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# Fault Location Estimation on Transmission Lines using Wavelet Transform

A. Y. Abdelaziz, M. A. L. Badr, Mustafa S. Ahmed

Department of Electrical Power and Machines, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

almoatazabdelaziz@hotmail.com, sbadr4446@yahoo.com, eng_mustafaelbouseli@yahoo.com

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**Abstract**

This paper presents an algorithm to determine the fault location on transmission line based on wavelet transformation analysis. The algorithm is developed by analyzing the three phase currents ($I_a$, $I_b$ and $I_c$) using Wavelet Transformation, and then start to study the faulted phase(s) at different location (each 5% of the transmission line (TL) length). Fault simulation is carried out by EMTDC/PSCAD program. Two seconds window of waveform covering pre-fault and post-fault is used. The discrete wavelet transforms (DWTs) are used for data pre-processing and these data are used for interpolation to get equation determine fault distance. Four types of mother wavelet are used for signal processing to identify the effective wavelet family that is most suitable to be used in estimating fault location.

Index Terms: Discrete Wavelet Transform, Transmission Line, Fault Location

## 1. INTRODUCTION

Distance protection is considered as one of most important techniques used to identify the fault location and type of overhead transmission line and underground cables. The concept of conventional distance protection is to measure the variables (voltage & current) of the line or cable, and compare it with the T.L. parameters (impedance) (Peter Rush, Network Protection & Automation Guide, 2002; C. R. Bayliss and B. J. Hardy, 2007). The Artificial Neural Network (ANN) was also used to determine the fault location. ANN is composed of simple elements operating in parallel (Howard Demuth Mark Beale 2000), and the network function is determined largely by the connections between elements. ANN can be trained to perform a particular function by adjusting the values of the connections (weights) between elements. Commonly neural networks are adjusted, or trained, so that a particular input leads to a specific target output ( Khorashadi-zadeh, Zuyi Li, 2006; S. Yildirim and Ekici, Mustafa Poyraz 2004; Rao & Deoghare, 2011). Fuzzy logic method was also used to determine the fault location on transmission lines. The fuzzy logic principle is based on Fuzzification, Inference mechanism, Defuzzification (Tamer S. Kamel M. A. Mustafa Hassan, 2009; Koksal Erenturk, and Ismail H. Altas, 2004). The phasor measurement unit technology is also used for estimation of fault location in transmission lines (Mekhamer, et. al, 2012 and Abdelaziz, et. al, 2013).

The Wavelet Transform provides a time-frequency representation of the signal. It was developed to overcome the short coming of the Short Time Fourier Transform (STFT), which can also be used to analyze non-stationary signals. While STFT gives a constant resolution at all frequencies, the wavelet transform uses multi-resolution technique by which different frequency spectrums are analyzed with different resolutions. Hybrid ANN-Wavelets methods have been recently used in many power systems protection applications, e.g. classification of transient phenomena in power transformers (A. Y. Abdelaziz and Amr M. Ibrahim, 2011) and protection of FACTS compensated transmission lines ( Abdelaziz and Ibrahim, 2013).

Recently wavelet transform has been used for estimating fault location effectively (Janicek et al., 2007). The most important characteristic of wavelet transform is to analyze the waveform on time-scale rather than frequency. In this paper, the simulation of single line to ground fault (L-G), double line to ground fault (L-L-G) and three phase fault are preformed. Discrete wavelet transform (DWT) is used to analyze the current waveform to specific certain level of wavelet decomposition for fault at each 5% of T.L length, then the wavelet coefficients are calculated to determine the most appropriate parameter that only change gradually and smoothly with distance only and not change with any other factor (e.g. fault inception angle). Five types of mother wavelets, Haar (db1), Daubechies (db5), Symlets (sym7) and Coiflets (coif5) (S. Yildirim, S. Ekici, 2006) are examined to decide their viability for accurate fault location estimation.

## 2. DISCRETE WAVELET TRANSFORM

Wavelet Transform are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. They have advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes. Wavelets were developed independently in the fields of mathematics, quantum physics, electrical engineering, and seismic geology. Interchanges between these fields during the last years have led to many new wavelet applications such as image compression, turbulence, human vision, radar, and earthquake prediction. This paper introduces wavelets to the electrical power application. In this paper the wavelet which is named Discrete Wavelet Transform (DWT) by two scale factor was used. For any function (f), DWT is written as

$$\mathrm{DWT}(m,n)=\frac{1}{\sqrt{2^m}}\sum_k f(k)\psi\left(\frac{n-k2^m}{2^m}\right) \tag{1}$$

Where, $\Psi$ is mother wavelet. The decomposition for three levels (MATLAB R2011b, 2011) are shown Fig. 1.

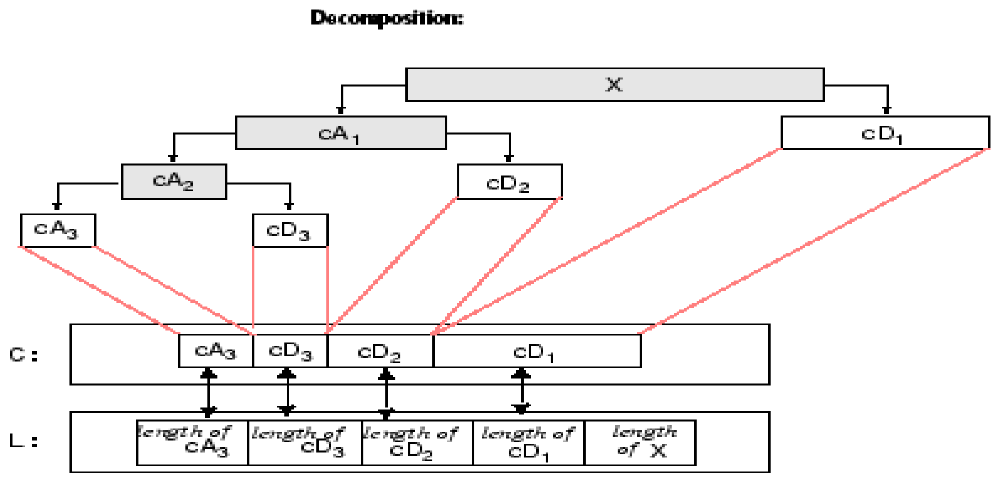



Fig.1: Three level signal decomposition diagrams

3. Interpolation Techniques

Interpolation is the process of using known data values to estimate unknown data values. Linear interpolation is a simple technique used to estimate unknown values that lie between known values. The concept of linear interpolation relies on the assumption that the rate of change between the known values is constant and can be calculated from these values using a simple slope formula. Then, an unknown value between the two known points can be calculated using one of the points and the rate of change. Linear interpolation is a relatively straight forward method, but is often not sophisticated enough to effectively interpolate station data to an even grid. Linear interpolation is often used to rigid evenly-spaced data, such as longitude / latitude gridded data, to a higher or lower resolution (Y. Prabhaker Reddy)

If the two known points are given by the coordinates (xo, yo) and (x1, y1), the linear interpolate is the straight line between these points. For a value x in the interval (xo, yo), the value y along the straight line is given from the equation

$$\frac{y-y_0}{x-x_0}=\frac{y_1-y_0}{x_1-x_0} \qquad (2)$$

Solving this equation for y, which is the unknown value at x, gives

$$y=y_0+(y_1-y_0)\frac{x-x_0}{x_1-x_0} \qquad (3)$$

Linear interpolation is often used to approximate a value of some function (f) using two known values of that function at other points. The error of this approximation is defined as

$$R_t=f(x)-p(x) \qquad (4)$$

Where p denotes the linear interpolation polynomial defined above

$$p(x)=f(x_0)+\frac{f(x_1)-f(x_0)}{x_1-x_0}(x-x_0) \qquad (5)$$

4. System under Study

This paper presents an analysis for three types of faults which are the most commonly occurring, Line to ground fault (about 70% of faults), Line to line to ground fault (about 25% of faults), 3-phase fault (about 5% of faults) (Lucas, 2005). By this purpose, a 300 km T.L length, 500 kV, 100 MW power transmitted, +sequence R= 0.041e-3 [ohm/m], +sequence $X_l$=0.528e-3 [ohm/m], +sequence $X_c$=127.23[Mohm*m], zero sequence R=0.449e-3[ohm/m], zero sequence $X_l$=2.02e-3 [ohm/m], zero sequence $X_c$=235.3 [Mohm*m] has been simulated using PSCAD/EMTDC program. The current waveforms which are obtained from the receiving end of power system and have been abstracted for further analysis. These signals are then used in DWT using a sampling frequency of 800 Hz. Five types of mother wavelets are used [(db1), (db5), (sym7) and (coif5)] for fault location estimation. The flow chart of the developed algorithm for estimation of the fault location is shown in Fig. 2.

