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Wavelet Based Protection Schemes for TEED Tramission Circuits

B.Sampath,M.tech and K.Vijayabhaskar Asst.professor
Department of Electrical Engineering,Svpcet,Puttur,Chittur Dist,AP,India.

Abstract

A novel approach to protection of TEED transmission lines using wavelet transforms with multiresolution analysis has been presented in this thesis.Transmission line should be detected and classified rapidly and accurately to maintain system reliability.Wavelet analysis used for signal processing. Synchronised sampling of the three phase voltage and current signals at the three ends of TEED transmission line over a moving window length of half cycle is carried out using GPS clock.The current signals are analyzed with Bior2.2 wavelet to obtain detailed coefficients of single decompositions.Fault Indices are calculated based on the sum of local and remote end detailed coefficients,and compared with the threshold values for different types of faults to detect and classify the faults.For estimation of approximate fault location,the ratio of absolute maximum and minimum detail D1 coefficients at all the three ends are compared.Simulations of power system are done using MATLAB software package.The algorithm has been tested for different fault locations and the results are found to be satisfactory in terms of reliability.

Index Terms— Teedcircuit, wavelets, multiresolutionanalysis, detail D1 coefficients.

1. INTRODUCTION

The performance of a power system is effected by faults on transmission,which results in interruption of flow .Quick detection of faults and accurate estimation of fault location ,help in faster in maintenance and restoration of supply resulting in improved economy and reliability of power supply Wavelet Transform(WT) is an effective tool in analyzing transient voltage and current signals associated with faults both in frequency and. time domain.

Chul-Hwan kim,et al have used Wavelet transforms to detect arcing faults.Joe-Air jiang,et al have used Haar Wavelet to detect dc component for identifying the faulty phases .Wavelet Transform (WT) has the ability to decompose signals into different frequency bands using multi resolution analysis (MRA). It can be utilized in detecting faults and to estimate the phasors of the voltage and current signals, which are essential for transmission line distance protection .A digital distance protection scheme for transmission lines based on analyzing the measured voltage and current signals at the relay location using WT with MRA is presented in this thesis. Computer simulation studies have been conducted using MATLAB software package to generate the voltage and current signals from the simulated network, which are then fed to the WT protection algorithm. The proposed distance protection lgorithm has been tested for solid ground faults, phase faults.

2. INTRODCTION TO TEED CIRCUITS

Electrical suuply line protection apparatus used with Teed circuits supply lines having three terminals comprising:a unit at one terminal and the other twoare at each of the other terminals. Broad band communication links between the three units and separate from the supply lines.Three terminal lines, or Teed circuits, often offer considerable economic, technical and environmental advantage over 2-terminal lines. However, it is well known that, for a number of reasons such lines are often considerably more difficult to protect than plain feeders using conventional unit or non-unit protection techniques. Systems 1, 2 and 3 represent the three external equivalents and L_I, L_{II} and L_{III} are the three line sections of the three-terminal line shown in Fig.1.

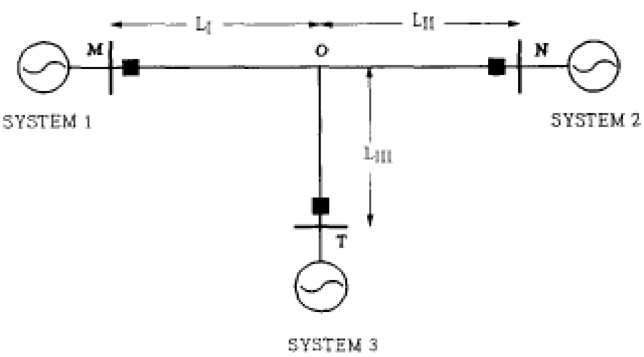

Fig1:Three-terminal lines with the external connected systems

3. WAVELET ANALYSIS

Both Fourier and short time Fourier transforms have their own drawbacks regarding the frequency and time resolutions, which are overcome by wavelet analysis. In recent years, wavelet transform(WT) has emerged as a powerful signal analysis tool, and is being used successfully in many areas including image compression, biomedical applications, speech processing, acoustics and numerical analysis. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. Wavelet analysis does not use a time-frequency region, but rather a time-scale region.

Fig 2: Wavelet Analysis

A wavelet is a waveform of effectively limited duration that has an average value of zero. Compared to sine waves, the basis of Fourier analysis, which do not have limited duration (they extend from minus to plus infinity) and are smooth and predictable, wavelets tend to be irregular and asymmetric.

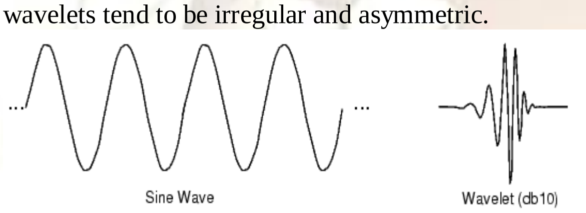

Fig 3.Sine wave and a wavewlet

Fourier analysis consists of breaking up a signal into sine waves of various frequencies. Similarly, wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or mother) wavelet.Just looking at pictures of wavelets and sine waves, it can be observed that signals with sharp changes might be better analyzed with an irregular wavelet than with a smooth sinusoid. Wavelet is denoted by the symbol Ψ (t).The wavelet transform represents the signal as a sum of wavelets at different locations (positions) and (scales (duration). The wavelet coefficients work as weight of the wavelets to represent the signal at these locations and scales. Wavelet transforms can be accomplished in 2 different ways.

