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# Fault Detection and Classification in Transmission Lines based on Wavelet Transform

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**Abstract:** ***In the paper, a novel wavelet transform based fault detection and classification technique is studied. The technique involves analysis of fault induced transient that can provide extensive information about the fault detection, classification, fault type, location and fault duration. These fault transients with system voltage and current can be effectively analyzed with the wavelet transform technique. In MATLAB simulink, two bus systems with various fault condition and their combination are simulated. The two bus system is also tested for various fault location. The simulation results indicate that the wavelet transform is an effective technique in the field of fault detection and classification of various fault categories.***

**Keywords:** Daubechies wavelet transform, fault classification, fault detection, power system fault, Transmission line, wavelet analysis.

## 1. Introduction

Recently, a large amount of capital investment is made for generation and transmission of electric power over a long distance to provide reliable and quality power to consumer. An electric power system is made up of different complex interacting element. Hence, there is always a large possibility of disturbances and faults. It is also important to run the system at high peak efficiencies and to protect it from any unwanted maloperation and unavoidable accidents. Events like lightning stroke, harmonics, high impedance fault, transmission line failure due to ageing equipment *etc.,* causes various accidents. These accidents can highly damage the transmission system with damaging line conductor, line insulator due to heavy flashover. Fast and accurate fault detection and its distance estimation help in restoring the power supply as soon as possible and to minimize the interruption to the power supply. Thus with employing highly accurate and fast fault detection technique power system economy and reliability of power supply can be improved [1].

Many researchers have suggested different techniques for fault detection and classification. In the past, the most common method of power system protection is based on impedance based relay protection it involves distance relay responding to the impedance of transmission line, which is proportional to its length of line. Later on, the most effective technique for fault distance and type allocation has been proposed which is based on travelling wave. Although, the technique give precise result in fault detection and fault distance allocation but it has certain disadvantages over distinguishing between travelling wave reflected from closely lying fault and incident wave [2]. Several digital techniques have been implemented for power system fault such as fuzzy system, expert system, artificial neural network based approaches [3]. Although the fuzzy and artificial neural network based approaches have been quite successful in determining the correct fault type, the main disadvantage of these techniques is that they required large training sets for good performance [4].

In a polyphase system different type of faults are categorized as: single line to ground fault (SLG), line to line fault (LL), double line to ground fault (DLG), triple line fault (LLL) and triple line ground fault (LLLG). Protecting the power system from all these fault categorize concern with the two major task: a) fault detection b) fault clearing which include fault detection and its distance estimation and consequently involves the fault classification, such that the type of fault is identified, the appropriate remedial action can be performed to restore power the supply and solve the problems [2].

## 2. Wavelet Transform

In the beginning of 1980's wavelet transformed was introduced in the field of speech and image processing. It is type of linear transformation like Fourier transform with one difference that it allows time localization of different frequency component of signal. Wavelet transform technique is a robust and versatile method to analyze non-stationary and non-periodic wide band signal such as transient signal. Unlike the Fourier transform, in the wavelet transform it decomposes a signal in terms of oscillation localized in both time and frequency domain. In the Fourier analysis it only decomposes the signal into frequency domain. Wavelet transform utilizes translated and shifted version of mother wavelet which has convenient properties according to time frequency localization.

### 2.1 Theory of Discrete wavelet Transform

Wavelet transforms algorithm process the data at different scales so that they may provide multiple resolution analysis at frequency and time domain. This capability of wavelet transform is being used to detect, classify and allocate various fault conditions. This property of multi-resolution analysis is particularly useful in fault transient, which localized high frequency component superimposed on power frequency signal. The basic concept of wavelet analysis is to select an appropriate wavelet function called "mother wavelet" and then perform analysis using shifted and dilated version of this wavelet.

The definition of continuous WT for given signal x (t) with respect to mother wavelet Ψ (t) is as shown in equation (1) and reference wavelet equation as shown in equation 2 [7]:

$$\text{CWT} \quad (x, a, b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} x(t) \Psi^{*} a, b\left(\frac{t-b}{a}\right) dt \qquad (1)$$

Where Ψ (t) is a mother wavelet and other wavelet

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \Psi\left(\frac{t-b}{a}\right) \qquad (2)$$

The constant a and b are dilation and translation parameter, respectively. CWT (x, a, b) denotes wavelet transform of signal x with scale (dilation) a and translation (time shift) b [2].

