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# Localisation of Fault Using Travelling Wave Theory Based on Multi-End System

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## Abstract

The aim of this paper is to study the fault location in a transmission line using MATLAB/SIM POWER SYSTEMS is carried out for 200Km long, 500KV connected to the load. Fault location can be done into two different configurations, the single end and multi-end methods. The comparison results show the efficiency of this method to study the objectives of this thesis is to propose an automated technique based on travelling waves for finding the fault location in transmission lines and to test the performance of the technique. The proposed method uses the measured fault current signals of the fault signals. The error in fault location estimation is a function of the sampling rate and the speed of propagation.

**Keywords**: Fault detector, Localization of faults, multi-end method, travelling waves, Short Time Fourier Transform.

## INTRODUCTION

### Fault Location by using Multi-end Method:

Various methods and different techniques of fault location have been developed in the literature References [1], [2], [29]. In traveling wave-based method, the fault location can be found by comparing the arrival time of the initial and reflected transient signals at the single end of the line terminals. Single ended methods show more economical advantages. In double-ended method, most of the research work was concentrated on two-end or three-terminal methods. However, in meshed networks, the single-ended method has many disadvantages because of multiple reflections from different impedance discontinuities such as bus and transformers which arrive the measuring point from multiple paths. These multi-path reflections impose many difficulties in identifying the main reflection from the fault location. References [4], [5], [6], [18], [19], [20]

## FAULTY LINE ESTIMATION

If there is a traveling wave recorder installed at a substation, the detection of the faulty line can be found by comparing the polarity of the incoming transient current and voltage signals. The fault location can be calculated by comparing the arrival time of the initial transients at two substations A and B using the known propagation speed of the TW transient signals. The fault location can be estimated using the arrival delays of a given fault transient at different locations in the power system knowing the minimum traveling time of these signals. The transmission line model considered for this work has been shown in fig1

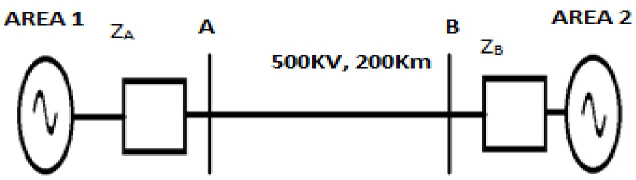

**Figure 1:** Two Area Transmission line network

Case I .Specifications:

Source Voltage: 500kV, 50Hz

Transmission Line Length: 200Km, distributed parameter transmission line model

| | |
|---|---|
| R1 = 0.01273 Ω/km; | R0 = 0.3864 Ω/km; |
| L1 = 0.9337e-3 H/km; | L0= 4.1264e-3 H/km; |
| C1 = 12.74e-9 F/km | C0 = 7.751e-9 F/km |