Continuous Wavelet Transform (CWT): It is the transform where one can obtain the surface of the wavelet coefficients for different values of scaling and translation factors. It maps a function of a continuous variable into a function of 2 continuous variables.

Discrete Wavelet Transforms (DWT): which is used to decompose a discretized signal into different resolution levels. It maps a sequence of numbers into a different sequence of numbers.

A. THE CONTINUOUS WAVELET TRANSFORM

Mathematically, the process of Fourier analysis is represented by the Fourier transform:

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$

Which is the sum over all time of the signal f (t) multiplied by a complex exponential. Next this complex exponential can be broken down into real and imaginary sinusoidal components.

Tthe continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function. The results of the CWT are many wavelet coefficients c,which are a function of scale and position.

Multiplying each coefficient by the appropriately

$$C(scale, position) = \int_{-\infty}^{\infty} f(t)\psi(scale, position, t)dt$$

scaled and shifted wavelet yields the constituent wavelets of the original signal:

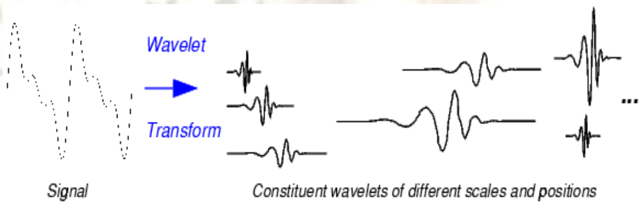

Fig 4: Breaking the signal into wavelets of different amplitudes using WT

Mathematically CWT is given by

$$CWT(a,b) = \int_{-\infty}^{\infty} x(t)\psi *_{a,b}(t)dt$$

Where

Ψ(t) is the base function $\psi_{a,b}(t) = \psi((t-b)/a)\sqrt{a}$

or the mother wavelet, the asterisk denotes a complex conjugate, and a,b Є R , a ≠ 0, are the dilation and translation parameters respectively .

B. DISCRETE WAVELET TRANSFORMS (DWT)

The foundations of the DWT go back to 1976 when croiser, esteban, and galand devised a technique to decompose discrete time signals. Crochiere, Weber, and Flanagan did a similar work on coding of speech signals in the same year. They named their analysis scheme as sub band coding. In 1983, Burt defined a technique very similar to sub band coding and named it pyramidal coding which is also known as multi resolution analysis. Later in 1989, vetterli and Le Gall made some improvements to the sub band-coding scheme, removing the existing redundancy in the pyramidal coding scheme.

Since the CWT transformation is achieved by dilating and translating the mother wavelet continuously over R, it generates substantial redundant information. Therefore, instead of continuous dilation and translation, the mother wavelet may be dilated and translated discretely by selecting $a = a_0^m$ *and* $b = n\, a_0^m b_0$, where a_0 and b_0 are fixed constants with $a_0 > 1$, $b_0 > 0$, m, n Є Z and Z is the set of positive integers.

And the *discrete wavelet* transform is given by

$$DWT(m,n) = \left(\sum_k x[k]\psi * \left(k - n a_0^m b_0 \big/ a_0^m\right) \right) a_0 - m/2$$

By comparing the eq (3.8) with general equation for impulse response (FIR) digital filter

$$y(n) = \sum_k x[k]h[n-k]/c$$

It can be seen that Ψ (k) is the impulse response of Low pass digital filter with transfer function Ψ (ω). For a_0 = 2, each dilation of Ψ (k) effectively halves the bandwidth of Ψ (ω). Multilevel DWT filter banks implement the DWT eqn (3.9) in the forward transform stage and the IDWT in the reverse transform stage.By careful selection of a_0 and b_0 , the family of dilated mother wavelets constitutes an orthonormal basis of L^2 (R) . An orthonormal basis is basis that consists of a set of vectors S such that u.v = 0 for each distinct pair of u, v Є S. with the simplest choice of a_0 and b_0 are a_0 = 2 and b_0 = 1 the wavelet transform is called a dyadic- orthonormal wavelet transform.

C. MULTI-RESOLUTION ANALYSIS

In MRA, wavelet functions and scaling functions are used as building blocks to decompose and construct the signal at different resolution levels. The wavelet function will generate the detail version of the decomposed signal and the scaling function will generate the approximated version of the decomposed signal. That is wavelet function constitutes the high pass digital filter and the scaling function constitutes low pass digital filter.let c_0 (n) be a discrete –time signal recorded from a physical measuring device. This signal is to be decomposed into a detailed and smoothed representation. From the MRA technique, the decomposed signals at scale 1 are c_1(n) and d_1(n) ,where c_1(n) is the smoothed version of the original signal (or approximation), and d_1(n) is the detailed representation of the original signal c_0(n) in the form of wavelet transform coefficients.
They are defined as

$$c_1(n) = \sum_k h(k-2n)c_0(k)$$

$$d_1(n) = \sum_k g(k-2n)c_0(k)$$

Where h (n) and g (n) are the associated filter coefficients that decompose c_0(n) in to c_1 (n) and d_1(n) respectively. That means in first stage decomposition the original signal is divided into two halves of frequency bandwidth. The next higher scale decomposition is now based on the signal c_1(n). The decomposed signal at scale 2 is given by

$$c_2(n) = \sum_k h(k-2n)c_1(k)$$

$$d_2(n) = \sum_k g(k-2n)c_1(k)$$

Higher scale decompositions are performed in the same way as described above. Thus the procedure is repeated until the signal is decomposed to a pre-defined certain level.

