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A Comparative Study of Different Traveling Wave Fault Location Techniques

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Abstract: *Power transmission lines transfer a huge amount of electricity from generation stations to distribution centers. The flow of the large currents causes faults along transmission lines, leading to extended power outages and equipment failure. When a fault occurs along a line at a particular location, a reduction of voltage at that point leads to a high frequency inversion known as a traveling wave electromagnetic impulse. The velocity of propagation of the traveling wave along the line provides information about the fault. This study focuses on problems that cause a short circuit in a long-distance transmission line and develops a fault location method using traveling wave techniques. Single- and double-ended techniques are used to extract the voltage and the current traveling wave reflection and arrival times to locate the fault for three phases. The captured traveling wave signals input into MATLAB using a wavelet transform filter to obtain their frequency components. Four different techniques – two single-ended techniques (close in fault and remote end fault) and two double-ended techniques (close end and remote end) – are simulated on the IEEE 9-bus transmission system using MATLAB Simulink. This comparative study examines the application of different traveling wave techniques to find the most accurate technique for locating a transmission line fault.*

Keywords: *transmission lines, fault location; traveling waves, wavelet transformer*

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I. Introduction

Electricity generation plants provide power to load centers and numerous electricity consumers over transmission line grid towers. Under normal operation conditions, the line retains a balanced condition. However, a fallen tree, defective equipment, overloading, human inaccuracies, aging and ice storms can put lines in an unbalanced operation condition, leaving them unprotected against faults. A series of electrical faults can cause mechanical damage, which needs to be repaired before returning the line to service. The voltage and current in a power system can be calculated under both normal and abnormal conditions [1].

Faults in a transmission line system are caused by an abnormal flow of current, leading to extended power outages along the line and equipment failure. When a fault occurs along a line, the voltage at that particular point becomes reduced, which leads to a traveling wave electromagnetic impulse [2]. These waves spread in both directions along the line from the point of occurrence at a speed near that of light. Instrument transformers can be used to capture and analyze these unwanted signals using a filter. The length of the line can be detected using these captured signals, and the initial stage of these waves can be located.