The CWT has digitally implemented counterpart known as discrete wavelet transform. The DWT of a signal is given by following equation (3):

$$\text{DWT} \ (x, m, n) = \frac{1}{\sqrt{a_0^m}} \sum_{l} x(k) \Psi\left(\frac{n - l a_0^m}{a_0^m}\right) \qquad (3)$$

Where the parameter a and b are replaced by l and m being integer variable. The most frequently used selection $a_0 = 2$ and $b_0 = 1$.

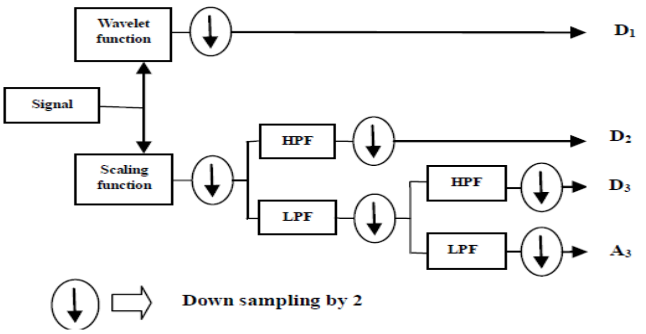


**Figure 1:** Wavelet decomposition tree [6]

The wavelet transform, multi-resolution analysis of signal is carried out. The MRA of signal is implemented with the help of two filters, one of which pass (HP) and another low pass (LP) filter. The signals are passed through a series of high pass filter to analyze the high frequencies, and it is passed through a series of low pass filter to analyze the low frequencies. Hence the signal is decomposed into two component approximation and detail. Approximation is high scale, low frequency component and detail is the low scale high frequency component. Such decomposition of signal is further carried out with approximation and detail component. This is called wavelet decomposition tree which is shown in fig. 1.

## 3. Development of Power System Model

A two bus power system has been modeled in MATLAB simulink. A typical model of a 400 kV and 300 km EHV transmission line with 2 three phase source connected at both end is as shown in fig. 2.

Sources 1 and 2: 400 kV each,

Source impedance: $R_1$:1.31Ω, $R_0$: 2.33 Ω, $X_0$: 26.6 Ω, $X_1$: 15 Ω,

Transmission line impedances: $R_1$- 8.25Ω, $R_0$- 82.5 Ω, $X_0$: 308 Ω, $X_1$- 94.5 Ω,

Capacitance: $C_1$-13nF/km, $C_0$- 8.5nF/km,

Power: 100 MVA, Line length -300 km,

Fault resistance - 0.001 Ω

### 3.1 Detection Methodology

Different types of fault are simulated on two bus power system model as shown in fig.2. Ten different types of short circuit fault such as Single Line Ground fault(SLG), Double line fault(LL), Triple line fault(LLL) on all three phases with or without involvement of ground are artificially simulated on MATLAB two bus power system model. With various fault condition corresponding current and voltage waveform information generated and is recorded at one of the end of the system. Inspection and comparison of these result with the healthy waveform reveals considerable difference between the normal and faulty condition. These differences are helpful in detecting the faulty condition. However, the no. of such patterns are being large and visually are not being much different, some post processing of various fault patterns is necessary for accurate fault detection.

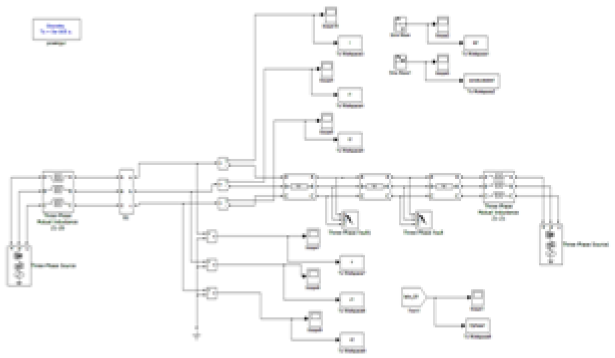

**Figure 2:** MATLAB simulink model of 2 bus power system

Thus, in the present study discrete wavelet transform has been used as an effective tool for post processing and extraction of valuable feature from the fault pattern for fault detection. In the wavelet analysis, the Daubechies wavelet transform db6 is used as mother wavelet for signal analysis. The line current signals are used as the input signal for the wavelet analysis. The fault transient of the study cases are analysed through DWT at Db6 level 1.Both approximation and detail information related fault current are extracted from the original signal with the multiresolution analysis. When any fault occurs on line, it can be seen that variations within the decomposition coefficient of the current signal contains the useful fault information.