Fault is created at 0.0008 and cleared at 0.0009, simulation time 0.0015

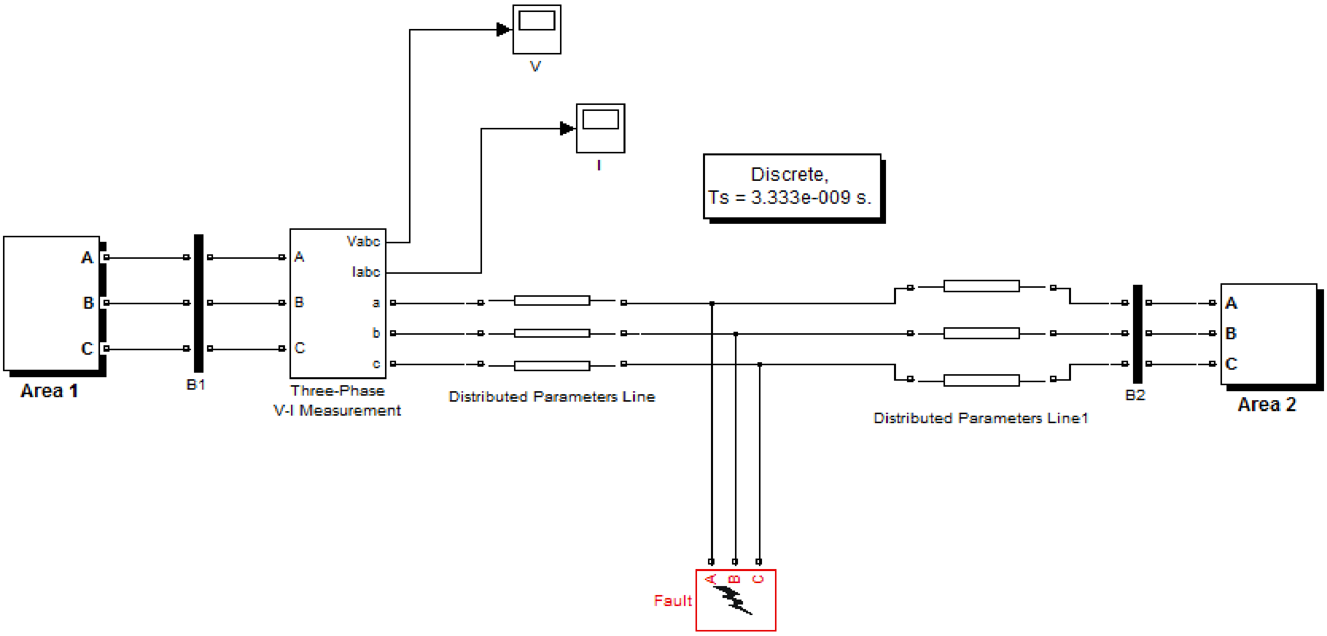

**Figure 2:** Two Area Systems network

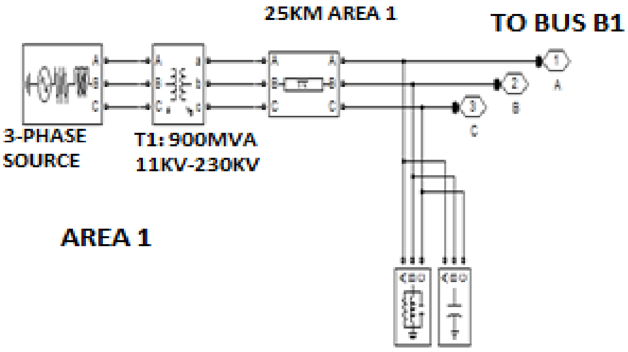

**Figure 3:** Area 1 Systems network

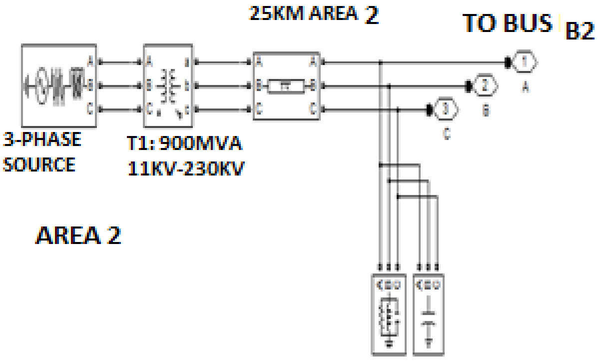

**Figure 4:** Area 2 Systems network

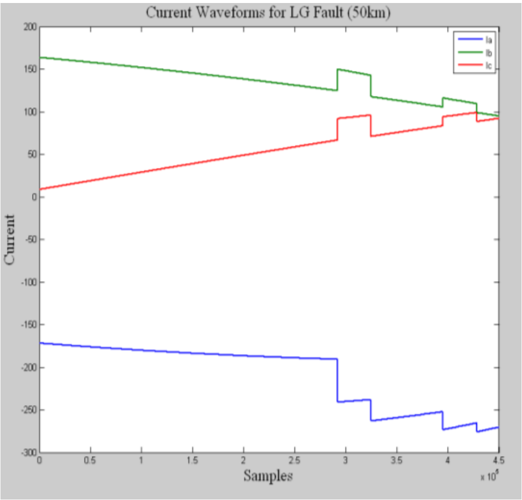

**Figure 5:** Current wave form, L-G fault at 50km

The above current waveform represents an LG fault created at distance of 50km on a transmission line of 200km long, the fault creation time is 0.0008sec and the shift in voltage wave form appears at 0.00097245sec, this is due to the travelling time taken by the fault to appear at the relay point.

Fault is created at 0.0008 Seconds.

But the fault appeared at 0.00097245 Seconds.