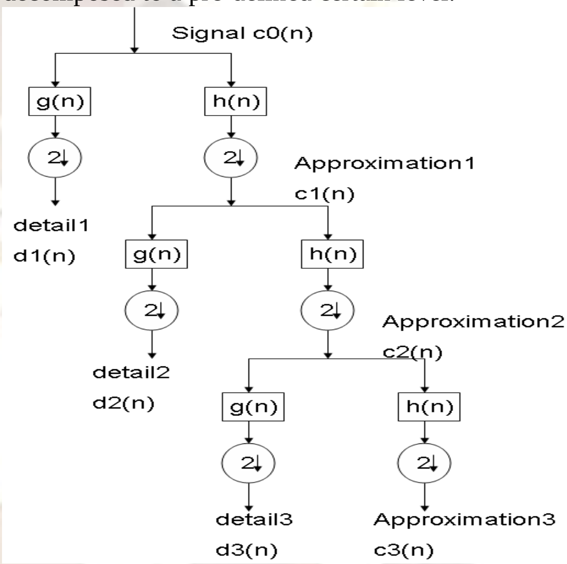

Fig 5: Multi Resolution Analysis

D.WAVELET RECONSTRUCTION

The discrete wavelet transform is used to analyze, or decompose signals and images. This process is called decomposition or analysis. The other half of the story is how those components can be assembled back into the original signal without loss of information. This process is called reconstruction, or synthesis. The mathematical manipulation that effect synthesis is called the inverse discrete wavelet transform.

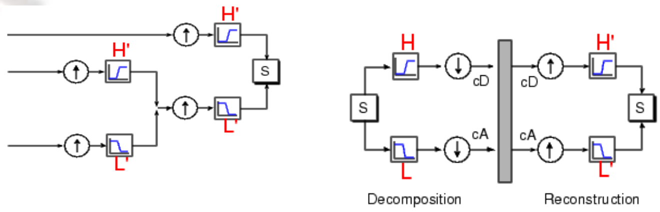

Fig 6: Signal Reconstruction Process

4. FAULT DETECTION TECHNIQUE

The single line diagram of the AC system along with the various blocks of the proposed scheme considered is shown in Figure 4.1. The transmission line to be protected in the system connects three AC systems represented by equivalent voltage source behind constant impedance. The transmission line is modeled as ‘ T ’ shape and is represented in three sections each of five pi-sections connected in cascade form voltage source to TEE junction. The system is simulated using MATLAB.

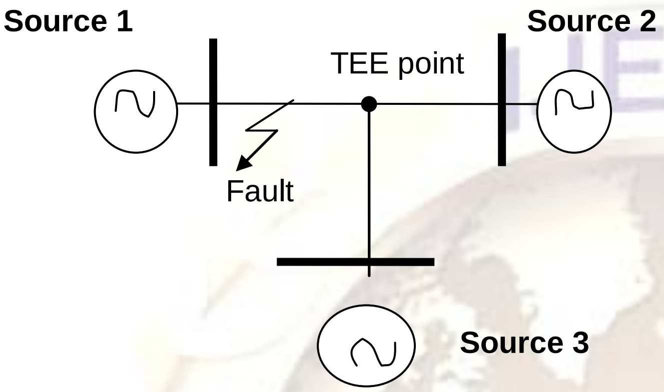

Fig7: Simulated Power System

The data of the AC system considered for the studies is follows.

Component	Parameters
Frequency	60 Hz
Source -1	Voltage $V_1 = 500\angle 20^o k$ V Equivalent Impedance Z_1 =17.177 +j45.529 Ω
Source -2	Voltage $V_2 = 500\angle 0^o k$ V Equivalent Impedance Z_2 =15.31 +j45.925 Ω
Source -3	Voltage $V_3 = 500\angle 20^o k$ V Equivalent Impedance Z_3 =17.177 +j45.529 Ω
Transmission Line (300Km) (S1 to S2 or S1 to S3)	Z_1 =4.983 +j 117.83 Ω Y_1 = j1.468 x 10^{-3} Ω^{-1} Z_o = 12.682 +j 364.196 Ω Y_o = j1.099 x 10^{-3} Ω^{-1}
Power Flow	S = 433.63 (MW) +j 294.52(MVAR)

Table 1: System Parameters for Simulation

5. DETECTION AND CLASSIFICATION OF FAULTS

A moving window of half cycle length is selected for the detection and classification purpose. The single level decomposition of three phase currents of the local terminal is obtained with Bior.2.2 mother wavelet. The transmitter transmits the detail coefficients ($D1_L$) obtained over a moving window to the remote terminal though the communication channels. The receiver receives the detail coefficients from local terminal transmitter and remote end transmitter. At each terminal the remote terminal d1-coefficients ($D1_R$) are added to the local detail coefficients ($D1_L$) to obtain effective D1 coefficients ($D1_E$). The Fault Index (**I_{f1}**) of each phase current is then calculated as summation of effective d1-coefficients (over a window length) given by the equation

$I_{f1} = \Sigma \left| D1_E \right|$

However double line to ground (LLG) faults cannot be distinguished from line to line (LL) faults just by knowing the number of faulty phases. To discriminate the LLG faults from LL faults, another fault index called ground fault index I_{f2} is calculated, with the help of all three phase current indexes which is given by equation

$\mathbf{I_{f2}} = {}^1/_3 \, \Sigma I_{f1}$

This fault index I_{f2} is nothing but fault index of the zero sequence current. If double line fault involves ground the transients would appear in neutral current or the zero sequence and hence the fault index I_{f2} will have large value. If ground is not involved in double line fault there will not be any path for zero sequence current and hence the fault index will have very low value. This concept is made use to discriminate the LL faults from LLG faults. Hence the fault index I_{f2} is compared with a predetermined threshold T_{h2} to discriminate LL faults from LLG faults. If I_{f2} is greater than T_{h2} the fault is classified as LLG fault otherwise the fault is LL fault.

