approximate fault distance based on impedance based algorithm for phase -to-ground (B-C-G) and phase A to-ground (A-G) faults can be computed respectively [9]. Traveling wave theory based fault classification schemes were also employed for transmission line protection [10].

If the incident traveling wave and the corresponding reflection from the fault point are successfully detected, the location of the fault can be rapidly identified [11]. There are many applications of wavelet transform in power system including high impedance fault detection, identification of power system disturbance, phase selection, etc

The idea of high-voltage transmission-line protection using traveling waves was introduced with a different point of view to the conventional techniques. This idea is based on the fact that an abrupt change of voltage at the fault point results in transient waves which propagate along the transmission line close to the light velocity.

The ability of wavelets to focus on a short-time interval for high frequency components improves the analysis of signals, particularly in the presence of transient components [12].

In this paper, a novel digital protection scheme based on wavelet transient energy is presented. Fault simulation is carried out using MATLAB2011b. The sampling data of fault current are decomposed 5 wavelets after careful comparison of the characteristics of different wavelet transform in power system application.

The proposed CWT-based fault location procedure is conceived to be combined with a measurement system aimed at acquiring both the starting time of the transient and the relevant waveforms.

II. Travelling wave method

When a fault occurs in transmission lines, fault traveling wave will transmit from fault point to detective bus and opposite bus along the transmission lines. Because of discontinuous impedance, fault traveling wave to detective line will be reflected at detective bus and transmit to fault point, then will be reflected at fault point and transmit to detective bus for the second time. For the same reason, fault traveling wave to opposite bus will be reflected at opposite bus and transmit to fault point, and may be refracted at fault point and transmit to detective bus.

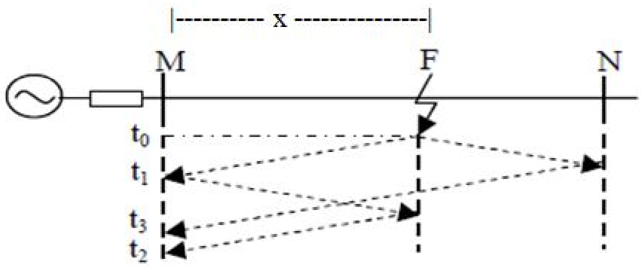

Fig. 1.Diagram of fault traveling wave propagation

As shown in Fig.1, *L* is the length of the fault lines, *x* is the fault distance from detective bus M, t_0 is the time when fault occurs, t_1 is the time when initial traveling wave arrives at detective bus, t_2 is the time when traveling wave reflected at fault point arrives at detective bus, t_3 is the time when traveling wave reflected at opposite bus and refracted at fault point arrives at detective bus

$$v = \sqrt{1/_{l_1 c_1}} = 2.98137 \times 10^5 \, km/s \quad \text{--} \tag{1}$$

The frequency spectrum of traveling waves is mainly distributed within the range of 10–100 kHz [7]. Generally, the frequency spectrum of an arriving wave at the relay location depends on several factors, such as inductance to resistance ratio of the transmission line (X/R), mutual coupling between phases, fault type, fault effective resistance, etc. Furthermore, substation high-voltage equipment and bus capacitances could influence the propagating waves in the power network. As a result, the power network presents a low-pass filtering characteristic to the traveling waves and, hence, frequency spectrum of the first arrived traveling wave could be different from those which correspond to the reflection of the first one from various discontinuity points in the power network [9].

III. Fault detection technique using wavelet transform

3.1. Extraction of characteristics using wavelet transform:

Wavelet transform is possible to extract information in time domain by decomposing the transient signal with short scale of window for high frequency band while with long window scale for low frequency band using scale and shift technique, contrary to Fourier transform [5].