Difference in Time = (0.0009725 – 0.0008)

= 0.0001725 Seconds

$V = \frac{1}{\sqrt{LC}}$ is the velocity of propagation.----(1)

$$V = \frac{1}{\sqrt{0.9337*10^{-3}*12.74*10^{-9}}} \quad \text{-------- (2)}$$

$$V = 2.899*10^{5}\,Km/\sec$$

Distance = Velocity * Time

Here, Distance = $2.899*10^{5}*0.0001725$

Distance = 50.00775.

**Table 1**

Location of Faults using double end method for a 200Km Transmission line

Case II. Specifications:

Source Voltage: **500kV**, 50Hz

Transmission Line Length: **500Km**, distributed parameter transmission line model

| | |
|---|---|
| R1 = 0.01273 Ω/km; | R0 = 0.3864 Ω/km; |
| L1 = 0.9337e-3 H/km; | L0= 4.1264e-3 H/km; |
| C1 = 12.74e-9 F/km | C0 = 7.751e-9 F/km |

Fault is created at 0.002 and cleared at 0.004, simulation time 0.004

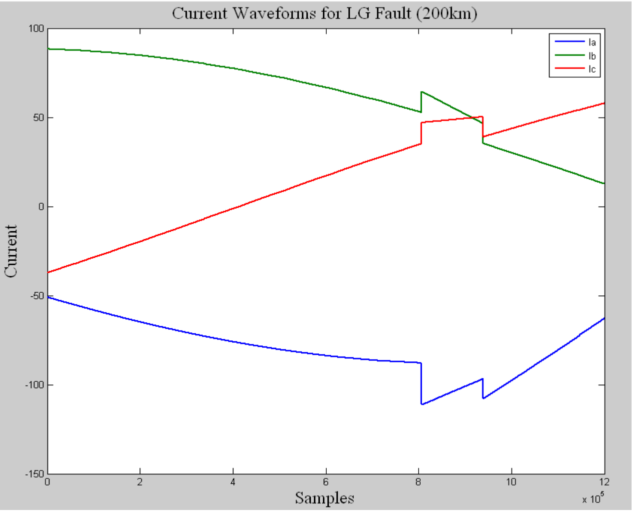

**Figure 6:** Current wave form, L-G fault at 200km

The above current waveform represents an LG fault created at distance of 200km on a transmission line of 500km long, the fault creation time is 0.002sec and the shift in voltage wave form appears at 0.0026898sec this is due to the travelling time taken by the fault to appear at the relay point.

**Table 2**

Location of Faults using double end method for a 500Km Transmission line

Case III. Specifications:

Source Voltage: **500kV**, 50Hz

Transmission Line Length: **700Km**, distributed parameter transmission line model

| | |
|---|---|
| R1 = 0.01273 Ω/km; | R0 = 0.3864 Ω/km; |
| L1 = 0.9337e-3 H/km; | L0= 4.1264e-3 H/km; |
| C1 = 12.74e-9 F/km | C0 = 7.751e-9 F/km |

Fault is created at 0.0028 and cleared at 0.006 simulation time 0.006

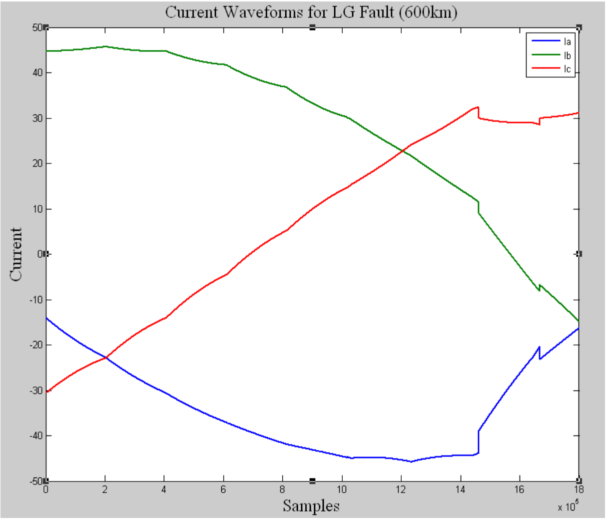

**Figure 7:** Current wave form, L-G fault at 600km

The above current waveform represents an LG fault created at distance of 600km on a transmission line of 700km long, the fault creation time is 0.0028sec and the shift in voltage wave form appears at 0.0048694sec this is due to the travelling time taken by the fault to appear at the relay point.