A. MODELING OF TRANSMISSION LINE

A typical 500 KV transmission system used in the simulation studies presented herein. It consists of three transmission line sections of 150 km each, fed from 500KV sources from three ends. The nominal power frequency is 60Hz. The single line diagram of the considered power system is already shown in section (4.1). The transmission line is modeled as five “Π” sections, each of 30Km length from each source to “TEE” point, connected in tandem. The system is simulated for different fault conditions using Matlab software package.

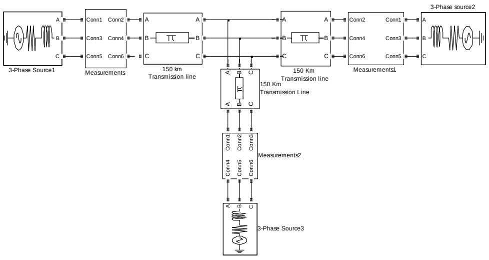

Fig .8:Transmission line model

B.DETECTION OF FAULT

Figures (9-11) illustrates the variations in three phase currents of three terminals in the event of ground fault on phase-A at 40% of the line on phase-A.

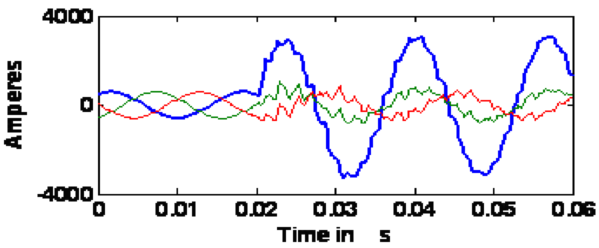

Fig.9: Three Phase currents at Source-1 of AG fault at 40% of the line

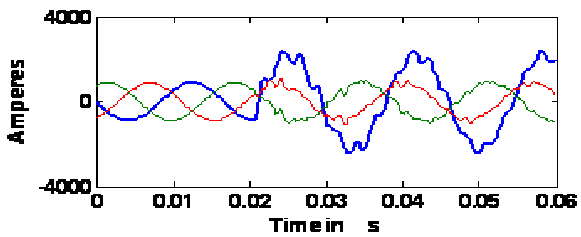

Fig.10 : Three Phase currents at Source-2 of AG fault at 40% of the line

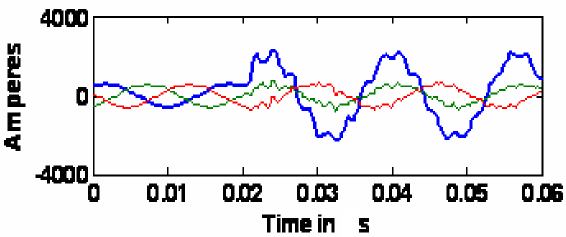

Fig.11: Three Phase currents at Source-3 of AG fault at 40% of the line

The fault indices of three phase currents in the event of ground fault are presented in Figure (5.9). It can be observed that the fault index of phase-A is very large compared to that of other phases. Hence the faulty phase can easily be identified. This is done by comparing the fault index $I_{f1}$with a predetermined threshold $T_{h1.}$ Thus the number of faulty phases can be determined by comparing fault index I_{f1} of each phase current with the threshold value Th1

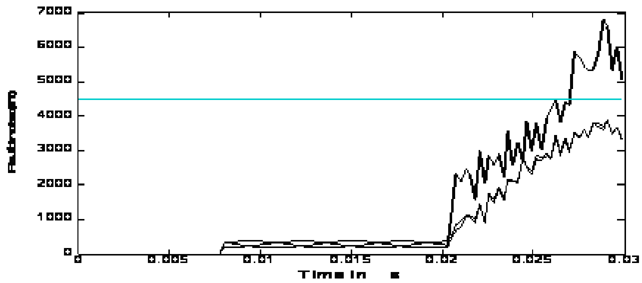

Figure .12: Identification Faulty Phases in the event of AG fault

C. CLASSIFICATION OF FAULT

However double line to ground (LLG) faults cannot be distinguished from line to line (LL) faults just by knowing the number of faulty phases. To discriminate the LLG faults from LL faults, another fault index called ground fault index I_{f2} is calculated, with the help of all three phase current indexes which is given by equation (4.2). This fault index I_{f2} is nothing but fault index of the zero sequence current. If double line fault involves ground the transients would appear in neutral current or the zero sequence and hence the fault index I_{f2} will have large value. If ground is not involved in double line fault there will not be any path for zero sequence current and hence the fault index will have very low value. This concept is made use to discriminate the LL faults from LLG faults. Hence the fault index I_{f2} is compared discriminate LL faults from LLG faults. I_{f2} for LLG faults is greater than I_{f2} for LL faults. This is illustrated in Figure 5.10.