The non-redundant representation and perfect reconstruction of the original signal can only be realized through compactly supported orthogonal wavelets [11]. Those that are frequently used for signal processing are Daubechies, Morlets, Coiflets and Symlets wavelets. These wavelets exhibit different attributes and performance criteria when applied to specific applications, such as detection of transients, signal compression and de noising

Unlike DWT, CWT can operate at any scale, specifically from that of the original signal up to some maximum scale. CWT is also continuous in terms of shifting: during computation, the analyzing wavelet is shifted smoothly over the full domain of the analyzed function. The CWT-analysis is performed in time domain on the voltage transients recorded after the fault in a bus of the distribution network As for mother wavelets, Harr, Daubechies, Biorthogonal, Coiflets, and Symlets may be listed, of which forms and properties are different depending on their types, accordingly optimum mother wavelet should be selected comparing the abilities of removing harmonics as well as extracting.

In addition, the number of decomposition steps is influenced from the sampling frequency of original signal. In the first decomposition step, it is decomposed into D1 component of high frequency band and A1 component of low frequency band.. The frequency band of D1 component is fs/2–fs/4 Hz, and A1 component isfs/4–0 Hz. In the second decomposition step, A1 component extracted from the first decomposition step is again decomposed D2 component of high frequency band and A2 component of low frequency band. The frequency band of D2 component is fs/4–fs/8 Hz and the frequency band of A2 component is fs/8–0 Hz band. As the signal of the desired component can be extracted via repetitious decomposition as like as this, number of decomposition steps should be decided by comparing the scale of sampling frequency with that of the frequency component of desired signal.

IV. Fault location information provided by continuous-wavelet transform

The CWT of a signal s(t) is the integral of the product between s(t) and the so-called daughter-wavelets, which are time translated and scale expanded/compressed versions of a function having finite energy w(t), called mother-wavelet. This process, equivalent to a scalar product, produces wavelet coefficients C(a, b), which can be seen as ‘‘similarity indexes’’ between the signal and the so-called daughter-wavelet located at position b (time shifting factor) and positive scale a:

$$C(a,b) = \int_{-\infty}^{\infty} s(t) \frac{1}{\sqrt{a}} \psi^* \left(\frac{t-b}{a} \right) dt$$ --- (2)

where * denotes complex conjugation. Eq. (2) can be expressed also in frequency domain

$$F(C(a,b)) = \sqrt{a} \Psi^*(a \cdot \omega) S(\omega)$$ ----- (3)

where F(C(a, b)), S(x) and W(x) are the Fourier transforms of C(a, b), s(t) and w(t), respectively. Eq. (3) shows that if the mother-wavelet is a band-pass filter function in the frequency-domain, the use of CWT in the frequency-domain allows for the identification of the local features of the signal. According to the Fourier transform theory, if the center frequency of the mother-wavelet W(x) is F0, then the one of W(ax) is F0/a. Therefore, different scales allows the extraction of different frequencies from the original signal – larger scale values corresponding to lower frequencies – given by the ratio between center frequency and bandwidth. Opposite to the windowed-Fourier analysis where the frequency resolution is constant and depends on the width of the chosen window, in the wavelet approach the width of the window varies as a function of a, thus allowing a kind of time-windowed analysis, which is dependent to the values of scale a. As known, the use of CWT, allows the use of arbitrary mother-wavelets which must satisfy the 'admissibility condition':

$$C_h = \int_{-\infty}^{+\infty} \frac{|\Psi(\omega)|^2}{\omega} d\omega < \infty$$ ----- (4)

Eq. (4) is satisfied by the two following conditions:

- mean value of w(t) equal to zero;
- fast decrease to zero of w(t) for t ! ±1.

Provided that the mother-wavelet satisfies specific conditions, in particular the orthogonality one, the signal can also be reconstructed from the transform coefficients. Several mother-wavelet has been used in the literature in this paper.

Unlike DWT, CWT can operate at any scale, specifically from that of the original signal up to some maximum scale. CWT is also continuous in terms of shifting: during computation, the analyzing wavelet is shifted smoothly over the full domain of the analyzed function.