## 4. Simulation Results and Comparison of Wavelet Results

Different types of fault are simulated using MATLAB simulink and after recording transient signal in the Matlab workspace, these recorded signals are decomposed using wavelet toolbox with Daubechies wavelet transform. In the wavelet toolbox, various wavelet transform component such as maximum, minimum, standard deviation, threshold detail coefficient are analysed if these signal component exceed that of normal condition wavelet transform component fault is detected and accordingly the fault type is classified.

### 4.1 Normal Condition

The 2 bus MATLAB power system model is simulated with no fault condition. The current for this case is obtained with no fault condition and detail coefficients are as shown in fig. 3 and 4 respectively. Daubechies wavelet transform of the signal at db6 level 1 is utilised for fault detection with analysing Maximum, Minimum, Standard Deviation of Detail Coefficient and Threshold Detail Coefficient are shown in the table I. The table I showing the various parameter value for healthy condition.

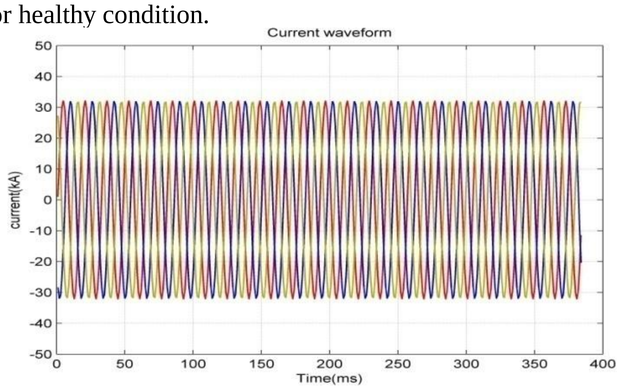


**Figure 3:** Current signals for no fault condition

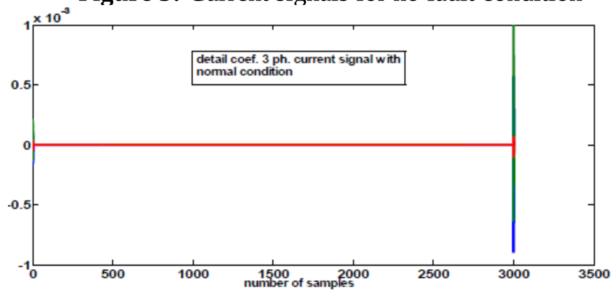


**Figure 4:** Detail coefficients for no fault condition

### 4.2 Single Phase to Ground Fault

Three phase current signal with phase A to ground fault is as shown in fig. 5. The fig. 5 shows that the phase consisting faulty condition, the corresponding current signal of that phase is increased compared to other healthy phases. The fig. 6 shows the detail coefficient for single line to ground fault condition, the higher peak in detail coefficient showing involvement of one of the phase fault. With the wavelet analysis of this current signal, various wavelet transform coefficient are analysed.

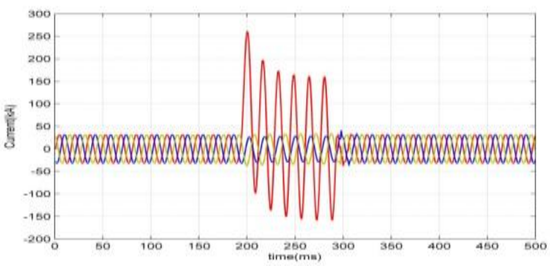


**Figure 5:** Three phase current signal at single phase to ground fault condition

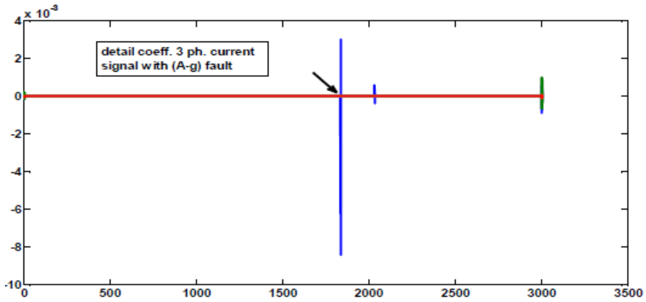


**Figure 6:**. Detail coefficient for single line ground fault condition

The SLG fault condition for different phases A, B and C described with the data included in Table I respectively, such that whichever phase consisting the fault condition the corresponding wavelet transform coefficient of that phase are at a higher level compared to the other 2 healthy phases and corresponding fault condition for particular phases fault can be detected.