Traveling waves have become one of the easiest and most accurate methods of transmission line fault location. Ref [3] describes the traveling wave technique for finding a fault location on transmission lines. The authors solve the problem of fault localization in a transmission system by measuring the fault current and fault voltage signal waves at each end of the line using single- and double-ended techniques, respectively. The authors in [3] also present a new wavelet multi-resolution method for signal analysis. The distance of the fault location can be calculated based on the arrival time of the travelling wave peaks. Ref [4] presents a single-ended technique by means of travelling waves in a power system using wavelet analysis. The authors explained that when using parameters of a line and the velocity of propagation for fault investigation, changes to the parameters of the transmission line will introduce large errors in determining fault locations [4]. The results of their study indicate that their proposed technique is capable of locating the fault using the velocity of propagation. Ref [5] presents a new method of fault protection in power lines: discrete wavelet transform (DWT). DWT, which extracts fault signals at different levels by performing wavelet decomposition, enables the fault location to be obtained from the signal wave initial and arrival times at each end of the line. The author in [6] presents the location and classification using wavelets to analyze faulted voltage and current signals in a transmission line. In this method, an algorithm is used to classify the faults using wavelets, and MATLAB simulation was used to generate fault signals. A neural network analysis in a complex domain, which is used to locate the fault on a transmission line system, implies an improvement from the original input signal in multi-resolution using wavelet analysis. In [7], the authors developed a cubical algorithm to locate a fault on the transmission line using wavelet multi-resolution analysis. Identification of fault direction and location was proposed using an artificial neural network and wavelets. This study shows the improvement of the arrival time of the peaks. Fault conditions do not affect this scheme. The result indicates that the fault location and the fault section average has an error of 0.001% [8]. The study in [9] proposed a Chebyshev Neural Network (ChNN) and discrete wavelet transform (DWT) in which fault data samples are used for half a cycle. The method gives a better performance than other method. Ref [10], which presents a radial distribution fault location technique using wavelet transforms, shows how to determine transient arrival times based on the time difference between different measurements and uses this time difference to determine the fault location. The test was carried out in IEEE 34-bus using ATP/EMTP, and the system detected a fault in an unbalanced and larger distribution system. The study in [11] presents a continuous wavelet transform analysis for transient voltage generated by faults in a power system. The authors discovered that the traveling wave originated by a fault provides a correlation with some characteristic frequencies. This research presents two terminal transmission lines to analyze grounded faults. Using this method, the authors took the voltage and current waveforms from the individual substation to extract and use these signals as input parameters to the algorithm. The system simulation was achieved using MATLAB Simulink [12]. A technique of line fault location by means of traveling wave has been presented in this research. A detecting device was used to detect the voltage and current traveling wave signals at the bus bar, and the signals were extracted using traveling wave distance measurement principles. The fault location was obtained using B-type double-terminal traveling wave algorithm. Simulations were carried out for different types of fault and at different sampling frequencies [13]. This work presented a time-frequency in transmission lines system, which implies that the single-ended technique has more advantages and costs. A problem was encountered due to the time of arrival and the velocity of propagation of the line determination. Therefore, a novel time frequency characteristics single-ended fault location technique was proposed in this study. The authors used least squares and wavelet transform methods to obtain the frequency component of the traveling wave. The simulation was carried out using PSCDA/EMTDC software [14]. A comparison was made between two fault location algorithms, the first used line parameters and the second was conducted without line parameters [15]. The authors presented a wide area power grid traveling wave fault location, which shows how traveling wave recorders (TWR) are placed in a complex power grid to record the faulted voltage and current. This method was found to have higher accuracy than the existing fault location method [16]. A double circuit fault location on a parallel transmission line connected on the same pole, the two circuits are connected with a mutual coupling. The algorithms were also developed but they were unable to solve the fault location error, because of the difference in the line parameters. This result to high cost by employing a communication device in the system [17]. A novel method of fault location in multi circuits on series compensated network by pinpoint in the transmission line. The method utilizes the unsynchronized current and voltage phasors, while considering the shunt capacitance of the transmission line to determine the actual fault distance [18]. This research presented a fault location analysis using neural network and wavelet transform algorithms, which estimates the faults per cycle of the three-phase voltage and current signals. The ANN incorporates the standard deviation as an input to locate the fault in the phases [19]. The author presents a conventional way of finding the fault on a transmission line network using traveling wave frequency characteristics; high frequency components were used to estimate the fault location along the line [20]. The author presents a wavelet transform and Fourier transform fault estimation on transmission lines using an ANN, DWT and discrete Fourier transform. In each case, a relay is set to measure the current and voltage magnitudes. DWT was observed to have better accuracy than the other method s for ground faults [21]. A transmission line fault type identification method was presented in [22], which describes the distance between towers and the repair costs. This technique provides a quick response to the system for repair. The author of [23] presents a platform for locating faults in the transmission line using data provided by a digital relay. This technique provides graphical information via a calibration display of the faults, and the current and voltage can be obtained. This paper presents a long transmission line fault location algorithm, frequency time domain provides high accuracy and less consumption time. The technique is able to locate faults and is unaffected by parameter variations [24]. The author presents limited voltage measurements in a multi-circuit transmission line system; an algorithm was developed to determine the fault on the first and second buses in the system. At each level, the voltage measurement from the bus was considered. The findings indicate that the technique can locate a fault occurrence distance along the line [25]. This paper presents a novel fault location system based on dual voltage in a transmission line. A formula was derived based on a voltage positive sequence in the network. PSASP is used as an input to MATLAB, and the simulation result shows that the technique is able to clarify the fault type in each case [26]. The study in [27] presents an active line impedance fault location estimation in a high voltage transmission line, which uses voltage and current measurements to locate the fault using a converter. The study in [28] presents an accurate and fast fault location in a series compensated transmission network. The DWT is used to extract the voltage and current signals in each cycle [28].