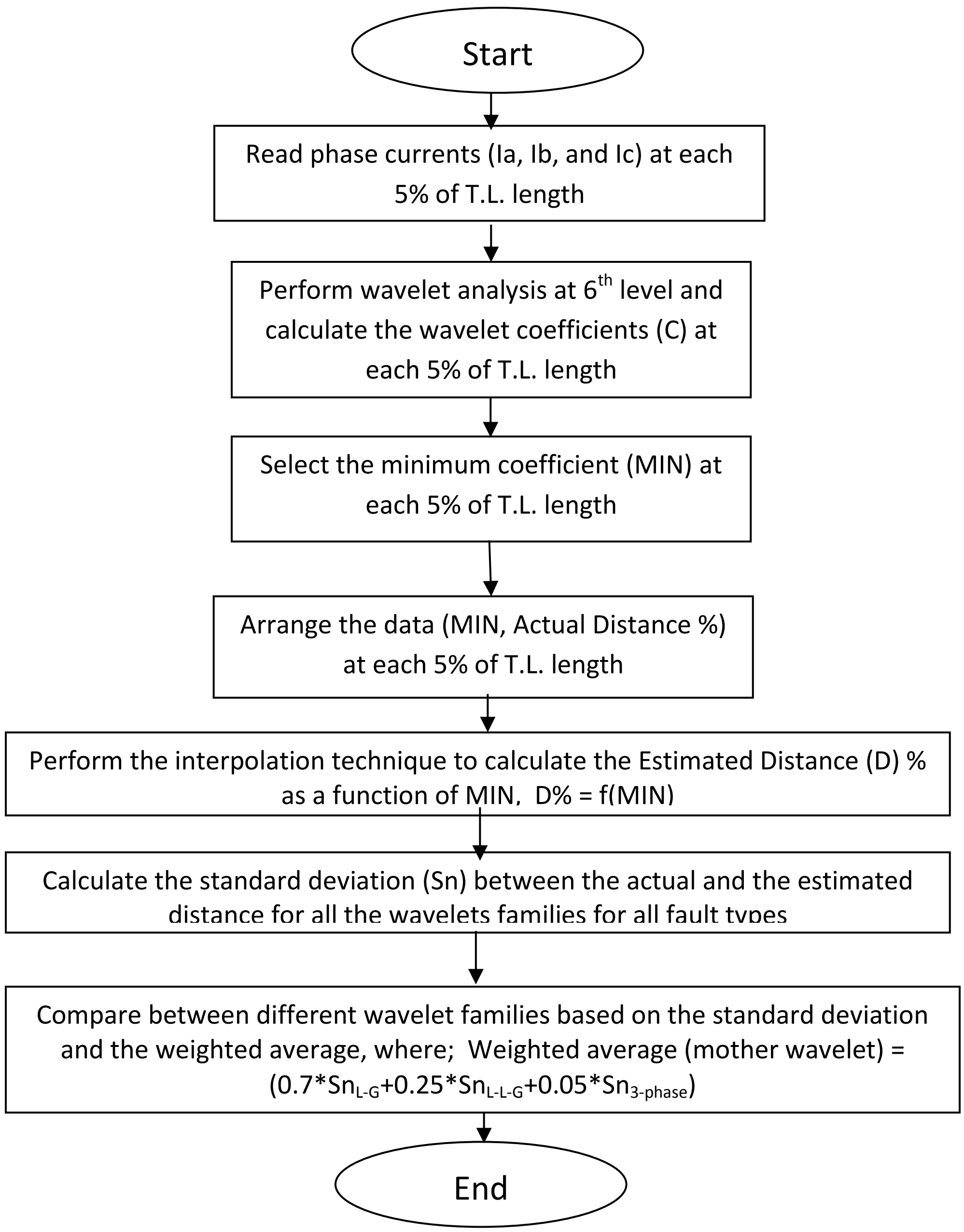



Fig. 2: Algorithm of the fault distance estimation.

The wavelet coefficients analyses for the faulted and healthy phase(s) current, for example at 15% of T.L. length are shown in Figs 3-6.

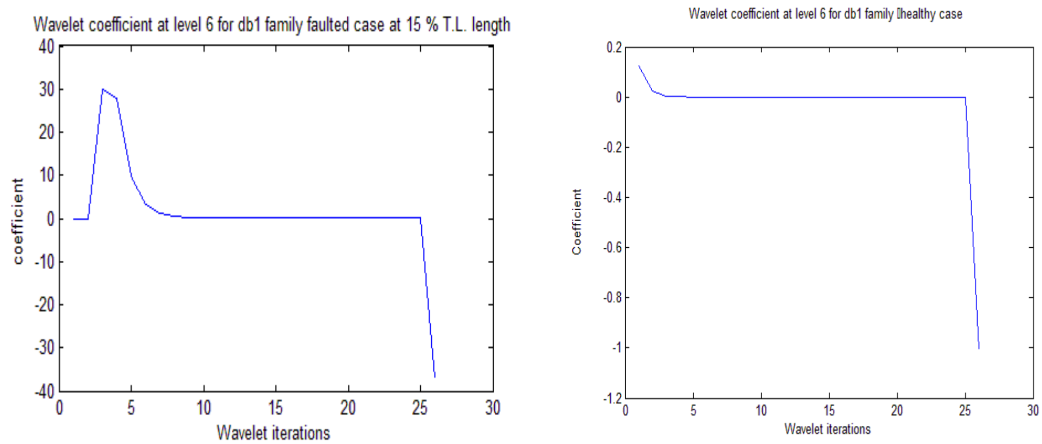



Fig. 3: Wavelet coefficient at level 6 for db1 family
faulted and healthy case at 15 % T.L. length

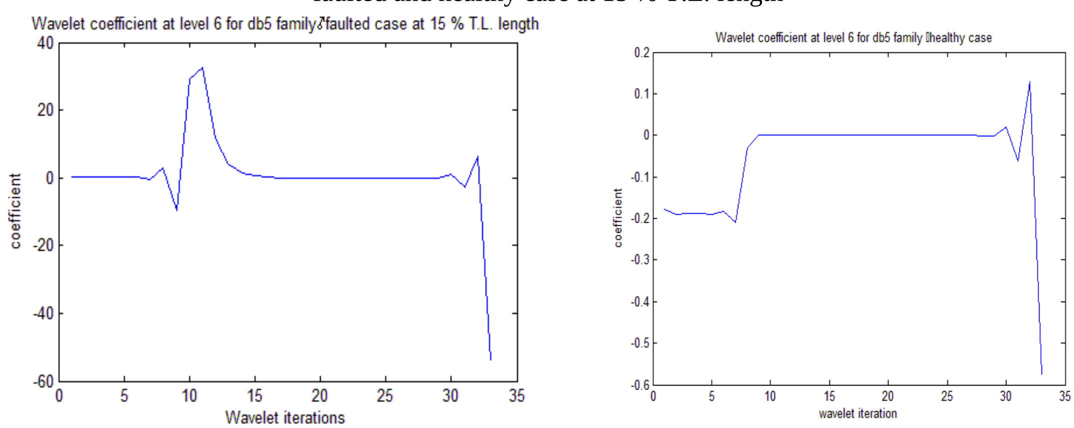



Fig. 4: Wavelet coefficient at level 6 for db5 family
faulted and healthy case at 15 % T.L. length