**Table 3**

Location of Faults using double end method for a 700Km Transmission line

## LITERATURE REVIEW

### Fault Location Signal Processing Techniques

A traveling wave, a sharply varying signal, is a real challenge for the traditional mathematical methods. As a high-frequency signal, the traveling wave is difficult to separate from interference noise. In this regard, some signal processing techniques have been adopted. Typically, the traveling waves are mingled with noise as the traveling-wave-based fault location systems require a high sampling rate so that the fault information can be estimated accurately. The various signal processing techniques are investigated concerning their application to fault location using traveling wave signals for overhead transmission line. These techniques enable the time-frequency representation of fault signals to be computed. Such computations are used to determine the most appropriate technique for the detection of the traveling waves under investigation. The analysis is carried out using TW output signals from the MATLAB simulations for a typical power system with a single circuit overhead transmission line connecting two 500-kV buses as depicted in Figure 8.

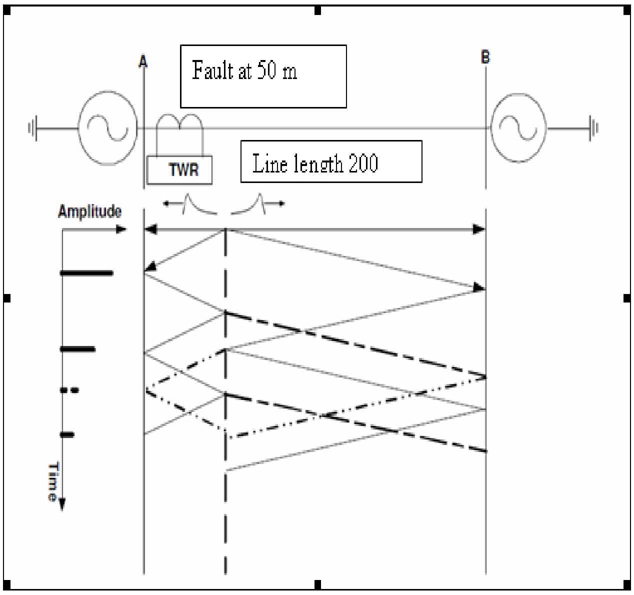

**Figure 8:** Lattice diagram for a fault at the first half of a transmission line

## METHODOLOGY

### Frequency Domain Approach:

Fourier transform-based fault location algorithms have been proposed since a long time. Most of the proposed algorithms use voltages and currents between fault initiation and fault clearing. To find out the frequency contents of the fault signal, several transformations can be applied, namely, Fourier, STFT, and Wavelet etc.

### Fourier Transform:

Fourier transform (FT) is the most popular transformation that can be applied to traveling wave signals to obtain their frequency components appearing in the fault signal. Usually, the information that cannot be readily seen in the time domain can be seen in the frequency domain. The FT and its inverse give a one-to-one relationship between the time domain $x(t)$ and the frequency domain $X(\omega)$ .Given a signal $I(t)$ , the FT $FT(\omega)$ is defined by the following equation:

$$FT = \int_{-\infty}^{\infty} I(t).e^{-j\omega t} dt \text{ ----------------- (3)}$$

Where $\omega$ is the continuous frequency variable. This transform is very suitable for stationary signal, where every frequency components occur in all time. The FT gives the frequency information of the signal, but it does not tell us when in time these frequency components exist. The information provided by the integral corresponds to all time instances because the integration is done for all time intervals. It means that no matter where in time the frequency f appears, it will affect the result of the integration equally. This is why FT is not suitable for non-stationary signals. The FT has good results in the frequency-domain but very poor results in the time domain. When the current surge hits the fault point, it is reflected with the same sign and travels back to the source end of the line. Then, it is reflected again from the source end with the same sign and returns back to the fault point. Since the duration of this complete cycle is $4\tau$ ($\tau$ is the propagation time of the surge from the source end to the fault point) the main component of the current signal after the circuit breaker opening has a frequency equal to $f = \frac{1}{4\tau}$

so that the distance to the fault may be obtained as $FL = \frac{v}{4f}$

Time-Frequency-Domain Approach:

The traveling wave based fault locators utilize high frequency signals, which are filtered from the measured signal. Discrete Fourier Transform (DFT) based spectral analysis is the dominant analytical tool for frequency domain analysis. However, the DFT cannot provide any information of the spectrum changes with respect to time. The DFT assumes the signal is stationary, but the traveling wave signal is always non-stationary. To overcome this deficiency, the Short Time Fourier Transform and the Wavelet Transform allow representing the signal in both time and frequency domain through time windowing functions. The window length determines a constant time and frequency resolution. The nature of the real traveling wave (TW) signals is non-periodic and transient; such signals cannot easily be analyzed by conventional transforms. So, Short Time Fourier Transform and the Wavelet Transform must be selected to extract the relevant time-amplitude information from a TW signal. In the meantime, the SNR ratio can be improved based on prior knowledge of the signal characteristics.