The aim of the present paper is to investigate which traveling waves techniques can locate faults on the transmission line system more accurately and quickly than the existing methods using wavelet transform. Two single-ended techniques (close in fault and remote end fault) and two double-ended techniques (close end and remote end) are simulated, and a comparative study is conducted to find the most accurate transmission line fault location.

II. Wavelet Transform

Wavelet transform is an approximation of a signal by a sum of short waves. These short waves are called wavelets, and they are characterised by a compact support, which means that the signal does not last forever. Another characteristic of this wavelet is that the area under the curve must be zero, which shows that the energy is distributed in positive and negative directions. In wavelet analysis, signals are multiplied by a mother wavelet $\varphi *_{a,b\,(t)}$ by a function of time. Mathematically, a wavelet transform of a signal is given as

$$x(a,b) = \int_{-\infty}^{\infty} x(t)\, \varphi *_{a,b\,(t)}\ \partial t \qquad (1)$$

where a and b are the scale and translation of a two by two matrix and x(t) is the signal.

2.1. Signal Translation Scale

Translation of these signals involves shifting these wavelets forward in time while we analyse the entire signal. The scale of a signal either decreases or increases; therefore, wavelets for lower frequencies can be used to compress higher frequency signals but they are less accurate than higher to lower frequency signals. This study applies the wavelet transformation method to decompose the frequency domain signals in the time frequency domain using a Daubechies (db) filter [29].

When a fault occurs in a network, a signal is produced at that point in the form of wave, which propagates along the transmission line. These signals are obtained from bus bars placed at each end of the line. The captured signal determines the distance of that fault based on the velocity of propagation and the length of the line. The velocity of the propagation depends on the capacitance and inductance of the line [30, 31]. The waves propagated along the line might contain other frequency domains [32, 33]. The first method depends on the frequency spectrum approximation and the second is the wavelet transformation method (The db filters are classified as db4, db6, db8 and db10).

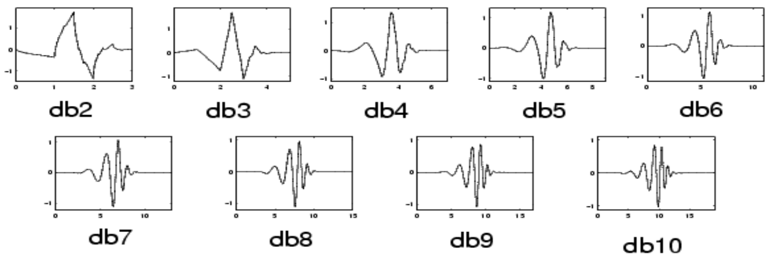

Fig 1. Daubechies Wavelet filter classification.

Short transient disturbance analysis is made by db4 and db6 wavelet filters and fast transient disturbance for db8 and db10 in [34]. The Db4 wavelet was used in this research because the line frequency signal domains should be decomposed into scales [35].

III. Different Traveling Wave Techniques

3.1. Single-Ended Technique (Close End)

In this technique, fault occurrences are within first half of the line. Voltage and current waves are taken as inputs on one bus end in the line, and at a point of fault two waves will propagate; the first wave travels backward to the initial stage and the other travels forward to the extreme end and bounces back to the initial stage. Therefore, by taking half of a delay time provided by the arrival of the two peaks in scale, we multiply by the velocity of that line to determine the distance of that fault. Therefore, the ground fault distance can be calculated by

$$D = \frac{Vt_d}{2} \qquad (2)$$

and $$t_d = t_b - t_a \tag{3}$$

where V is the velocity of propagation and t_d is the interval between the two peaks.