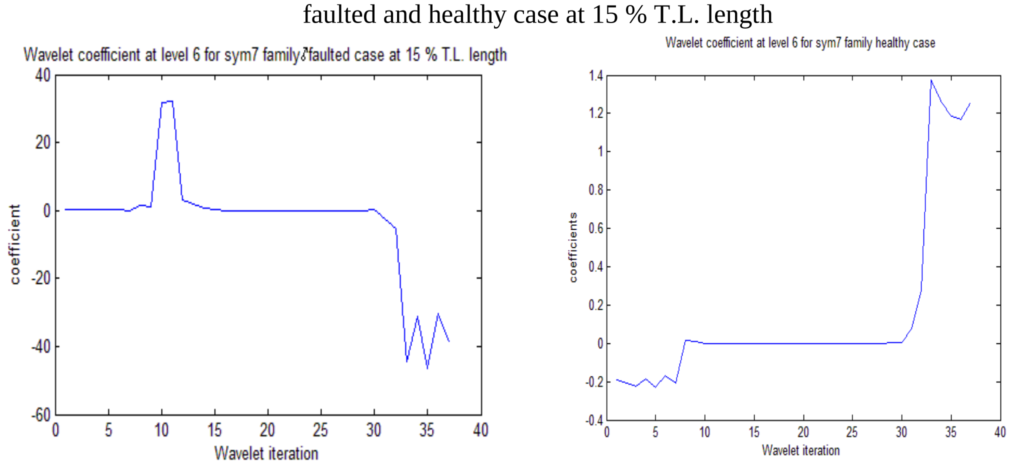



Fig. 5: Wavelet coefficient at level 6 for sym7 family
faulted and healthy case at 15 % T.L. length

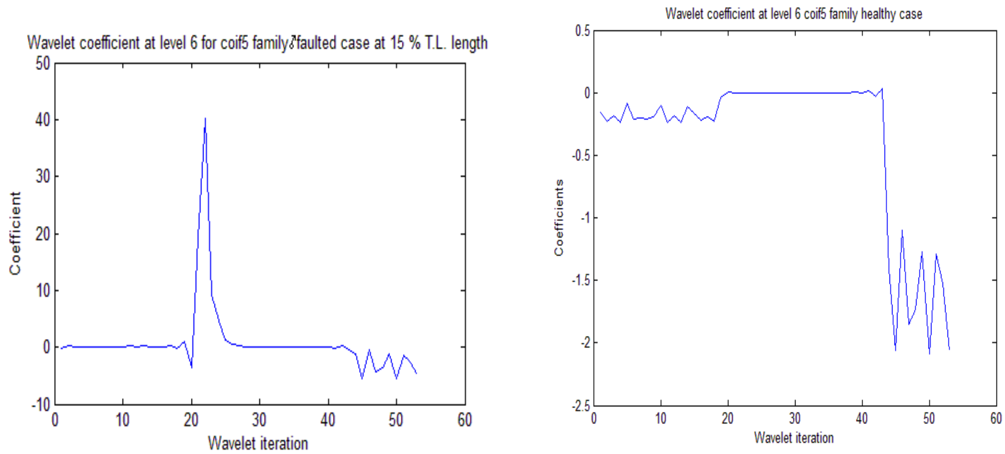



Fig. 6: Wavelet coefficient at level 6 for coif5 family
faulted and healthy case at 15 % T.L. length

## 5. Simulation Results

### 5.1 Line to ground fault

The simulation for a single line to ground fault is shown in Fig. 7

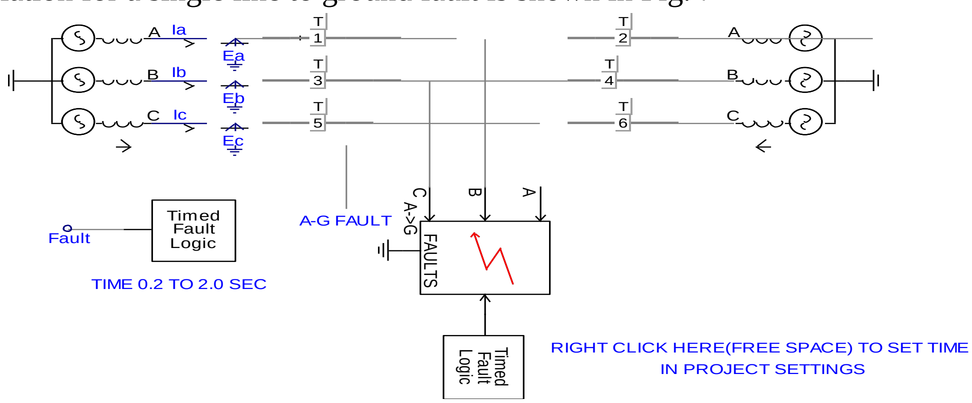
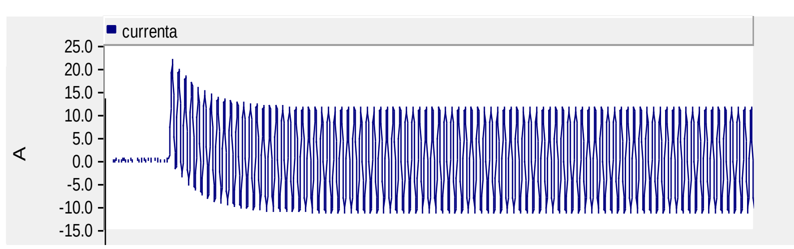



Fig.7. Line to ground fault simulation

The currents (Ia, Ib, Ic) are recorded as shown in Fig. 8, then they are arranged in numerical form. The simulation was carried out every 5% of T.L. The data of faulted phase is analyzed using Haar (db1), Daubechies (db5), Symlets (sym7) and Coiflets (coif5).



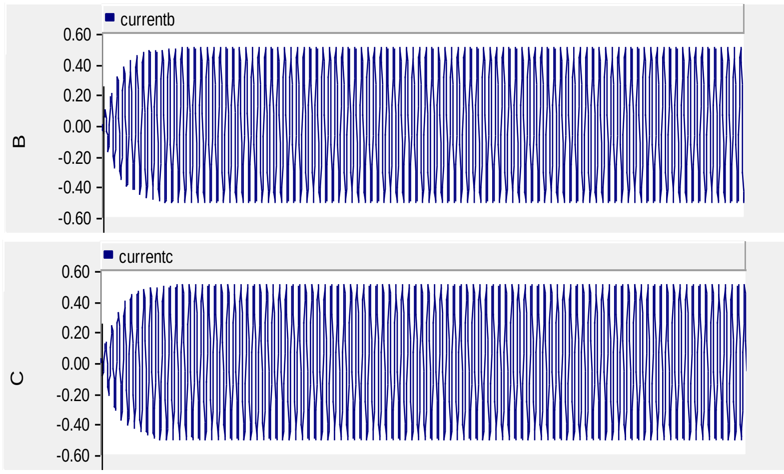



Fig. 8: (Ia, Ib, Ic) at 5% of T.L. length for line to ground fault (Ia faulted phase) in p.u system

### 5.1.1 Haar (db1) family

The analysis of fault type using Haar (db1) family

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2)+0.121 (6)

where

x= MIN wavelet coefficient at level 6 db1, a1 = 6.321; b1 = -6.447; c1 = 1.158; a2 = 555.5 ; b2 = 18.61; c2 = 15.08; a3 = 1.16; b3 = -41.8; c3 =16.28; a4 = 3.321; b4 = -27.94; c4 = 47.87; a5 = 6.778e+005 ;b5 = 284.6 ; c5 = 96.77

The results are shown in Table 1.