### 4.3 Double Line Ground Fault

Three phase current signal with double line to ground fault is as shown in fig. 7. The fig. 8 shows the detail coefficient for double line to ground fault, the peak in the detail coefficient showing the involvement of two phases with ground fault condition. With the wavelet analysis of this current signal, various wavelet transform coefficient are analysed. Double line to ground fault condition for different phase's involvement such as phase A-B-G, phase B-C-G and phase A-C-G described with the data included in Table I respectively.

In the wavelet analysis, the current signal are decomposed with the daubechies wavelet transform Db6 level 1.From the table data, it can be seen that the phases which involve with double line ground fault condition are having wavelet transform coefficient at a higher value compared to that of other healthy phase showing the involvement of fault condition.

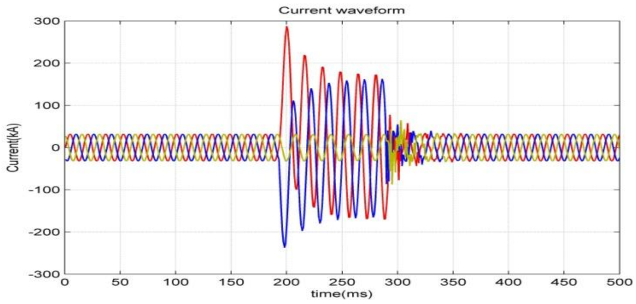


**Figure 7:** Three phase current signal at double line to ground fault condition

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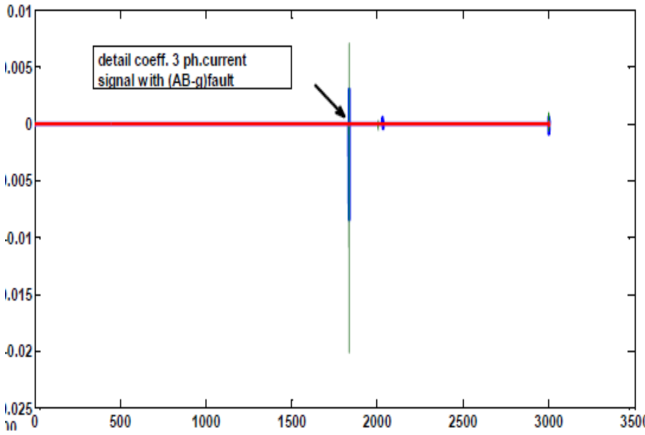

**Figure 8:** Detail coefficient for double line to ground fault condition

## 4.4 Double Line Fault

Three phase current signal with phase A-B double line fault is as shown in fig. 9. With the phasor estimation of various fault condition it become difficult to detect whether the double line fault condition having involvement of ground or without ground condition. As in the both condition the waveforms differ only by a smaller magnitude hence with the wavelet analysis of this current signal and analysing of various wavelet coefficient, double line and double line ground fault can be distinguished.

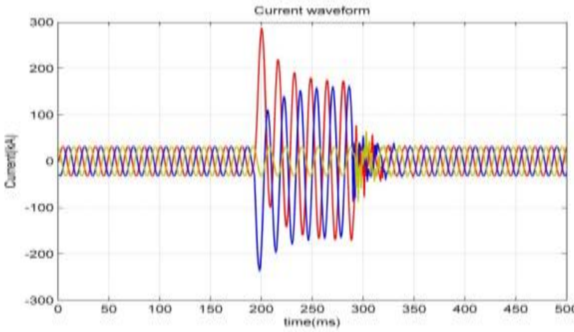

**Figure 9:** Three Phase Current Signal at Double Line Fault Condition

The fig. 10 shows the detail coefficient for double line fault condition. The higher magnitude peak in the fig. 10 shows detail coefficient for double line fault condition.