Figure 2 is a flow chart of the single-ended (close end) technique, which is described by the following steps:

i. Place voltage and current measuring device at the sending end.
ii. Set the total simulation time.
iii. Create the fault occurrence time and type.
iv. Measure the voltage and current output at the sending end.
v. Apply the wavelet transform to the captured voltage and current signal to time frequency.
vi. Record and compare the time intervals.
vii. Compute the LC parameters of the line as V.
viii. Calculate the fault distance D in kilometres.

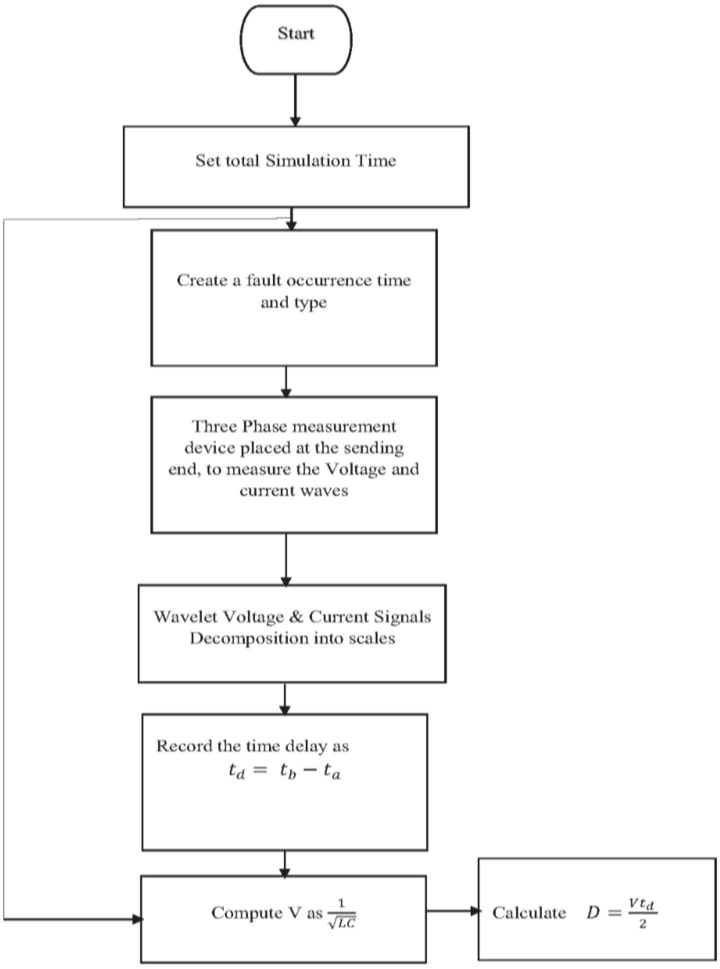

Fig 2. Flow chart of Single Ended (Close End) Technique

3.2. Single-Ended Technique (Remote End)

In this technique, fault occurrences are located at the extreme ends of the entire line. The current and voltage waveforms are taken as inputs from the sending end bus in the line. The reflected signal at the second bus might be considered based on the distance of the fault along the line. Therefore, one of the two waves travels backward to the bus as the first peak and the other travels forward as the second peak to the second bus and bounces back to the initial stage. In this ungrounded case,

$$t_d = 2\tau - t_x \tag{4}$$

where τ is the total traveling wave length and t_x represents the interval time between the two peaks. Therefore,

$$\tau = \frac{L}{V} \tag{5}$$

where L is the entire length of the line and V is the velocity of propagation of the line, and

$$V = \frac{1}{\sqrt{LC}} \tag{6}$$

where L is the inductance of the line and C is the capacitance of the line.

Figure 3 is the flow chart of the single-ended (remote end) technique, which is described by the following steps:

i. Place voltage and current measuring device at the sending end.
ii. Set the total simulation time.
iii. Create fault occurrence time and type.
iv. Measure the voltage and current output at the sending end.
v. Apply wavelet transform to the captured voltage and current signal to time frequency.
vi. Record and compare the time interval.
vii. Compute the LC parameters of the line as V.
viii. Compute total length over V multiply as τ.
ix. Compute t_d as 2 multiply by τ minus t_x.
x. Calculate fault distance D in kilometres.