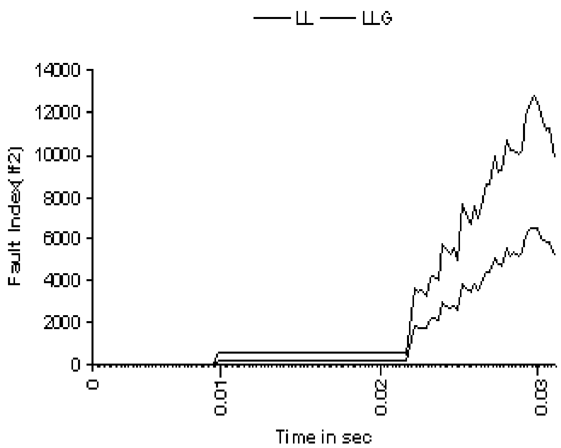

Figure.13: Discrimination between LL and LLG faults

D.TESTING OF PROPOSED ALGORITHM

The proposed algorithm has been tested for all types of faults at different locations by simulating LG, LL, LLG and LLLG faults at different locations of transmission line. The testing has been done for the distances from Sources 1 to 2 and for the distances for Source 1 to 3. The variation of Fault Index I_{f1} with the location for all types of faults for distances from 1 to 2 is illustrated in the Figures (14-17). The variation of Fault Index I_{f1} with the location for all types of faults for distances from 1 to 3 is illustrated in the Figures (18-21). The fault index I_{f1} of all faulty phases varies with the type of fault. However its value remains greater than Threshold T_{h1}. The fault Index of healthy phases remains less than the threshold value.