The CWT-analysis is performed in time domain on the voltage transients recorded after the fault in a bus of the distribution network. The analyzed part of the transient recorded signal (t), which can correspond to a voltage or current fault transient, has a limited duration (few milliseconds) corresponding to the product between the sampling time Ts and the number of samples N. The numerical implementation of the CWT to signal s(t) is a matrix C(a, b) defined as follows:

$$C(a, iT_s) = T_s \frac{1}{\sqrt{|a|}} \sum_{n=0}^{n-1} \psi^* \left[\frac{(n-i)T_s}{a} \right] s(nT_s);$$
$$i = 0, 1, \ldots, N. \quad \text{---} \quad (5)$$

V. Modeling and simulation

In order to verify the methodology of the proposed technique, it is necessary to obtain the relevant data signals from the power system, under different possible operating conditions. It is well known that field fault testing on real power systems is difficult because of technical and economical reasons. In addition, the field test data usually suffer from certain limitations. That is why a real electrical distribution system, under different conditions, has been accurately modeled and simulated with Sim Power System Block set of MATLAB. Sim Power System Block set in MATLAB is a complete and powerful electrical engineering software tool that allows engineers to build electrical models in Simulink environment and change their operation conditions.

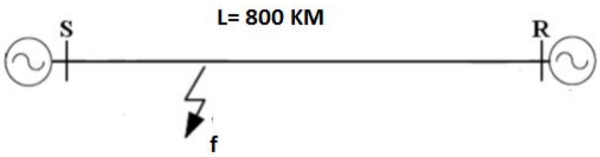

Fig 2. One line diagram for 1000 kv line

Fig 2 shows the one line diagram of 1000 kv line with a total length of 800 km.

In order to demonstrate the correctness of the assembled algorithm proposed, a model with length of 800km, voltage grade of 1000kV and frequency of 60Hz is built for simulation. As shown in Fig.3, Fault type can be set through the module of Fault Setting Ports for measurement. Waveforms of normal currents and voltages and fault voltage and current can be detected by the way of oscillograph module, and data of voltages and currents will be put out through the scope.

Transmission lines distributed parameters are given as Following

Positive sequence resistance r1 = 0.89 Ω

Zero sequence ro = 0.89Ω

Positive sequence inductance l1 =0.0414 H

Zero sequence l0 = 0.0414H

Source resistance = 0.8Ω

Source inductance = 10e-3Ω

Frequency =60 Hz

Fig 4 Shows the Voltage and current waveform at normal condition respectively.

Fig 5 shows the Fault voltage and current waveforms respectively when single phase (C) to Ground fault occurs..