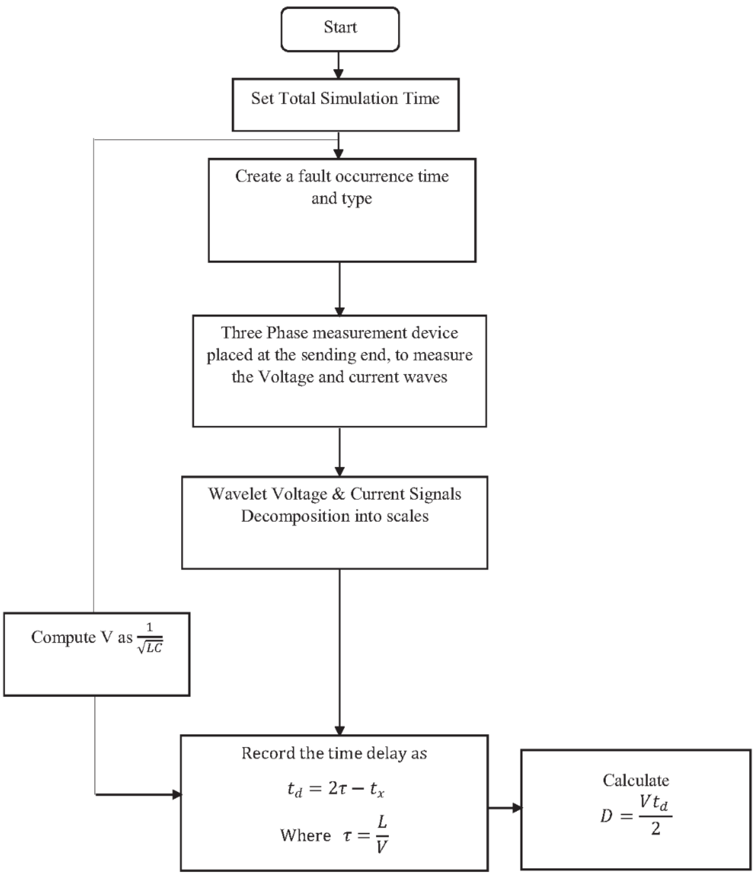

Fig 3. Flow chart of Single Ended (Remote End) Technique

3.3. Double-Ended (Close End) Technique

In this method, communication between the two buses is required along the line because the peaks travel along the entire line from one bus to the other. The grounded fault voltage and current magnitude are recorded at each bus, and the velocity of propagation is determined by the line parameters. Therefore, the difference in time from equation (3) and the velocity of propagation from equation (6) are subtracted by the total length and given as

$$D = \frac{Vt_d - L}{2} \tag{7}$$

where L is the entire length, V is the velocity of propagation of the line and t_d is the difference between two consecutive peaks.

Figure 4 is a flowchart of the double-ended close end technique, which is described by the following steps:

i.