Table 1 Results of db1 family (LG)

| Actual Distance (%) | MIN wavelet coefficient at level 6 db1 | Estimated Distance D(MIN)% | error % | Actual Distance (%) | MIN wavelet coefficient at level 6 db1 | Estimated Distance D(MIN)% | error % |
|---|---|---|---|---|---|---|---|
| 5 | -58.452 | 5.103 | 0.103 | 55 | -14.709 | 54.948 | -0.052 |
| 10 | -45.483 | 10.127 | 0.127 | 60 | -13.601 | 59.953 | -0.047 |
| 15 | -37.192 | 15.076 | 0.076 | 65 | -12.628 | 64.967 | -0.033 |
| 20 | -31.428 | 20.028 | 0.028 | 70 | -11.763 | 69.982 | -0.018 |
| 25 | -27.183 | 25.046 | 0.046 | 75 | -10.990 | 74.986 | -0.014 |
| 30 | -23.920 | 30.066 | 0.066 | 80 | -10.292 | 79.971 | -0.029 |
| 35 | -21.330 | 35.057 | 0.057 | 85 | -9.659 | 84.931 | -0.069 |
| 40 | -19.221 | 40.025 | 0.025 | 90 | -9.080 | 89.885 | -0.115 |
| 45 | -17.467 | 44.987 | -0.013 | 95 | -8.548 | 94.966 | -0.034 |
| 50 | -15.983 | 49.959 | -0.041 | 100 | -8.101 | 99.973 | -0.027 |

The standard deviation $Sn_{(LG\text{-}db1)} = 0.062$.

### 5.1.2 Daubechies (db5) family

The analysis of fault location using Daubechies (db5) family

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2)+0.015 (7)

where

x= MIN wavelet coefficient at level 6 db5, a1 = 5.525e+013; b1 = 37.22; c1 =8.692; a2 = 114.3; b2 = 20.47; c2=30.83; a3= 0; b3 = -37.04; c3 = 0.3342; a4 = 176.7; b4 = 11.97; c4 = 15.84; a5 = 87.46; b5 = 59.82; c5 = 85.34;

The results are shown in Table 2

Table 2 Results of db5 family (LG)

| Actual Distance (%) | MIN wavelet coefficient at level 6 db5 | Estimated Distance D(MIN)% | error % | Actual Distance (%) | MIN wavelet coefficient at level 6 db5 | Estimated Distance D(MIN)% | error % |
|---|---|---|---|---|---|---|---|
| 5 | -84.523 | 5.021 | 0.021 | 55 | -21.585 | 54.988 | -0.012 |
| 10 | -66.044 | 9.993 | -0.007 | 60 | -19.970 | 59.988 | -0.012 |
| 15 | -54.150 | 15.038 | 0.038 | 65 | -18.550 | 64.995 | -0.005 |
| 20 | -45.845 | 20.014 | 0.014 | 70 | -17.289 | 70.004 | 0.004 |
| 25 | -39.707 | 24.995 | -0.005 | 75 | -16.160 | 75.007 | 0.007 |
| 30 | -34.980 | 30.003 | 0.003 | 80 | -15.141 | 79.996 | -0.004 |
| 35 | -31.221 | 35.018 | 0.018 | 85 | -14.217 | 84.973 | -0.027 |
| 40 | -28.155 | 40.021 | 0.021 | 90 | -13.372 | 89.958 | -0.042 |
| 45 | -25.603 | 45.012 | 0.012 | 95 | -12.595 | 95.013 | 0.013 |
| 50 | -23.442 | 49.998 | -0.002 | 100 | -11.918 | 99.973 | -0.027 |

The standard deviation $Sn_{(LG-db5)} = 0.019$.

### 5.1.3 Symlet (sym7) family

<u>The analysis of fault location using Symlet (sym7) family</u>

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2)+0.0015 (8)

where

x= MIN wavelet coefficient at level 6 sym7, a1=20.92; b1=-4.212; c1=7.978; a2=3.06e+014; b2=50.6; c2 = 10.72; a3 = 181.9; b3= 82.98; c3 = 81.85; a4 = 0; b4 = 187.8; c4 =30.44; a5 = 112.3; b5 = 14.72; c5 = 23.66;

The results are shown in Table 3

Table 3 Results of (Sym7) family (LG)

| Actual Distance (%) | MIN wavelet coefficient at level 6 sym7 | Estimated Distance D(MIN)% | error % | Actual Distance (%) | MIN wavelet coefficient at level 6 sym7 | Estimated Distance D(MIN)% | error % |
|---|---|---|---|---|---|---|---|
| 5 | -72.113 | 5.020 | 0.020 | 55 | -18.684 | 54.969 | -0.031 |
| 10 | -56.580 | 9.950 | -0.050 | 60 | -17.294 | 59.973 | -0.027 |
| 15 | -46.513 | 15.027 | 0.027 | 65 | -16.072 | 64.998 | -0.002 |
| 20 | -39.451 | 20.010 | 0.010 | 70 | -14.986 | 70.025 | 0.025 |
| 25 | -34.217 | 24.971 | -0.029 | 75 | -14.014 | 75.031 | 0.031 |
| 30 | -30.175 | 29.971 | -0.029 | 80 | -13.137 | 80.002 | 0.002 |
| 35 | -26.956 | 34.999 | -0.001 | 85 | -12.341 | 84.952 | -0.048 |
| 40 | -24.328 | 40.019 | 0.019 | 90 | -11.613 | 89.946 | -0.054 |
| 45 | -22.137 | 45.012 | 0.012 | 95 | -10.945 | 95.115 | 0.115 |
| 50 | -20.280 | 49.987 | -0.013 | 100 | -10.400 | 99.988 | -0.012 |

The standard deviation $Sn_{(LG-sym7)} = 0.0373$.

### 5.1.4 Coiflets (coif5) family

<u>The analysis of fault location using Coiflets (coif5) family</u>

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-

((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2)-0.001 (9)

where

x= MIN wavelet coefficient at level 6 coif5, a1 = 2.209e+014; b1 = -0.776; c1 = 0.1512; a2 = 11.19; b2 = -1.42; c2 = 0.43; a3 =0.4557; b3 = -2.045; c3 = 0.1722; a4 = 37.42; b4 = -0.8404; c4 = 1.538; a5 = 0; b5 = -2.892; c5 = 0.01074; a6 = 78.39; b6 = 1.499; c6 = 5.52

The results are shown in Table 4

Table 4 Results of (coif5) family (LG)

| Actual Distance (%) | MIN wavelet coefficient @ level 6 coif 5 | Estimated Distance D(MIN)% | error % | Actual Distance (%) | MIN wavelet coefficient @ level 6 coif 5 | Estimated Distance D(MIN)% | error % |
|---|---|---|---|---|---|---|---|
| 5 | -7.533 | 5.387 | 0.387 | 55 | -2.606 | 55.097 | 0.097 |
| 10 | -6.481 | 9.693 | -0.307 | 60 | -2.433 | 60.026 | 0.026 |
| 15 | -5.625 | 14.818 | -0.182 | 65 | -2.280 | 64.902 | -0.098 |
| 20 | -4.947 | 20.072 | 0.072 | 70 | -2.143 | 69.963 | -0.037 |
| 25 | -4.404 | 25.149 | 0.149 | 75 | -2.020 | 75.028 | 0.028 |
| 30 | -3.962 | 30.056 | 0.056 | 80 | -1.908 | 79.970 | -0.030 |
| 35 | -3.597 | 34.931 | -0.069 | 85 | -1.807 | 85.008 | 0.008 |
| 40 | -3.290 | 39.887 | -0.113 | 90 | -1.714 | 89.961 | -0.039 |
| 45 | -3.028 | 44.945 | -0.055 | 95 | -1.629 | 97.531 | 2.531 |
| 50 | -2.803 | 50.046 | 0.046 | 100 | -1.629 | 97.539 | -2.461 |

The standard deviation $Sn_{(LG\text{-}coif5)}$ = 0. 800625.