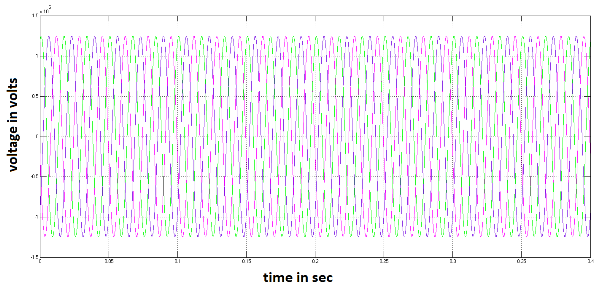

Fig.4 a. Voltage waveform at normal condition

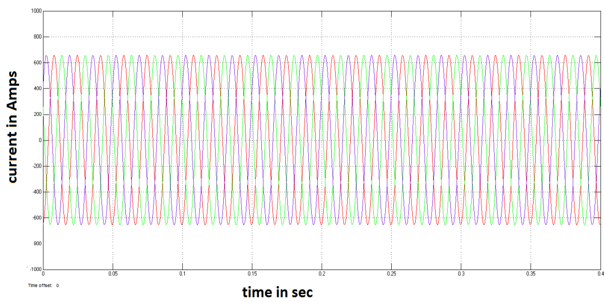

Fig.4.b. Current waveform at normal condition

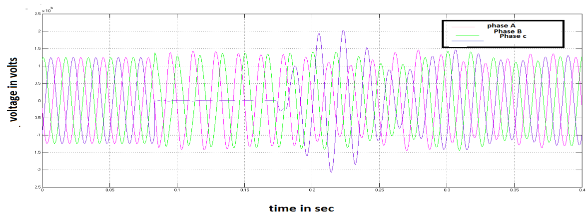

Fig 5.a. Voltage waveform at fault condition

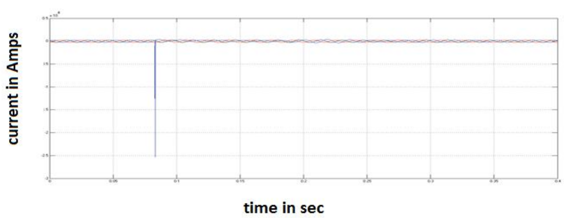

Fig.5.b. Current waveform at fault condition

The related transient information on high frequency and low frequency based on Daubechies series wavelet can reflect the fault information uniquely. In addition, the higher the number of wavelet levels used, the closer the reconstructed function is to the original. For function representation with a number of discrete points, where the number of discrete points in the original function equals to the number of wavelet base functions, the reconstruction is perfect.

Wavelet functions and scaling functions are used to decompose and reconstruct the signal at different resolutions levels. According to Parseval's theorem if the wavelets form an orthogonal basis, the energy in each of the expansion components are related to their wavelet coefficients.

The characteristic of the wavelet base is interacted, and the application performance of wavelets in signal processing can be balanced by selecting the wavelet levels. The calculation amount is larger and the reconstruction accuracy of the original signal is higher as the wavelet level is higher. Large amount of calculation affects the speed of the protection. In order to ensure the calculation speed of the distance protection as well as the reconstruction accuracy of the original signal, different wavelet is employed in the protection scheme

It is found that Haar6, Db6, Sym6, Bior6 and Coif6 wavelet are best in high-frequency extraction. When Fault occurs in phase ''C'' of the system, the current model as shown in fig 6