**Short Time Fourier Transform:**

To overcome the shortcoming of the DFT, short time Fourier transform (STFT, Denis Gabor, 1946) was developed. In the STFT defined below, the signal is divided into small segments which can be assumed to be stationary. The signal is multiplied by a window function within the Fourier integral. If the window length is infinite, it becomes the DFT. In order to obtain the stationary, the window length must be short enough. Narrower windows afford better time resolution and better stationary, but at the cost of poorer frequency resolution. One problem with the STFT is that one cannot determine what spectral components exist at what points of time. One can only know the time intervals in which certain band of frequencies exist. The STFT is defined by following equation:

$$\mathrm{STFT}(t,\omega)=\int_{-\infty}^{+\infty} I(t).w(t-\tau).e^{-j\omega t}dt$$

Where $I(t)$ is the measured signal, $\omega$ is frequency, $w(t-\tau)$ is a window function, $\tau$ is the translation, and (t) is time.

To separate the negative property of the DFT described above, the signal is to be divided into small enough segments, where these segments (portion) of the signal can be assumed to be stationary. These transforms can be displayed in a three dimensional system (Amplitude of transform, frequency, time). And it is clearly seen in time and frequency domain. To get better information in time or frequency domain, parameters of the window can be changed. As afore mentioned, narrow windows give good time resolution, but poor frequency resolution. Wide windows give good frequency resolution, but poor time resolution. Thus, it is required to compromise between the time and frequency resolutions. For example, a function may contain a high peak on an interval while it is small elsewhere. This function could represent a current wave packet, which is just a peak traveling from one point to another in a transmission line. A Fourier series will not do as well when representing this function because the sine and cosine functions, which make up the Fourier series, are all periodic and thus it is hard to focus on the local behavior of this wave packet.

Given a function $x(t)$, its Continuous Wavelet Transform (CWT) is defined as follows:

$$\mathrm{CWT}=(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} x(t)\psi^{*}\left(\frac{t-b}{a}\right)dt \quad \text{---------(4)}$$

The transformed signal is a function with two variables b and a, the translation and the scale parameter respectively. $\psi(t)$ is the mother wavelet, which is a band-pass filter and $\psi^{*}$ is the complex conjugate form. The factor $\frac{1}{\sqrt{a}}$ is used to ensure that each scaled wavelet function has the same energy as the wavelet basis function. It should also satisfy the following admissible condition:

$$\int_{-\infty}^{\infty}\psi(t)dt=0 \quad \text{-------- (5)}$$

The term translation refers to the location of the window. As the window is shifted through the signal, time information in the transform domain is obtained. a is the scale parameter which is inversely proportional to frequency. High scales give global information of the signal (that usually spans the entire signal), whereas low scales give detailed information of a hidden pattern in the signal that usually lasts a relatively short time. In practical applications, low scales (high frequencies) do not last for long, but they usually appear from time to time as short bursts. High scales (low frequencies) usually last for the entire duration of the signal. Wavelet transform of sampled waveforms can be obtained by implementing the DWT, which

is given by:

$$\mathrm{DWT}(k,n,m)=\frac{1}{\sqrt{a_0^m}}\sum x[n]\psi\left(\frac{k-nb_0a_0^m}{a_0^m}\right)$$

Where $\psi(t)$ is the mother wavelet, and the scaling and translation parameters a and b in (3:13) are replaced by $a_0^m$ and $nb_0a_0^m$ respectively, n and m being integer variables. In the standard DWT, the coefficients are sampled from the CWT on a dyadic grid.