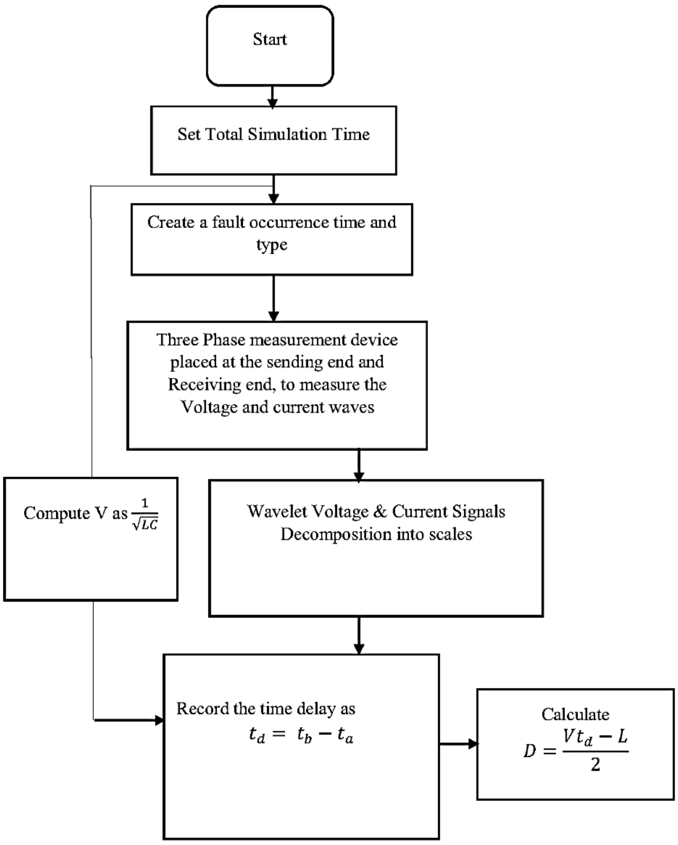

Figure 4. Flow chart of Double Ended (Close End) Technique

3.4. Double-Ended (Remote End) Technique

In this method, communication is required between the two buses along the line because the peaks travel along the entire line from one bus to the other. The ungrounded fault voltage and current magnitude are recorded at each bus, and the velocity of propagation is determined by the line parameters. Therefore, one wave travels backward to the bus as the first peak and the other travels forward as the second peak to the second bus and bounces back to the initial stage. In this case, equation (4) is substituted into equation (7), which gives

$$D = \frac{V(2\tau - t_x) - L}{2} \qquad (8)$$

where L is the total length and V is the velocity of propagation of the line.

Figure 5 shows a flow chart of the double-ended technique, which is described by the following steps:

i. Place a voltage and current measuring device at the sending and receiving ends.
ii. Set the total simulation time and create a fault.
iii. Measure the voltage and current output at the sending and receiving ends.
iv. Apply a wavelet transform to the captured voltage and current signal to time frequency.
v. Record and compare the time interval as t_d .
vi. Compute the LC parameters of the line as V.
vii. Compute the entire travel time τ as $2 * \frac{L}{V}$
viii. Compute the total length of the line as L.
ix. Calculate fault distance D in kilometres.