### 5.2 Line to line fault

The simulation for a line to line fault is shown in Fig. 9.

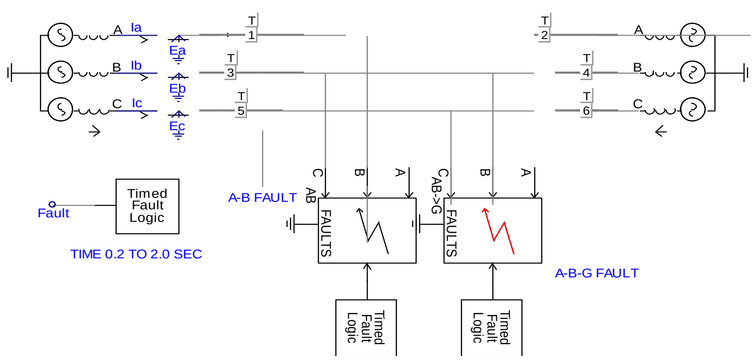



Fig. 9: Line to line to ground fault simulation

The currents (Ia, Ib, Ic) are recorded as shown in Fig. 10, then they are arranged in numerical form. The simulation was carried out every 5% of T.L. The data of faulted phase is analyzed using Haar (db1), Daubechies (db5), Symlets (sym7) and Coiflets (coif5).

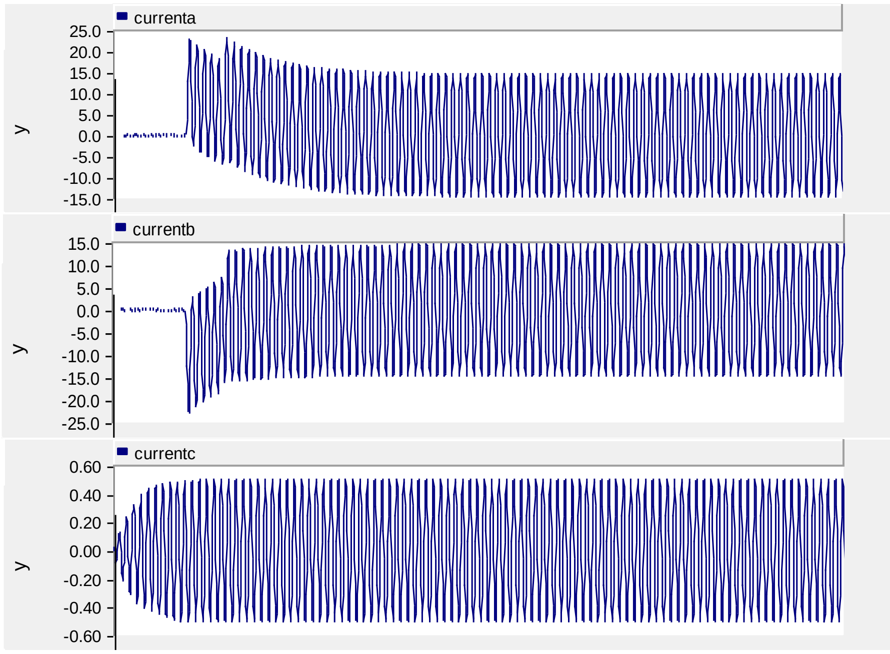



Fig.10: (Ia, Ib, Ic) at 5% of T.L. length for line to line to ground fault (Ia, Ib faulted phase) in p.u. system

### 5.2.1 Haar (db1) family

<u>The analysis of fault type using Haar (db1) family</u>

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2) + a6*exp(-((x-b6)/c6).^2)- 0.031 (10)

where

x = MIN wavelet coefficient at level 6 db1, a1 =0; a5 = 69.4; b1 = 2.076; b5 = 9.397; c1 = 0.03681; c5 = 21.62; a2 = -4711; a6 = 0; b2 = 14.83; b6 =-3.279; c2 = 11.5; c6 = 2.22e-014; a3 = 2.872e+004; b3 = 25.67; c3 = 14.39; a4 = 47.03; b4 = 19.66; c4 = 52.16

The results are shown in Table 5.

Table 5 Results of db1 family (LLG)

| Actual Distance (%) | MIN wavelet coefficient at level 6 db1 | Estimated Distance D(MIN)% | error % | Actual Distance (%) | MIN wavelet coefficient at level 6 db1 | Estimated Distance D(MIN)% | error % |
|---|---|---|---|---|---|---|---|
| 5 | -58.453 | 5.03 | 0.028 | 55 | -14.709 | 55.02 | 0.021 |
| 10 | -45.484 | 10.03 | 0.026 | 60 | -13.602 | 60.03 | 0.027 |
| 15 | -37.193 | 15.03 | 0.034 | 65 | -12.628 | 65.02 | 0.024 |
| 20 | -31.429 | 20.02 | 0.016 | 70 | -11.764 | 70.01 | 0.009 |
| 25 | -27.183 | 25.02 | 0.021 | 75 | -10.990 | 74.98 | -0.016 |
| 30 | -23.921 | 30.03 | 0.031 | 80 | -10.293 | 79.96 | -0.044 |
| 35 | -21.331 | 35.03 | 0.027 | 85 | -9.659 | 84.94 | -0.063 |
| 40 | -19.222 | 40.02 | 0.016 | 90 | -9.080 | 89.94 | -0.059 |
| 45 | -17.468 | 45.01 | 0.009 | 95 | -8.548 | 94.98 | -0.016 |
| 50 | -15.984 | 50.01 | 0.012 | 100 | -8.074 | 99.90 | -0.102 |

The standard deviation $Sn_{(L\text{-}L\text{-}G\text{-}db1)}$ = 0.037.

### 5.2.2 Daubechies (db5) family

<u>The analysis of fault location using Daubechies (db5) family</u>

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2)+0.015 (11)

Where

x= MIN wavelet coefficient @ level 6 db5, a1 = 5.525e+013; b1= 37.22; c1 = 8.692; a2 = 114.3; b2 = 20.47; c2 = 30.83; a3 =0; b3 = -37.04; c3 = 0.3342; a4=176.7; b4 = 11.97; c4 =15.84; a5 = 87.46; b5 = 59.82; c5 = 85.34;

The results are shown in Table 6

Table 6 db5 family (LLG)

| Distance (%) | MIN wavelet coefficient at level 6 db5 | Estimated Distance D(MIN)% | error % | Distance (%) | MIN wavelet coefficient at level 6 db5 | Estimated Distance D(MIN)% | error % |
|---|---|---|---|---|---|---|---|
| 5 | -84.523 | 5.021 | -0.021 | 55 | -21.585 | 54.988 | 0.012 |
| 10 | -66.044 | 9.993 | 0.007 | 60 | -19.970 | 59.988 | 0.012 |
| 15 | -54.150 | 15.038 | -0.038 | 65 | -18.550 | 64.995 | 0.005 |
| 20 | -45.845 | 20.014 | -0.014 | 70 | -17.289 | 70.004 | -0.004 |
| 25 | -39.707 | 24.995 | 0.005 | 75 | -16.160 | 75.007 | -0.007 |
| 30 | -34.980 | 30.003 | -0.003 | 80 | -15.141 | 79.996 | 0.004 |
| 35 | -31.221 | 35.018 | -0.018 | 85 | -14.217 | 84.973 | 0.027 |
| 40 | -28.155 | 40.021 | -0.021 | 90 | -13.372 | 89.958 | 0.042 |
| 45 | -25.603 | 45.012 | -0.012 | 95 | -12.595 | 95.013 | -0.013 |
| 50 | -23.442 | 49.998 | 0.002 | 100 | -11.919 | 99.973 | 0.027 |

The standard deviation $Sn_{(L\text{-}L\text{-}G\text{-}db5)}$ = 0.019.