The wavelet coefficients (WTC) of the signal are derived using matrix equations based on decomposition and reconstruction of a discrete signal. Actual implementation of the DWT involves successive pairs of high-pass and low-pass filters at each scaling stage of the DWT. This can be thought of as successive approximations of the same function, each approximation providing the incremental information related to a particular scale (frequency range). The first scale covers a broad frequency range at the high frequency end of the spectrum and the higher scales cover the lower end of the frequency spectrum however with progressively shorter bandwidths. Conversely, the first scale will have the highest time resolution. Higher scales will cover increasingly longer time intervals.

## RESULTS

Case I: Double end:

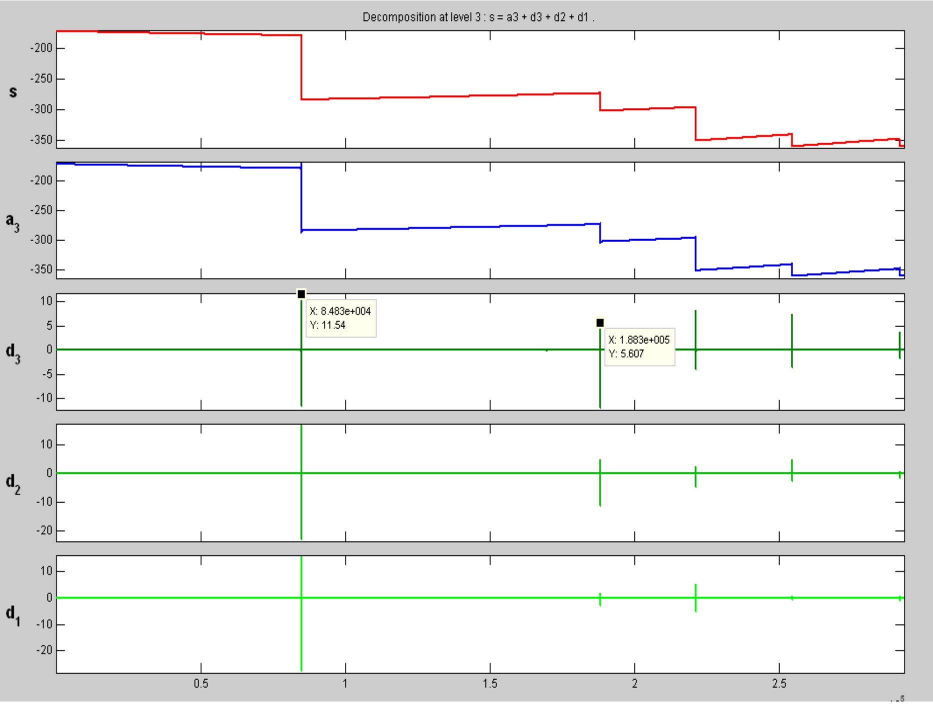

**Figure 9 (a):** Current Waveform for L-G fault at 50 km with Wavelet Transform

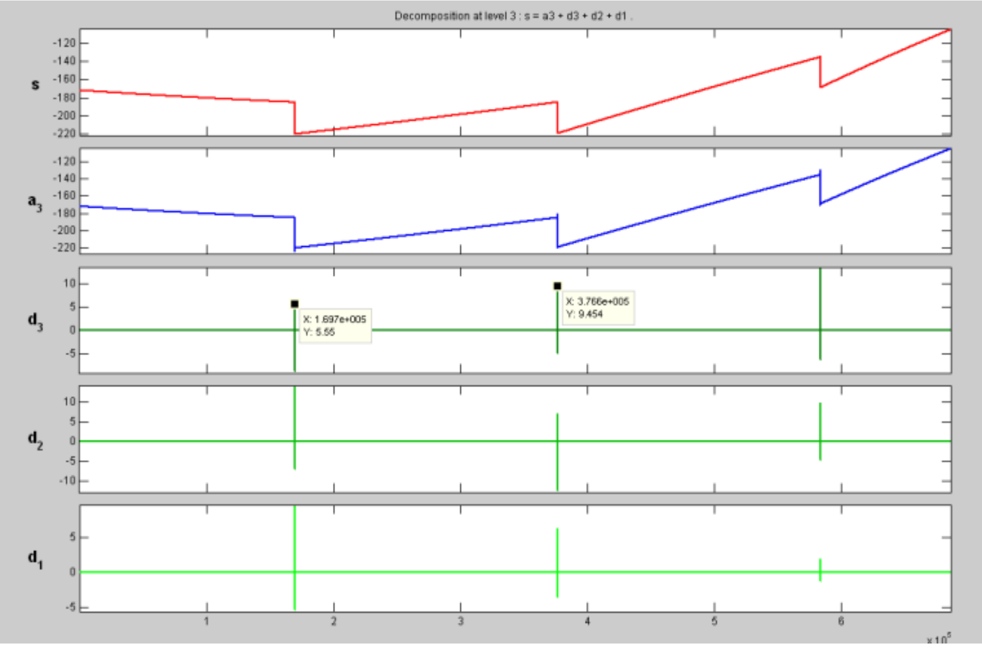

**Figure 9 (b):** Current Waveform for L-L fault at 100 km with Wavelet Transform

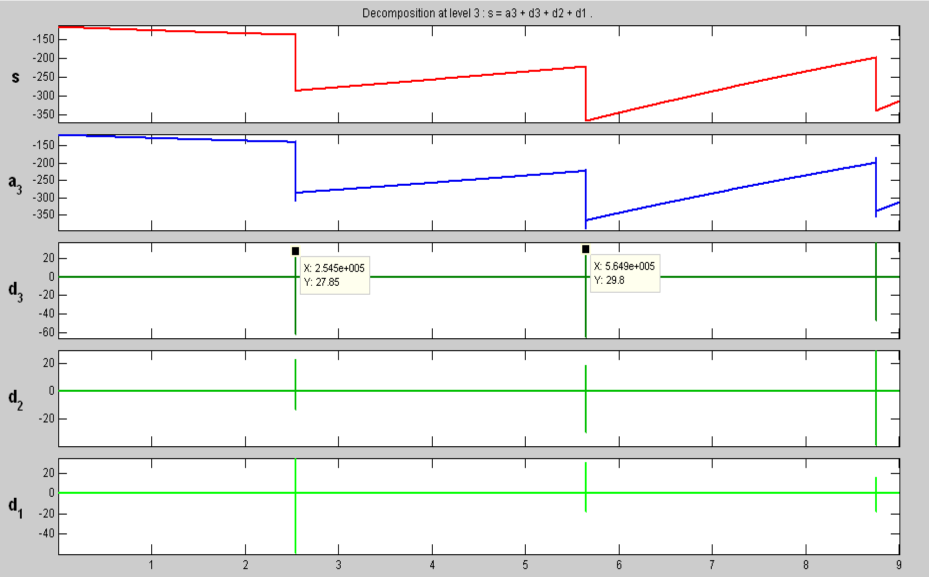

**Figure 9 (c):** Current Waveform for L-L-G fault at 150 km with Wavelet Transform

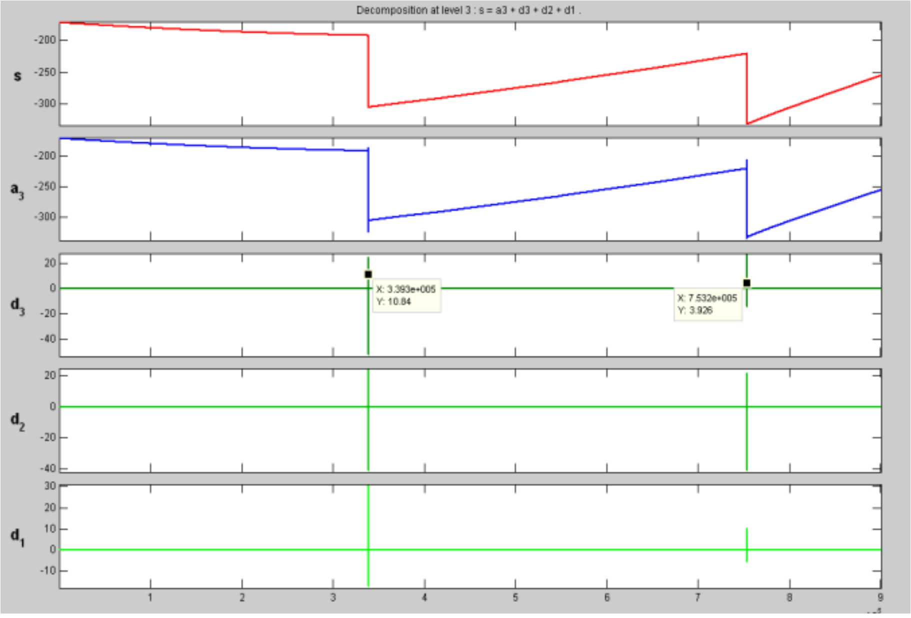

**Figure 9 (d):** Current Waveform for L-L-L fault at 200 km with Wavelet Transform

## CONCLUSION

In this thesis presented a fault locator that is based on the characteristics of the travelling waves initiated from the fault. This part of the work has addressed the problem of fault distance estimation utilizing