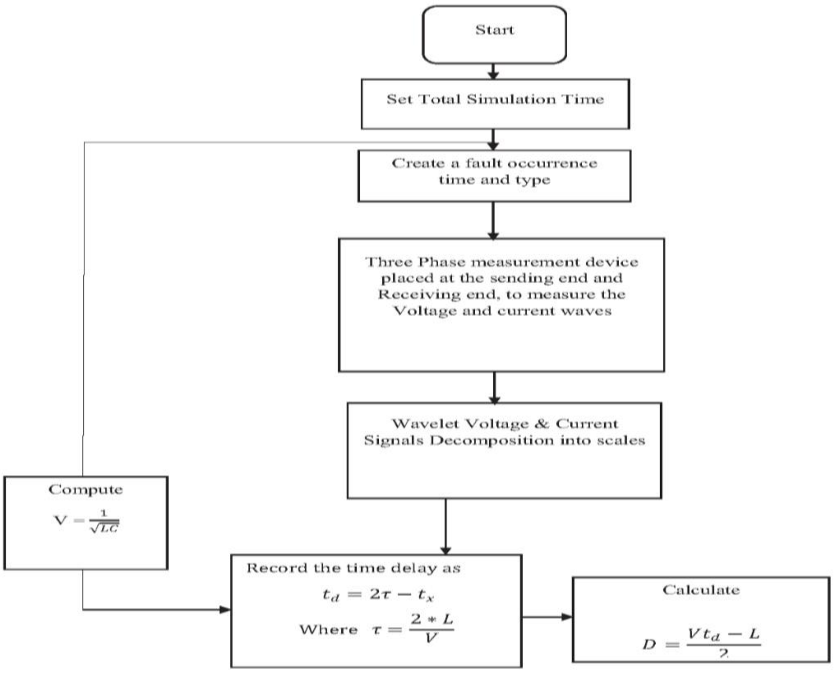

Figure 5. Flow chart of Double Ended (Remote End) Technique

IV. Case Study and Results

This section presented four proposed techniques and described the test power system which was simulated in the MATLAB Sim power system to generate data [36]. The model of the system shown in Fig 6 was modelled on the MATLAB simulation program. This model consists of three generators, nine buses and six transmission line systems. Faults were applied to each of the line as shown in Table 1. The single- and double-ended techniques were implemented to locate the distance of the faults on the lines. Each case was simulated depending on the parameters of the line such as fault creation and simulation time. The traveling wave propagates from the fault point, and wavelets were used to decompose the signal wave generated into signal scales and calculate the fault distance. The voltage and current waveform were measured at each stage because adjustments are made for each type of fault.

Table 1. Transmission line Parameters of 9-bus power system

Line Name	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
From Bus	4	4	5	6	8	7
To Bus	5	6	7	9	9	8
Length of Line (km)	225	186	112	60	138	80
Number of conductors	3	3	3	3	3	3
Resistance (Ω/km)	0.0529	0.08993	0.16928	0.20631	0.062951	0.044965
Inductance (mH/km)	1.192	1.29	2.259	2.38	1.414	1.01
Capacitance (nF/km)	8.82	7.922	15.34	17.95	10.47	7.471
Number of ground wire	1	1	1	1	1	1

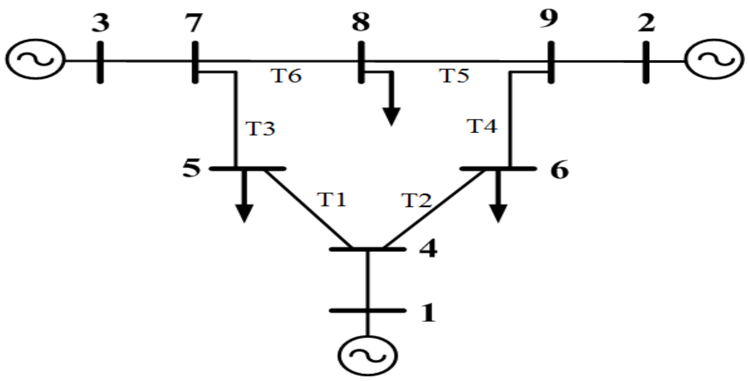

Fig 6. Model of IEEE 9-Bus power system

Since there are six transmission lines in the system, there is six possible cases as occurrence of fault on any of existed transmission lines. In all case four various types of faults such as single lie to ground (SLG), double line to ground (LLG), line to line (LL) and three phase (3φ) faults have been simulated and the accurate fault location have been estimated by different travelling wave methods and wavelet transformer.

The figure 7 shows the Phase (a) fault current output wave characteristics between Bus 4 to Bus 5 (line T1) when connected to the ground. In this case, fault was created at time 11.0 sec and the simulation time is 18.9 sec. It was observed that Phase (a) rises higher than Phase (b) and Phase (c) ; and all are unstable at that particular point of fault occurrence at a distance 113 km between Bus 4 to Bus 5, while the entire length of T1 is 225 km. The figure 8 shows the voltage output at T1 for Phase (a) fault waveform characteristics between Bus 4 to Bus 5 when connected to the ground. It was observed that Phase (a) is stable while phase b and c were unstable at that particular point of fault occurrence at a distance 113 km between Bus 4 to Bus 5.