### 5.2.3 Symlet (sym7) family

<u>The analysis of fault location using Symlet (sym7) family</u>

Using the interpolation, the estimated distance can be calculated as:

D%= a1*exp (-((x-b1)/c1).^2) + a2*exp (-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2)-0)-0.017 (12)

where

X = MIN wavelet coefficient at level 6 sym7, a1=3.533e+013; b1=9.676; c1=3.585; a2=308.2; b2=15.51; c2=15.6; a3=-7.895; b3=-18.27; c3=24.29; a4 =3.701e+006; b4= 481; c4= 150.5

The results are shown in Table7.

Table 7 Sym7 family (LLG)

| Distance (%) | MIN wavelet coefficient at level 6 sym7 | result D(MIN) | error % | Distance (%) | MIN wavelet coefficient at level 6 sym7 | result D(MIN) | error % |
|---|---|---|---|---|---|---|---|
| 5 | -72.113 | 4.964 | 0.036 | 55 | -18.684 | 54.994 | 0.006 |
| 10 | -56.580 | 9.973 | 0.027 | 60 | -17.294 | 59.993 | 0.007 |
| 15 | -46.513 | 15.032 | -0.032 | 65 | -16.072 | 65.001 | -0.001 |
| 20 | -39.451 | 19.990 | 0.010 | 70 | -14.986 | 70.013 | -0.013 |
| 25 | -34.216 | 24.968 | 0.032 | 75 | -14.014 | 75.022 | -0.022 |
| 30 | -30.175 | 29.986 | 0.014 | 80 | -13.137 | 80.022 | -0.022 |
| 35 | -26.956 | 35.011 | -0.011 | 85 | -12.341 | 85.004 | -0.004 |
| 40 | -24.328 | 40.021 | -0.021 | 90 | -11.613 | 89.974 | 0.026 |
| 45 | -22.137 | 45.016 | -0.016 | 95 | -10.945 | 95.027 | -0.027 |
| 50 | -20.280 | 50.004 | -0.004 | 100 | -10.401 | 99.996 | 0.004 |

The standard deviation $Sn_{(L\text{-}L\text{-}G\text{-}sym7)}$ =0. 0198.

### 5.2.4 Coiflets (coif 5) family

<u>The analysis of fault location using Coiflets (coif5) family</u>

Using the interpolation, the estimated distance can be calculated as:
D%= a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2) + a6*exp(-((x-b6)/c6).^2)+0.073 (13)
Where
X= MIN wavelet coefficient @ level 6 coif5, a1=11.98; b1= -6.27; c1= 2.324; a2 = -8.26; b2 = -6.347; c2 = 1.52; a3 =1.367e+015; b3 =135.5; c3 =25.03; a4 = -2.315; b4 = -7.72; c4 = 0.6796; a5 = 41.72; b5 = 2.703; c5 = 14.66; a6 = 42.48; b6 = 42.89; c6= 69.99
The results are shown in Table 8.

Table 8 Coif5 family (LLG)

| Distance (%) | MIN wavelet coefficient at level 6 coif5 | result D(MIN) | error % | Distance (%) | MIN wavelet coefficient at level 6 coif5 | result D(MIN) | error % |
|---|---|---|---|---|---|---|---|
| 5 | -63.559 | 4.276 | 0.724 | 55 | -8.828 | 54.940 | 0.060 |
| 10 | -40.329 | 10.413 | -0.413 | 60 | -7.850 | 60.022 | -0.022 |
| 15 | -29.045 | 15.227 | -0.227 | 65 | -7.239 | 64.931 | 0.069 |
| 20 | -22.555 | 19.943 | 0.057 | 70 | -6.691 | 70.160 | -0.160 |
| 25 | -18.551 | 24.876 | 0.124 | 75 | -6.251 | 74.575 | 0.425 |
| 30 | -15.586 | 30.211 | -0.211 | 80 | -5.801 | 80.029 | -0.029 |
| 35 | -13.459 | 35.231 | -0.231 | 85 | -5.370 | 86.086 | -1.086 |
| 40 | -11.822 | 40.031 | -0.031 | 90 | -5.215 | 88.411 | 1.589 |
| 45 | -10.557 | 44.812 | 0.188 | 95 | -4.786 | 95.149 | -0.149 |
| 50 | -9.532 | 50.256 | -0.256 | 100 | -4.511 | 99.726 | 0.274 |

The standard deviation $Sn_{(L\text{-}L\text{-}G\text{-}coif5)}$ =0. 112.

### 5.3 3-phase fault

The simulation for a 3-phase fault is shown in Fig. 11.

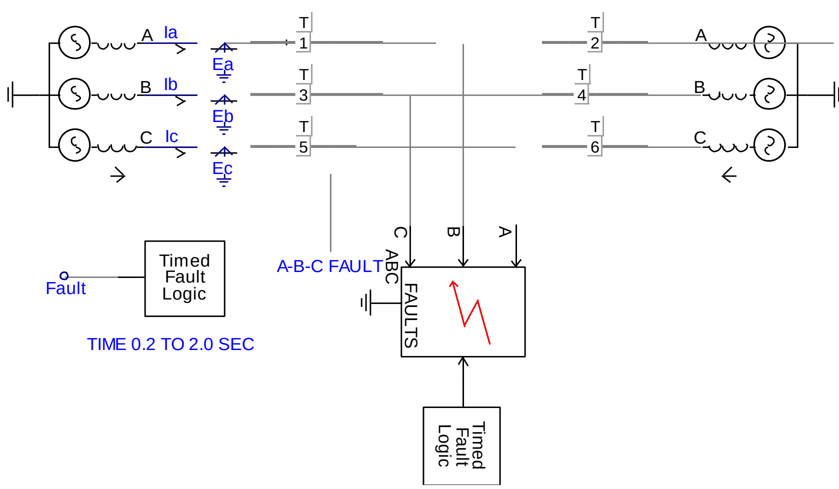



Fig. 11: 3-phase fault simulation

The currents (Ia, Ib, Ic) are recorded as shown in Fig. 12, then they are arranged in numerical form. The simulation was carried out every 5% of T.L. The data of faulted phase is analyzed using Haar (db1), Daubechies (db5), Symlets (sym7) and Coiflets (coif5).