the measurements of currents as well as voltage travelling wave signals at two area transmission line systems. The travelling wave theory was introduced and the properties of the travelling waves on transmission lines were also discussed. The objective of this thesis was to propose an automated technique based on travelling waves for finding the fault location in transmission lines and to test the performance of the technique. The proposed method uses the measured fault current signals of the fault signals. The error in fault location estimation is a function of the sampling rate and the speed of propagation. The techniques were tested using data generated by executing various cases in MATLAB/SIMULINK. Various types of faults were applied at various locations on the transmission lines. It is possible to achieve greater accuracy with multi-end methods developed in this manuscript compared to the traditional fault location methods.

**Table 1**

| Fault | L-G | | L-L | | LLG | | LLL/LLLG | |
|---|---|---|---|---|---|---|---|---|
| Distance (Km) | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error |
| 25 | 24.99 | -0.01 | 24.99 | -0.01 | 24.99 | -0.01 | 24.99 | -0.01 |
| 50 | 49.99 | -0.01 | 49.99 | -0.01 | 49.99 | -0.01 | 49.99 | -0.01 |
| 75 | 74.99 | -0.03 | 74.99 | -0.03 | 74.99 | -0.03 | 74.99 | -0.03 |
| 100 | 99.98 | -0.01 | 99.98 | -0.01 | 99.98 | -0.01 | 99.98 | -0.01 |
| 125 | 124.97 | -0.01 | 124.97 | -0.01 | 124.97 | -0.01 | 124.97 | -0.01 |
| 150 | 149.96 | -0.02 | 149.96 | -0.02 | 149.96 | -0.02 | 149.96 | -0.02 |