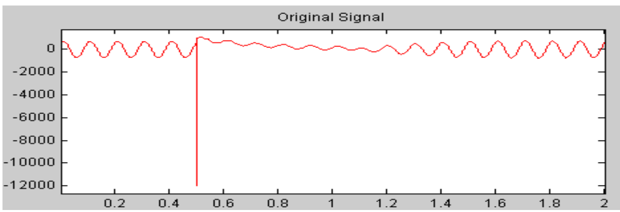

Fig 6.a Original fault current signal

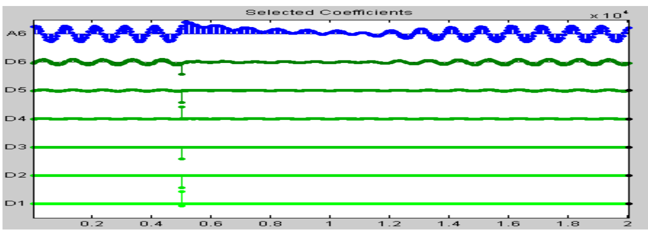

Fig 6.b. Co efficient using Haar wavelet

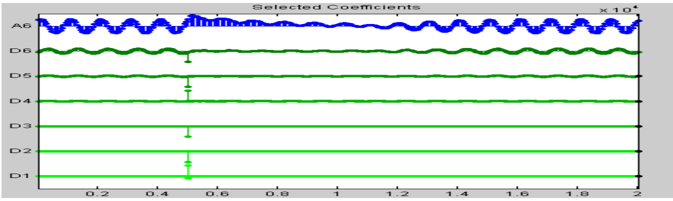

Fig 6.c. Co efficient using db wavelet

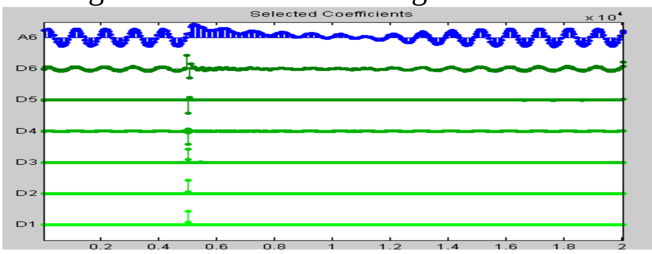

Fig 6.d. Co efficient using sym wavelet

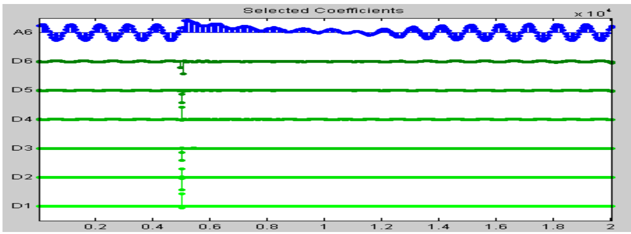

Fig 6.e. Co efficient using coif wavelet

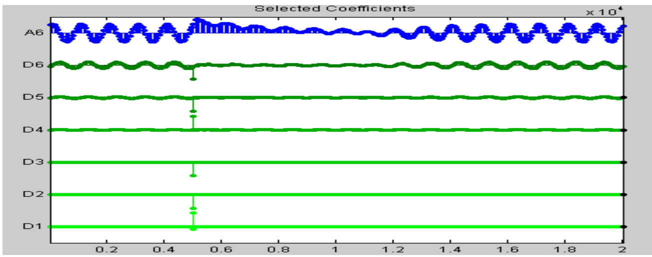

Fig 6.f. Co efficient using bior wavelet

The wavelet decomposition coefficients based on Haar6, Db6, Sym6, Bior6 and Coif6are given in Figs. 6 respectively. They indicate that the information on high frequency wavelet level is higher. Large amount of calculation affects the speed of the protection. In order to ensure the calculation speed of the distance protection as well as the reconstruction accuracy of the original signal, different wavelet is employed in the protection scheme.

In order to select the optimal mother wavelet, the absolute values of the decomposition coefficient are summated over a one-cycle window for each fault position. Simulation result indicates that Daubechies 6 and Biorthogonal 6 mother wavelets are most effective to detect fault on transmission lines.

The A6 component of low frequency domain and D1, D2, D3, D4, D5, D6 components of high frequency domain are extracted through the three step decomposition shown in. Fig. 6 and shows the components acquired by wavelet transform and the frequency domain of components in one line ground fault.