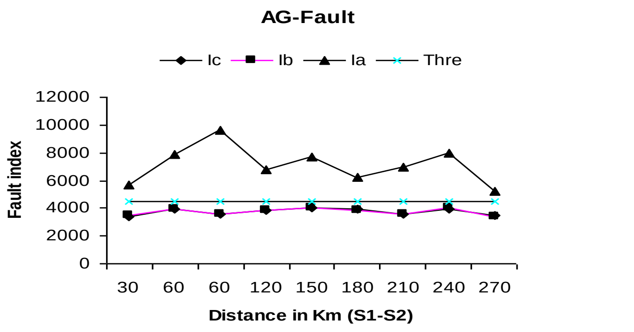

Fig.14: Variations in Fault Indexes of three phase currents for AG Fault

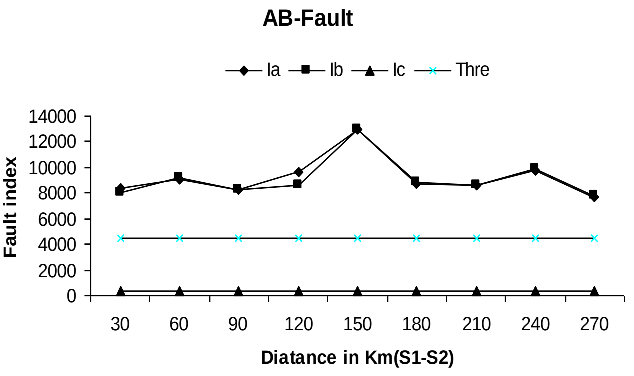

Fig.15: Variations in Fault Indexes of three phase currents for AB Fault

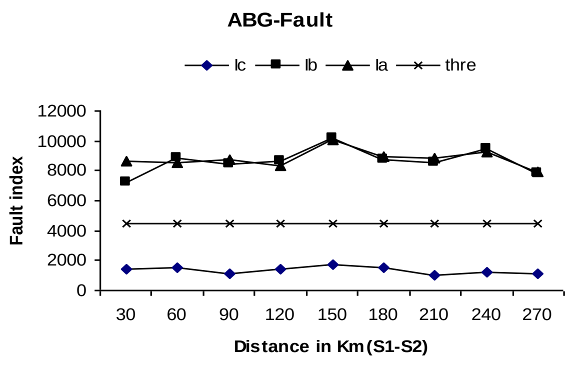

Fig.16: Variations in Fault Indexes of three phase currents for ABG Fault

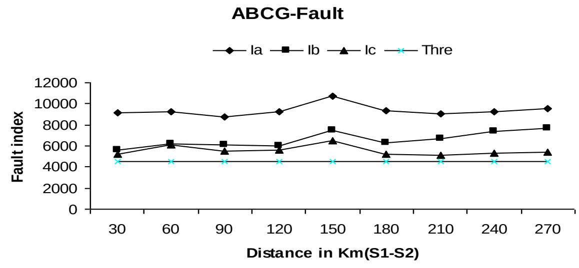

Fig.17: Variations in Fault Indexes of three phase currents for ABCG Fault

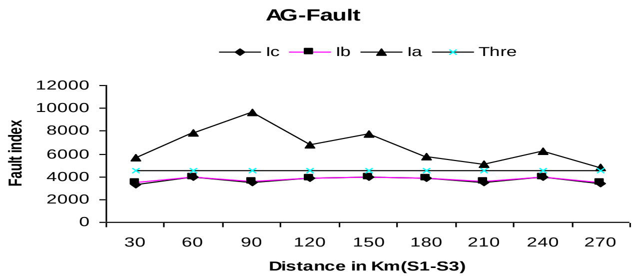

Fig.18: Variations in Fault Indexes of three phase currents for AG Fault

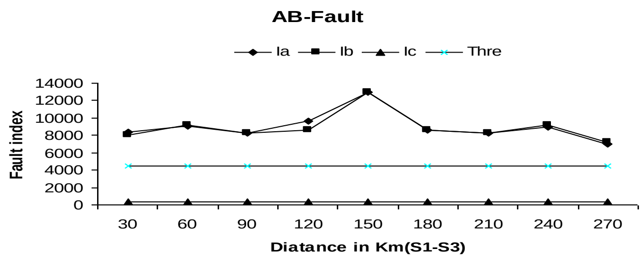

Fig.19: Variations in Fault Indexes of three phase currents for AB Fault

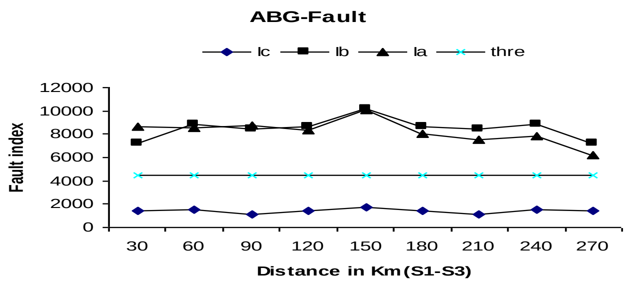

Fig. 20: Variations in Fault Indexes of three phase currents for ABG Faults

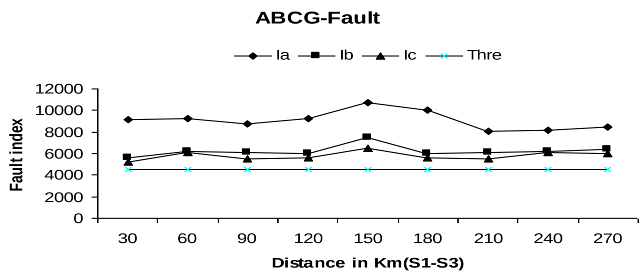

Fig.21: Variations in Fault Indexes of three phase currents for ABCG Fault

E. ESTIMATION OF APPROXIMATE LOCATION OF FAULT

The above proposed algorithm is also used for estimating the approximate location of fault occurrence. For that we have to get the detail coefficients of local terminal of three phase currents at different locations, which are decomposed by using bior 2.2 mother wavelet at single level decomposition. From that we have to get the maximum and minimum D1 coefficient values and then by observing the values of that we can tell that whether the fault has occurred before the TEE point or after the TEE point.For ground fault at 20% of the line on phase-A, The detail coefficients of three phase currents of the local terminal by the single level decomposition are obtained and they are shown in the figures (22-24).

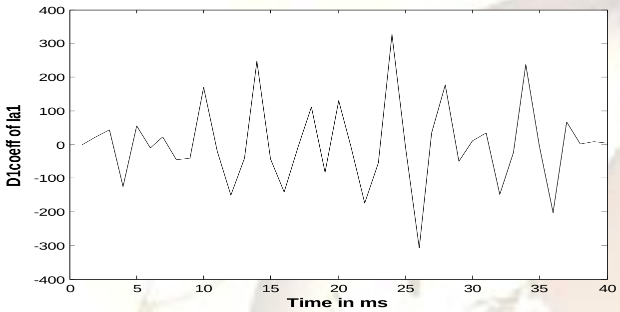

Fig.22: Local D1-coefficients at Source -1 of Phase-A

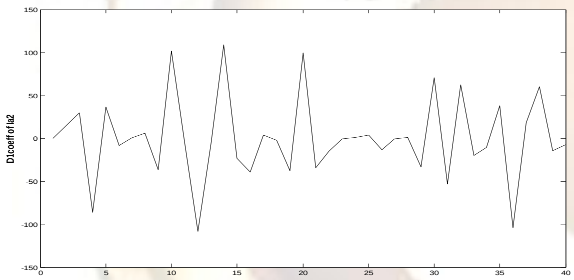

Fig.23: Local D1-coefficients at Source -2 of Phase-A

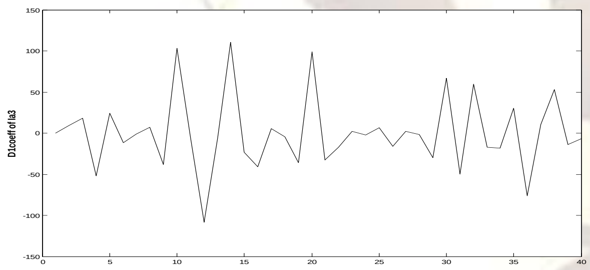

Fig.24: Local D1-coefficients at Source -3 of Phase-A

For ground fault at 60% of the line on phase-A, The detail coefficients of three phase currents of the local terminal by the single level decomposition are obtained and they are shown in the figures (25-27).