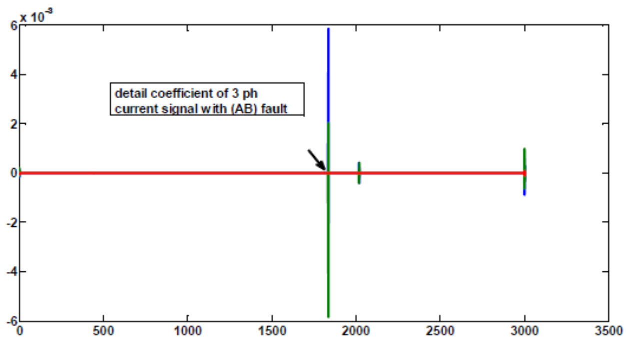

**Figure 10:** Detail coefficient for double line fault condition

Double line fault condition for different phases involvement such as phase A-B, phase B-C and phase A-C described with the data included in Table I respectively. From the table data it can be seen that, wavelet analysis of three phase current signal of double line fault condition is performed and various wavelet transform coefficient are analysed. It is shown that the phases which involve with the faulty condition are having the wavelet transform coefficient at a higher level compared to other healthy phase. Along with this, the table data also shows the important feature which distinguishes between the double line and double line ground fault condition. Unlike that of the DLG fault condition, in double line fault condition the 2 parameter are having nearly identical value for which the 2 phases involved with the fault condition i.e. standard deviation and threshold detail coefficient are identical component. Also the energy of the DLG fault is higher compared to that of double line fault.

## 4.5 Triple Line to Ground Fault

Three phase current signal with phase A-B-C-G triple line to ground fault condition is as shown in fig. 11. The figure shows that all three phase current signal increased suddenly at certain fault condition occurrence. The fig. 12 shows detail coefficient for triple line ground fault condition.

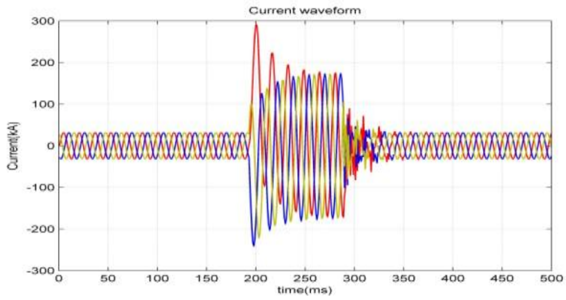

**Figure 11:** Three Phase Current Signal at Triple Line Ground fault Condition

Triple line to ground fault condition with phase A-B-C-G described with the data included in Table I. As it involves all the three phases, the wavelet transform coefficient of all the three signals are at a increased level compared to that of normal healthy phase in table I.

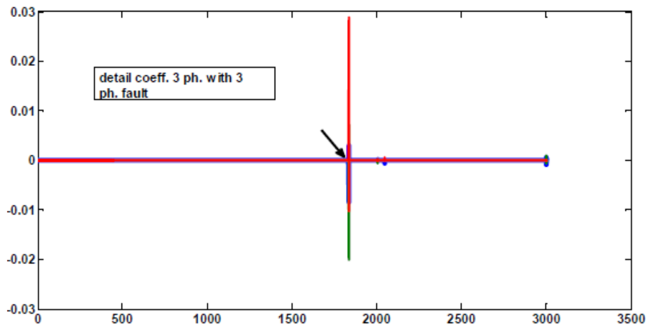

**Figure 12:** Detail coefficient for Triple line to ground fault condition

## 4.6 Triple Line Fault

Three phase current signal with phase A-B-C triple line fault condition is as shown in fig. 13. With the phasor estimation it is quite difficult to distinguish between the triple line and triple line ground fault condition. As in the both condition the waveforms differ only by a smaller magnitude hence with the wavelet analysis of this current signal and analyzing of various wavelet coefficient, triple line and triple line ground fault can be distinguished. The fig. 14 shows detail coefficient for triple line fault condition. The table I shows the various values of parameter that are analyzed for triple line fault condition.