| 175 | 174.98 | -0.009 | 174.98 | -0.009 | 174.98 | -0.009 | 174.98 | -0.009 |
| 200 | 199.97 | -0.01 | 199.97 | -0.01 | 199.97 | -0.01 | 199.97 | -0.01 |

**Table 2**

| Fault | L-G | | L-L | | LLG | | LLL/LLLG | |
|---|---|---|---|---|---|---|---|---|
| Distance (Km) | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error |
| 100 | 99.98 | -0.02 | 99.98 | -0.02 | 99.98 | -0.02 | 99.98 | -0.02 |
| 200 | 199.97 | -0.015 | 199.97 | -0.015 | 199.97 | -0.015 | 199.97 | -0.015 |
| 300 | 299.95 | -0.016 | 299.95 | -0.016 | 299.95 | -0.016 | 299.95 | -0.016 |
| 400 | 399.94 | -0.015 | 399.94 | -0.015 | 399.94 | -0.015 | 399.94 | -0.015 |
| 500 | 499.93 | -0.014 | 499.93 | -0.014 | 499.93 | -0.014 | 499.93 | -0.014 |

**Table 3**

| Fault | L-G | | L-L | | LLG | | LLL/LLLG | |
|---|---|---|---|---|---|---|---|---|
| Distance (Km) | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error | Calculated Distance (Km) | % error |
| 100 | 99.98 | -0.02 | 99.98 | -0.02 | 99.98 | -0.02 | 99.98 | -0.02 |
| 200 | 199.97 | -0.015 | 199.97 | -0.015 | 199.97 | -0.015 | 199.97 | -0.015 |
| 300 | 299.95 | -0.016 | 299.95 | -0.016 | 299.95 | -0.016 | 299.95 | -0.016 |
| 400 | 399.94 | -0.015 | 399.94 | -0.015 | 399.94 | -0.015 | 399.94 | -0.015 |
| 500 | 499.93 | -0.014 | 499.93 | -0.014 | 499.93 | -0.014 | 499.93 | -0.014 |
| 600 | 599.91 | -0.015 | 599.91 | -0.015 | 599.91 | -0.015 | 599.91 | -0.015 |
| 700 | 699.90 | -0.014 | 699.90 | -0.014 | 699.90 | -0.014 | 699.90 | -0.014 |

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