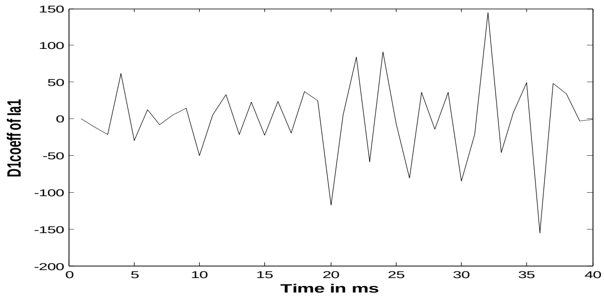

Fig.25: Local D1-coefficients at Source -1 of Phase-A

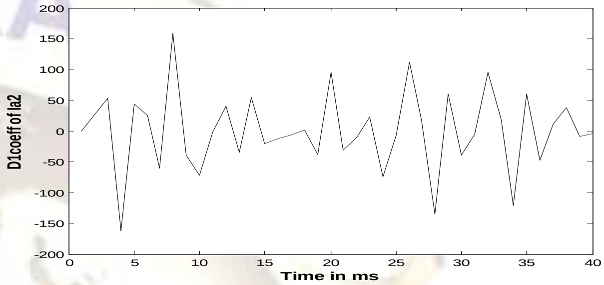

Fig.26: Local D1-coefficients at Source -2 of Phase-A

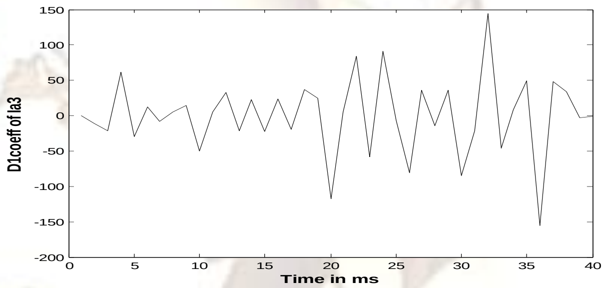

Fig.27: Local D1-coefficients at Source -3 of Phase-A

For ground fault at 80% of the line on phase-A, The detail coefficients of three phase currents of the local terminal by the single level decomposition are obtained and they are shown in the figures (28-30).

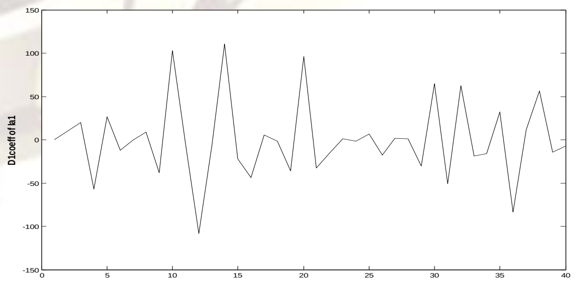

Fig.28: Local D1-coefficients at Source -1 of Phase-A

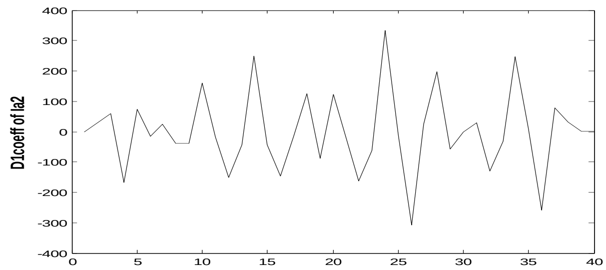

Fig.29: Local D1-coefficients at Source -2 of Phase-A

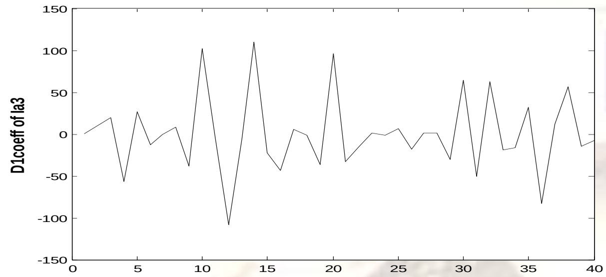

Fig.30: Local D1-coefficients at Source -3 of Phase-A

For ground fault at 50% of the line on phase-A, The detail coefficients of three phase currents of the local terminal by the single level decomposition are obtained and they are shown in the figures (31-33).

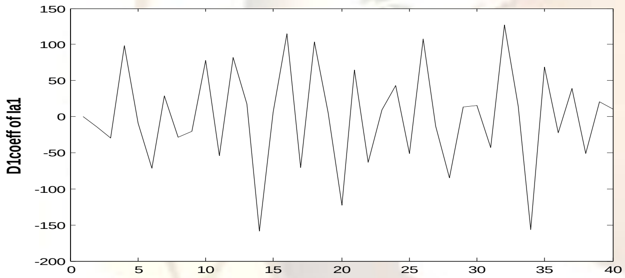

Fig.31: Local D1-coefficients at Source -1 of Phase-A

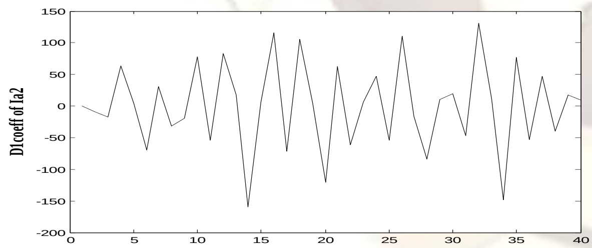

Fig.32: Local D1-coefficients at Source -2 of Phase-A

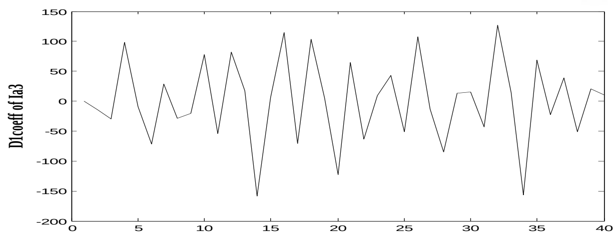

Fig33: Local D1-coefficients at Source -3 of Phase-A

For ground fault at 60% of the line on phase-A, and on the TEE section. The detail coefficients of three phase currents of the local terminal by the single level decomposition are obtained and they are shown in the figures (34-36).