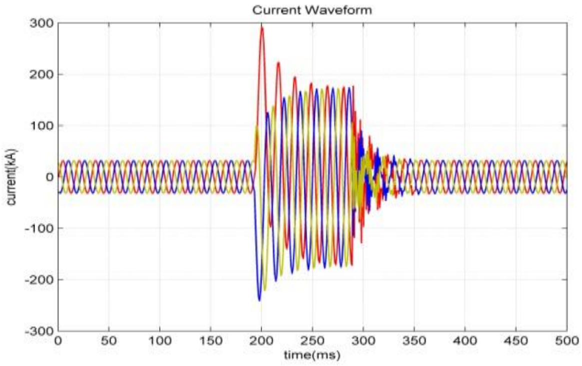


**Figure 13:** Three Phase Current Signal at Triple Line fault Condition

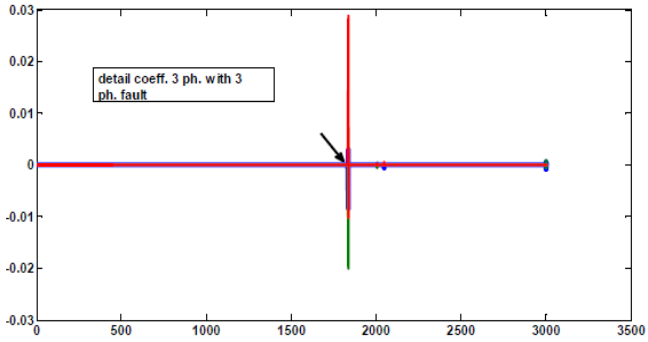


**Figure 14:** Detail coefficient for Triple line fault condition

**Table I:** Statistical Data For Different Fault Condition

| *Type of Fault* | *Phase A* | | | | *Phase B* | | | | *Phase C* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Max* | *Min* | *Std. Dev.* | *Thresh. Detail Coeff.* | *Max* | *Min* | *Std. Dev* | *Thresh. Detail Coeff* | *Max* | *Min* | *Std. Dev* | *Thresh. Detail Coeff* |
| Normal condition | 2.08 | -3.11 | 0.254 | 3.42 | 2.074 | -1.43 | 0.1913 | 2.224 | 1.037 | -0.657 | 0.1328 | 1.203 |
| L-G Phase A | 14.12 | -11.22 | 1.71 | 14.12 | 7.471 | -10.54 | 0.94 | 10.54 | 7.515 | -10.57 | 0.9384 | 10.57 |
| L-G Phase B | 8.304 | -11.23 | 1.209 | 11.23 | 14.15 | -17.29 | 1.783 | 17.29 | 8.259 | -11.69 | 1.038 | 11.69 |
| L-G Phase C | 7.645 | -9.301 | 1.058 | 9.301 | 8.154 | -9.251 | 1.047 | 9.251 | 31.76 | -11.64 | 2.258 | 31.579 |
| L-L Phase A –B | 117.7 | -67.93 | 10.71 | 117.24 | 67.89 | -117.6 | 10.71 | 117.6 | 1.037 | -0.6572 | 0.1285 | 1.203 |
| L-L Phase B –C | 2.087 | -3.11 | 0.2387 | 3.427 | 6.297 | -10.85 | 1.33 | 10.851 | 10.82 | -6.698 | 1.31 | 10.82 |
| L-L Phase C –A | 117.2 | -206.3 | 17.01 | 206.32 | 2.074 | -1.43 | 0.1812 | 2.224 | 206.6 | -117.1 | 17.02 | 206.5 |
| L-L-G Phase A-B-G | 32.46 | -63.44 | 5.769 | 63.44 | 115 | -42.69 | 7.985 | 114.9 | 57.35 | -91.95 | 7.686 | 91.15 |
| L-L-G Phase B-C-G | 66.96 | -87.8 | 8.068 | 87.87 | 77.15 | -67.66 | 7.72 | 77.15 | 84.28 | -67.9 | 7.678 | 84.28 |
| L-L-G Phase C-A-G | 70.93 | -133.4 | 9.974 | 113.38 | 110.7 | -71.31 | 9.14 | 110.6 | 137.1 | -93.1 | 10.57 | 137 |
| L-L-L Phases A-B-C | 160 | -272.9 | 22.68 | 272 | 132.9 | -85.8 | 11.4 | 132.88 | 140 | -75.8 | 11.39 | 140 |
| L-L-L-G Phases A-B-C-G | 106.2 | -82.88 | 11.15 | 106.2 | 101.9 | -89.29 | 10.33 | 101.2 | 108.3 | -68.44 | 9.075 | 108.3 |

## 5. Conclusion

In this paper a wavelet analysis based technique has been studied to detect and classify different shunt faults and their combination on two bus power system networks. A case study has been conducted on two bus system with different shunt faults are simulated on MATLAB simulink. All these faults can be correctly identified and classified with the help of discrete wavelet analysis using Db6 level 1. In the discrete wavelet analysis, various parameters such as maximum, minimum, standard deviation and threshold value of the wavelet detail coefficient are analyzed. The simulated results on the two bus system show that the studied technique can accurately detect and classify various
faults condition.

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