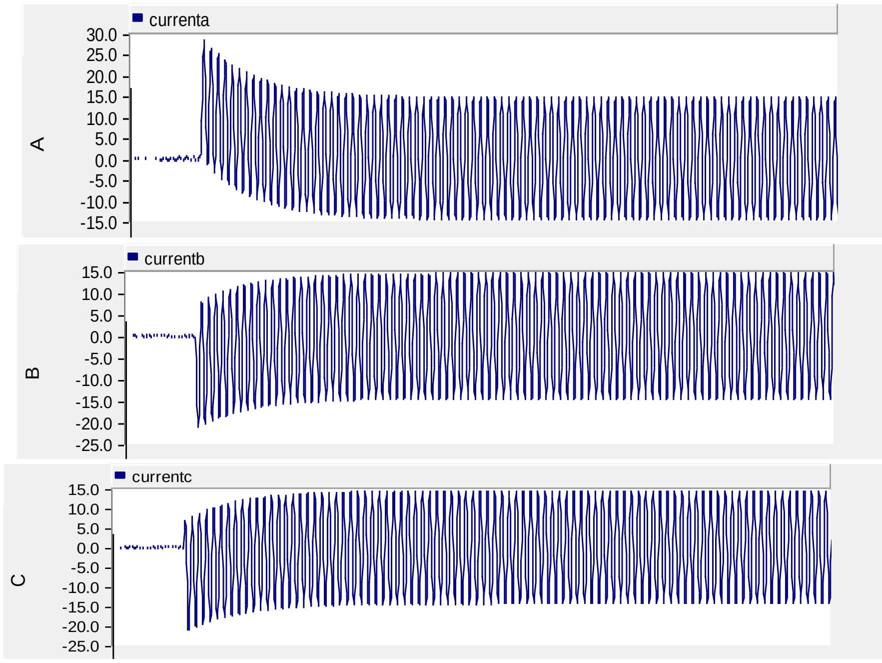



Fig.12. (Ia, Ib, Ic) at 5% of T.L. length for 3-phase fault in p.u system

### 5.3.1 Haar family

The analysis of fault type using Haar (db1) family

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2) + a6*exp(-((x-b6)/c6).^2)- 0.031 (14)

Where

X= MIN wavelet coefficient at level 6 db1, a1 = 0; a5 = 69.4; b1 = 2.076; b5=9.397; c1= 0.0368; c5 = 21.62; a2 =-4711; a6 = 0; b2 = 14.83; b6 =-3.279; c2= 11.5; c6 = 2.22e-014; a3=2.872e+004; b3=25.67; c3= 14.39; a4= 47.03; b4 =19.66; c4= 52.16

The results are shown in Table 9.

Table 9 db1 family (3-phase fault)

| Distance (%) | MIN wavelet coefficient at level 6 db1 | result D(MIN) | error % | Distance (%) | MIN wavelet coefficient at level 6 db1 | result D(MIN) | error % |
|---|---|---|---|---|---|---|---|
| 5 | -58.453 | 5.03 | 0.028 | 55 | -14.709 | 55.02 | 0.021 |
| 10 | -45.484 | 10.03 | 0.026 | 60 | -13.602 | 60.03 | 0.027 |
| 15 | -37.193 | 15.03 | 0.034 | 65 | -12.628 | 65.02 | 0.024 |
| 20 | -31.429 | 20.02 | 0.016 | 70 | -11.764 | 70.01 | 0.009 |
| 25 | -27.183 | 25.02 | 0.021 | 75 | -10.990 | 74.98 | -0.016 |
| 30 | -23.921 | 30.03 | 0.031 | 80 | -10.293 | 79.96 | -0.044 |
| 35 | -21.331 | 35.03 | 0.027 | 85 | -9.659 | 84.94 | -0.063 |
| 40 | -19.222 | 40.02 | 0.016 | 90 | -9.080 | 89.94 | -0.059 |
| 45 | -17.468 | 45.01 | 0.009 | 95 | -8.548 | 94.98 | -0.016 |
| 50 | -15.984 | 50.01 | 0.012 | 100 | -8.074 | 99.90 | -0.102 |

The standard deviation $Sn_{(3\text{-phase-db1})}$ = 0.037.

### 5.3.2 Daubechies (db5) family

The analysis of fault location using Daubechies (db5) family

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-

((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2) + a6*exp(-((x-b6)/c6).^2)-0.086 (15)
where
X = MIN wavelet coefficient at level 6 db5, a1 =7e+013; a5 = 402.2; b1= 231.1; b5=150.5; c1=44.24; c5 = 112.5; a2 = -11.98; a6=559.8; b2=-115.2; b6=52.85; c2=14.59; c6= 38.57; a3=-0.01396; b3=-18.73; c3 =1.559; a4=1.435e+010; b4=247; c4 =56.49
The results are shown in Table 10.

Table 10 db5 family (3-phase fault)

| Distance (%) | MIN wavelet coefficient at level 6 db5 | result D(MIN) | error % | Distance (%) | MIN wavelet coefficient at level 6 db5 | result D(MIN) | error % |
|---|---|---|---|---|---|---|---|
| 5 | -84.516 | 5.06 | 0.063 | 55 | -21.585 | 55.00 | 0.001 |
| 10 | -66.040 | 10.02 | 0.024 | 60 | -19.970 | 59.99 | -0.007 |
| 15 | -54.148 | 15.05 | 0.047 | 65 | -18.550 | 64.98 | -0.020 |
| 20 | -45.843 | 20.04 | 0.044 | 70 | -17.288 | 69.98 | -0.021 |
| 25 | -39.706 | 25.02 | 0.017 | 75 | -16.160 | 74.98 | -0.024 |
| 30 | -34.979 | 29.99 | -0.008 | 80 | -15.141 | 79.97 | -0.027 |
| 35 | -31.220 | 34.98 | -0.019 | 85 | -14.216 | 84.98 | -0.023 |
| 40 | -28.155 | 39.98 | -0.017 | 90 | -13.371 | 89.99 | -0.006 |
| 45 | -25.603 | 44.99 | -0.010 | 95 | -12.595 | 95.03 | 0.028 |
| 50 | -23.442 | 50.00 | -0.002 | 100 | -11.893 | 99.97 | -0.030 |

The standard deviation $Sn_{(3\text{-phase-db5})}$ = 0. 027.

### 5.3.3 Symlet (sym7) family

<u>The analysis of fault location using Symlet (sym7) family</u>

Using the interpolation, the estimated distance can be calculated as:

D% = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2) + a5*exp(-((x-b5)/c5).^2) + a6*exp(-((x-b6)/c6).^2)-0.017 (16)
where
X = MIN wavelet coefficient at level 6 sym7, a1=170.9; b1=6.858; c1=1.377; a2=1368; b2=148.2; c2=93.2; a3=2.698; b3=-7.859; c3= 12.24; a4=3932; b4 =39.06; c4= 22.08; a5 = -5.999; b5 = -22.14; c5 = 25.5; a6 = -0.004347; b6 = -13.93; c6= 1.948
The results are shown in Table 11.

Table 11 sym7 family (3phase)

| Distance (%) | MIN wavelet coefficient at level 6 sym7 | result D(MIN) | error % | Distance (%) | MIN wavelet coefficient at level 6 sym7 | result D(MIN) | error % |
|---|---|---|---|---|---|---|---|
| 5 | -84.516 | 5.01 | 0.011 | 55 | -21.585 | 54.99 | -0.009 |
| 10 | -66.040 | 10.00 | 0.001 | 60 | -19.970 | 59.99 | -0.006 |
| 15 | -54.148 | 15.01 | 0.011 | 65 | -18.550 | 65.00 | -0.003 |
| 20 | -45.843 | 19.99 | -0.008 | 70 | -17.288 | 70.00 | -0.001 |
| 25 | -39.706 | 24.99 | -0.011 | 75 | -16.160 | 75.00 | 0.003 |
| 30 | -34.979 | 29.99 | -0.008 | 80 | -15.141 | 80.01 | 0.006 |
| 35 | -31.220 | 34.99 | -0.008 | 85 | -14.216 | 85.01 | 0.008 |
| 40 | -28.155 | 39.99 | -0.009 | 90 | -13.371 | 90.01 | 0.007 |
| 45 | -25.603 | 44.99 | -0.010 | 95 | -12.595 | 95.02 | 0.023 |
| 50 | -23.442 | 49.99 | -0.011 | 100 | -11.893 | 100.02 | 0.020 |

The standard deviation $Sn_{(3\text{-phase-sym7})}$ = 0. 010.