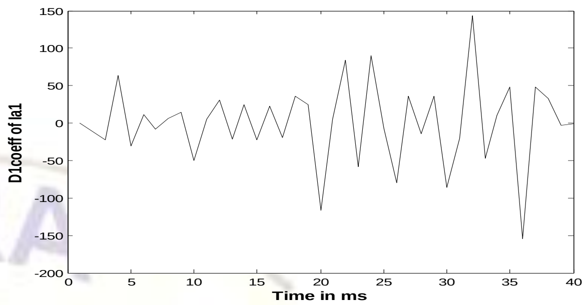

Fig.34: Local D1-coefficients at Source -1 of Phase-A

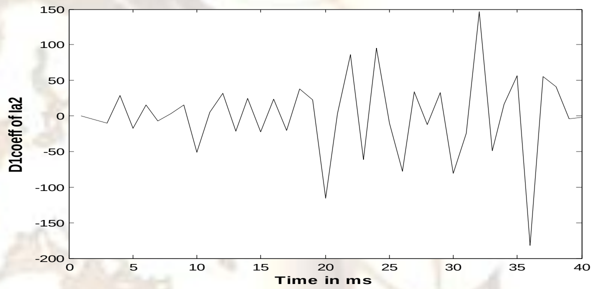

Fig.35: Local D1-coefficients at Source -2 of Phase-A

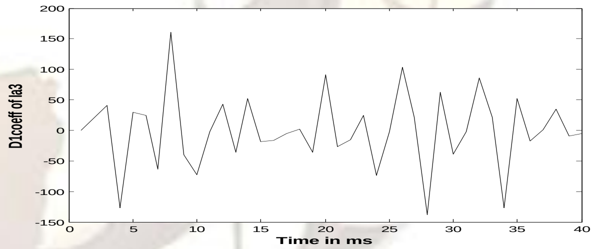

Fig.36: Local D1-coefficients at Source -3 of Phase-A

For ground fault at 80% of the line on phase-A, and on the TEE section. The detail coefficients of three phase currents of the local terminal by the single level decomposition are obtained and they are shown in the figures (37-39).

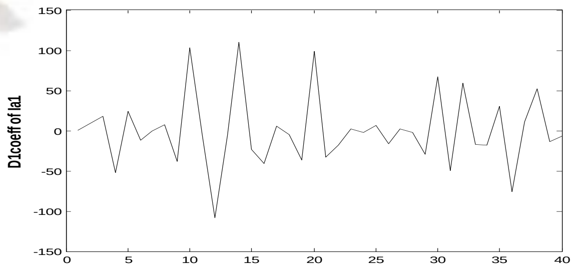

Fig.37: Local D1-coefficients at Source -1 of Phase-A

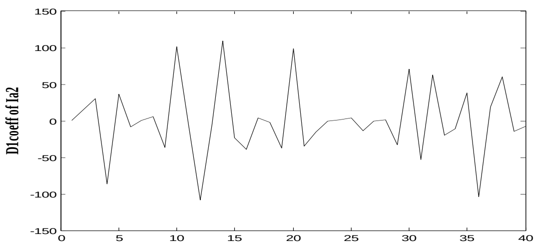

Fig.38: Local D1-coefficients at Source -2 of Phase-A

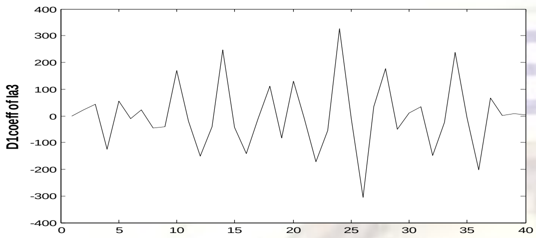

Fig.39: Local D1-coefficients at Source -3 of Phase-A

From the obtained values of D1 coefficients, the absolute values of maximum and minimum values are considered for future computation. After consideration of maximum and minimum D1 coefficients at local and remote terminal, ratios (R) are calculated for maximum to minimum; those values are given below in the table (2).

Location	Source1	Source2	Source3
20%	1.0673	1.0075	1.0162
40%	1.169	0.80	0.92
50%	0.797	0.797	0.797
60%	0.933	0.980	0.933
80%	1.0194	1.0717	1.0194
60%(Tee)	0.9274	0.80421	1.1617
80%(Tee)	1.0154	1.0067	1.068

Table2: Ratios of absolute values of max and min D1 coefficients.

Observing the above values we can say that whether the fault occurred before Tee point or after Tee point. The value of ratio (R) of D1 coefficients with respect to Source 1 is compared with the ratio of other two sources. Thus illustrated by the below logic,

If the ratio value(R) of source 1 is greater than the ratios of source 2 and source 3 the fault location is nearer to Source 1, with in the Tee point and in the Leg 1.

If the ratio value (R) of source 2 is greater than the ratios of source 1 and source 3

Then the fault location is nearer to Source 2, away from Tee point and in the Leg 2.

If the ratio value (R) of source 3 is greater than the ratios of source 1 and source 2

Then the fault location is nearer to Source 3, away from Tee point and in the Leg 3.

If the ratio value (R) of the Three Sources are equal

Then the fault location is at the Tee point.

By using the above logic we can estimate the fault location of faults with respect to Source 2 and Source 3.

5. CONCLUSION

In this thesis, a TEED transmission line fed from the three sources is simulated in Matlab environment. Wavelet Transform based Multi Resolution Analysis approach is successfully applied for effective detection and classification and approximate location of faults in TEED transmission lines. Synchronized sampling of three phase currents and voltages at the three terminals of TEED transmission line are carried out to improve the reliability of the protection system.Fault detection and classification is accomplished using detail D1-coefficients (obtained with Bior2.2) of currents at the three ends which are added up to get resultant detail coefficients at each terminal. Fault indexes are calculated using the resultant detail coefficients and compared with their respective threshold values for the purpose of detection and classification of faults in TEED transmission line.

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