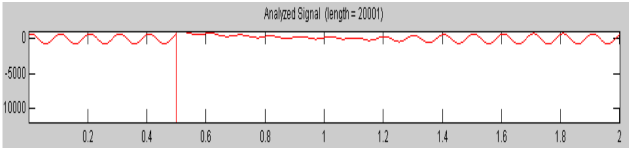

Fig.7 a. Analyzed current modal

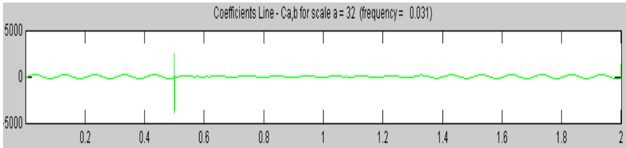

Fig 7b. Haar coefficient in CWT

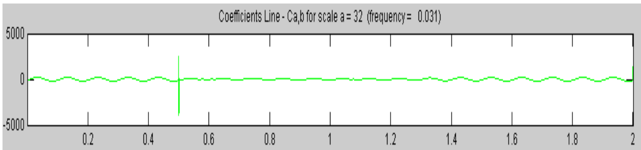

Fig 7 c. DB coefficient in CWT

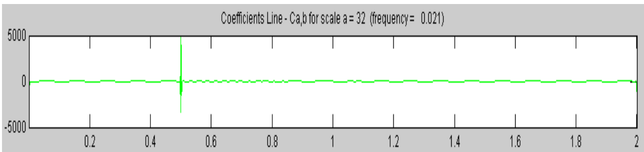

Fig 7 d. Sym coefficient in CWT

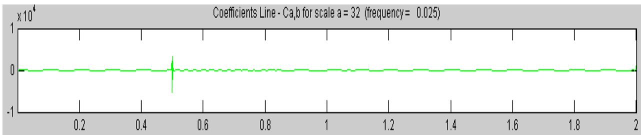

Fig 7 e. co if coefficient in CWT

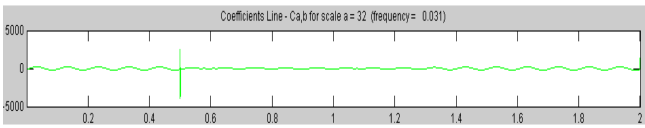

Fig 7f. Bior coefficient in CWT

The wavelet decomposition coefficients d(1, k) based on Haar, Db, Sym, and Coif, Bior. The related transient information based on Daubechies and Biorthogonal series wavelet can reflect the fault information uniquely. In addition, the higher the number of wavelet levels used, the closer the reconstructed function is to the original are given in Figs. 7 respectively. They further indicate that the feature extraction capability of the DB and Bior wavelet are the best among the selected wavelets In addition, the higher the number of wavelet levels used, the closer the reconstructed function is to the original

VI. CONCLUSION

A single-ended fault analysis algorithm based identification of the faulted half of the line and the accurate CWT based fault location method has been proposed in this paper. The accuracy of the impedance based fault section identification is found. Once the fault section is identified correctly, the fault location is computed with accuracy.

Fault was detected rapidly within 1 cycle by using D6 component that had been extracted by wavelet transform, and fault location estimation was improved by using A6 component of which harmonics had been removed.

The simulation results demonstrate that the proposed protection scheme for line protection is promising. A single-line to ground fault can be detected correctly using current modal.

VII.REFERENCE

[1] Z. Chen, C. M. Luo, and J. Su *et al.*, "A fault location algorithm for transmission line based on distributed parameter [C], " in *Proc. Inst. Elect.Conf. Develop. Power Syst. Protection*, pp. 411–413.

[2] G.-T. Kim, H.-S.Kim, and J.-Y. Choi, "Wavelet transform based power transmission line fault location using GPS for accurate time synchronization [C], " in *Proc. 27th Annu. Conf. IEEE Ind. Electron.Soc.*, pp.495–499.

[3] R.K. Aggarwal, Y. Aslan, A.T. Johns, New concept in fault location for overhead distribution systems using superimposed components, Generation, Transmission and Distribution, IEE Proceedings 144 (1997) 309–316.

[4] Z. Chen, J.C. Maun, Artificial neural network approach to single-ended fault locator for transmission lines, IEEE Transactions on Power Systems 15 (2000) 370–375.

[5] H. Heng, Z. Xu, Ba. Hui, Zhi L. Lai, A novel principle of single-ended fault location technique for ehv, Power Engineering Review IEEE 22 (2002) 61–161

[6] H.X. Ha, B.H. Zhang, Z.L. Lv, A novel principle of single-ended fault location technique for ehv transmission lines, IEEE Transactions on Power Delivery 18 (2003) 1147–1151.

[7] D. Spoor, J.G. Zhu, Improved single-ended traveling-wave fault-location algorithm based on experience with conventional substation transducers, IEEE Transaction on Power Delivery 21 (2006) 1714–1720.

[8] Z. Q. Bo, A. T. Johns, A. K. Aggarwal, "A novel fault locator based on the detection of fault generated high frequency transients, " in *1997*

Proc.Sixth IEE Developments in Power Systems Protection Conf., pp.197–200

[9] K. Ramar, A. A. Eisa, “New fault location algorithms for overhead transmission lines, ” *Int. Journal of Power and Energy Systems*, vol. 28, pp. 241–251, 2008.

[10] Osman AH, Malik OP. Transmission line distance protection based on wavelet transform. IEEE Trans Power Delivery 2004;19(2):515–23.

[11] C. Christopoulos, D. W. P. Thomas, and A. Wright, “Scheme based on traveling waves for the protection of major transmission lines, ” *Proc. Inst. Elect. Eng., Gen., Transm. Distrib.*, vol. 135, no. 1, pp. 63–73, Jan. 1988.

[12] Kim CH, Aggarwal R. Wavelet transforms in power systems. II. Examples of application to actual power system transients. IEE Power Eng J 2001;15(4):193–202.