### 5.3.4 Coiflets family

The analysis of fault location using Coiflets (coif5) family

Using the interpolation, the estimated distance can be calculated as:

D%= a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2)+0.014 (17)

where

X = MIN wavelet coefficient at level 6 coif5, a1=27.41; b1=-0.1792; c1=6.479; a2=0.1046; b2=-10.97; c2=1.017; a3=34.4; b3=14.39; c3=48.78; a4= 1.69e+015; b4 =486.6; c4 = 88.79

The results are shown in Table 12.

Table 12 coif 5 family (3phase)

| Distance (%) | MIN wavelet coefficient at level 6 coif 5 | result D(MIN) | error % | Distance (%) | MIN wavelet coefficient at level 6 coif 5 | result D(MIN) | error % |
|---|---|---|---|---|---|---|---|
| 5 | -53.921 | 4.962 | -0.038 | 55 | -13.162 | 54.930 | -0.070 |
| 10 | -41.602 | 9.920 | -0.080 | 60 | -12.157 | 59.933 | -0.067 |
| 15 | -33.832 | 14.961 | -0.039 | 65 | -11.275 | 65.008 | 0.008 |
| 20 | -28.478 | 19.976 | -0.024 | 70 | -10.492 | 70.029 | 0.029 |
| 25 | -24.559 | 24.997 | -0.003 | 75 | -9.792 | 75.021 | 0.021 |
| 30 | -21.562 | 30.029 | 0.029 | 80 | -9.161 | 80.043 | 0.043 |
| 35 | -19.191 | 35.054 | 0.054 | 85 | -8.589 | 85.064 | 0.064 |
| 40 | -17.265 | 40.052 | 0.052 | 90 | -8.065 | 90.048 | 0.048 |
| 45 | -15.668 | 45.021 | 0.021 | 95 | -7.584 | 94.976 | -0.024 |
| 50 | -14.319 | 49.973 | -0.027 | 100 | -7.125 | 100.001 | 0.001 |

The standard deviation $Sn_{(3\text{-phase-coif5})}$ = 0. 0096.

## 6. Discussion

The standard deviations of the different fault types and different wavelet families are shown in Table 13. The weighted average of Sn is calculated as in the equation in the flow chart, based on the fact that probability of fault types are 70% for LG faults, 25% for LLG faults and 5% for 3-phase faults. It can be seen from Table 13 that the Daubechies family db5 has the best performance in the estimation of fault location.

Table 13 Standard deviation of different fault types and different wavelet families

| | L-G fault | L-L fault | 3 phase fault | Weighted average |
|---|---|---|---|---|
| db1 (haar) | 0.062 | 0.062 | 0.037 | 0.0608 |
| db5 | 0.019 | 0.019 | 0.027 | 0.0194 |
| Symlet | 0.0373 | 0.02 | 0.01 | 0.0316 |
| Coiflet | 0.8006 | 0.112 | 0.0096 | 0.5889 |

## 7. Conclusion

The simulation of a 500 kV transmission line was performed using EMTDC/PSCAD with considering different fault locations on transmission line. The waveforms obtained from EMTDC/PSCAD have been converted as a MATLAB file for feature extraction. This feature vector has been used for interpolation and testing the equation to detect fault location precisely.

Four different types of mother wavelets have been tried to choose the most suitable one. It is found that better results are obtained using Daubechies ‘db5’ wavelet. The Daubechies family is the most effective family that can determine the location of fault, in spite of the Symlet family is more effective than Daubechies family at 3-phase fault analysis, but in general the 3-phase faults are rare to occur if it is compared with the line to ground fault. Therefore, the Daubechies family is accepted to be the better family for fault location estimation. The proposed method has provided a great accuracy to be used in transmission line fault location estimation.

References

Abdelaziz A. Y. and Ibrahim Amr M., (2011), Classification of Transient Phenomena in Power Transformers Based on a Wavelet-ANN Approach, The Online Journal on Electronics and Electrical Engineering, Vol. 3, No. 4, October 2011, pp. 462-467.

Abdelaziz A. Y. and Ibrahim Amr M., (2013), A Hybrid Wavelet-ANN-Based Protection Scheme for FACTS Compensated Transmission Lines, International Journal of Intelligent Systems and Applications (IJISA), Vol. 5, No. 7, June 2013, pp. 23-31.

Abdelaziz A. Y., Mekhamer S. F. and Ezzat M., (2013), Fault Location of Uncompensated/Series Compensated Lines Using Two-Ends Synchronized Measurements, Electric Power Components and Systems, Vol. 41, Issue 7, May 2013, pp. 693-715.

Bayliss C. R. and Hardy B. J., (2007), Transmission and Distribution Electrical Engineering, Third edition.

Frantisek Janicek, Martin Mucha and Marian Ostrozlik, A New Protection Relay Based on Fault Transient Analysis using Wavelet Transform, Journal of Electrical Engineering, Vol. 58, No. 5.

Hassan Khorashadi-Zadeh and Zuyi Li, , (2006) An ANN Based Approach to Improve the Distance Relaying Algorithm, Turk J Elec. Engineering, Vol. 14, No. 2.

Howard Demuth Mark Beale, 2000, Neural Network Toolbox, The Math Works, Version 4.

Koksal Erenturk and Ismail H. Altas, Fault Identification in a Radial Power System using Fuzzy Logic, Instrumentation Science and Technology, Vol. 32, No. 6, pp. 641–653, 2004.

Lucas J. R. (2005), Power System Analysis, Faults, October,

MATLAB R2011b, the Math Works, Inc..

Mekhamer S. F., Abdelaziz A. Y. and Ezzat M.,(2012), Fault Location in Long Transmission Lines Using Synchronized Phasor Measurements from Both Ends, Electric Power Components and Systems Journal, Vol. 40, Issue 7, May 2012, pp. 759-776.

Michael Fryer, Data Analysis Using Wavelets, Idaho National Engineering and Environmental Laboratory, Lockheed Martin Idaho Technologies, 1997.

Mrunalini M. Rao and P. M. Deoghare, (2011), A Novel Approach for Transmission Line Protection Using Wavelet Transform and Neural Network, International Journal of Instrumentation, Control and Automation (IJICA), Vol. 1, Issue 2.

Peter Rush, (2002), Network Protection & Automation Guide, 1st edition,.

Prabhaker Reddy Y., Mathematical Methods Interpolation, Guru Nanak Engineering College, Ibrahimpatnam, Hyderabad.

Robi Polikar, (1996), The Wavelet Tutorial, Rowan University, College of Engineering.

Tamer S. Kamel M. A. Moustafa Hassan, Adaptive Neuro Fuzzy Inference System (ANFIS) For Fault Classification in the Transmission Lines, The Online Journal on Electronics and Electrical Engineering (OJEEE), Vol. 2, No. 1, 2009.

Yildirim S. and Ekici S., (2006), Fault Location Estimation on Transmission Lines using Wavelet Transform and Artificial Neural Network, 2006 International Conference on Artificial Intelligence, ICAI 2006, Las Vegas, Nevada, USA, June 26-29, 2006.

Yildirim S. and Ekici S., Mustafa Poyraz, (2004), A Neural Network Based Approach for Transmission Line Faults, Firat University, Faculty of Technical Education, Department of Electrical Education, Elazığ , Turkey.