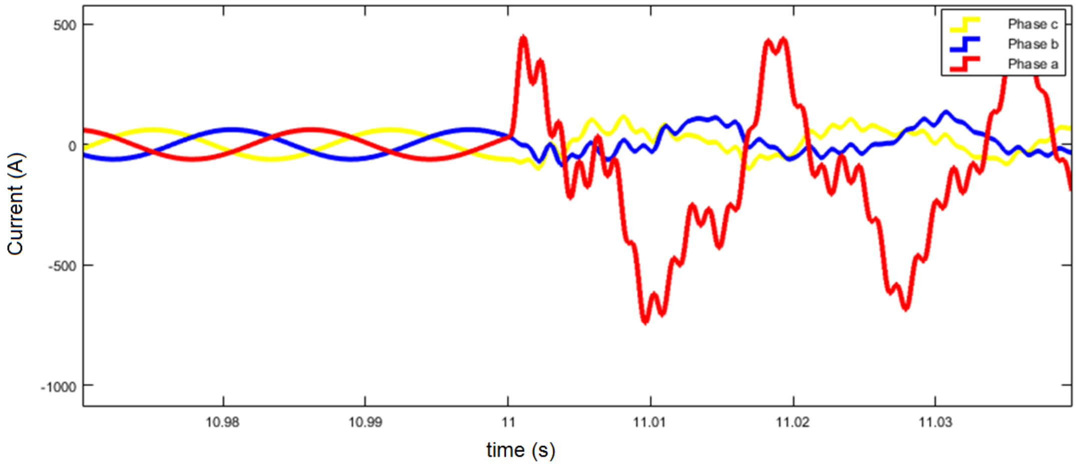

Fig 7. Current output waveforms in line T1 when phase (a) connected to the ground

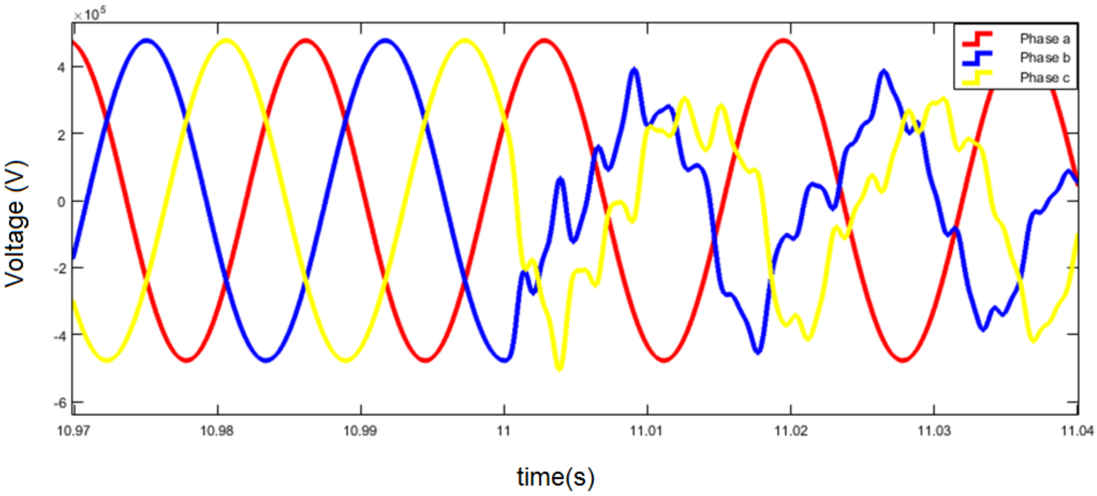

Fig 8. Voltage output waveforms in line T1 when phase (a) connected to the ground

The figure 9 shows the line ab fault current output wave characteristics between Bus 4 to Bus 5 when connected to the ground. It was observed that the line ab rises higher than line c, therefore all the lines were unstable at that particular point of fault occurrence at a distance 113km between Bus 4 to Bus 5. The figure 10 shows the voltage output at T1 for line ab fault waveform characteristics between Bus 4 to Bus 5 when connected to the ground. It was observed that the line c rises higher than line ab, therefore all the lines were unstable at that particular point of fault occurrence at a distance 113 km between Bus 4 to Bus 5, and the entire length is 225 km.

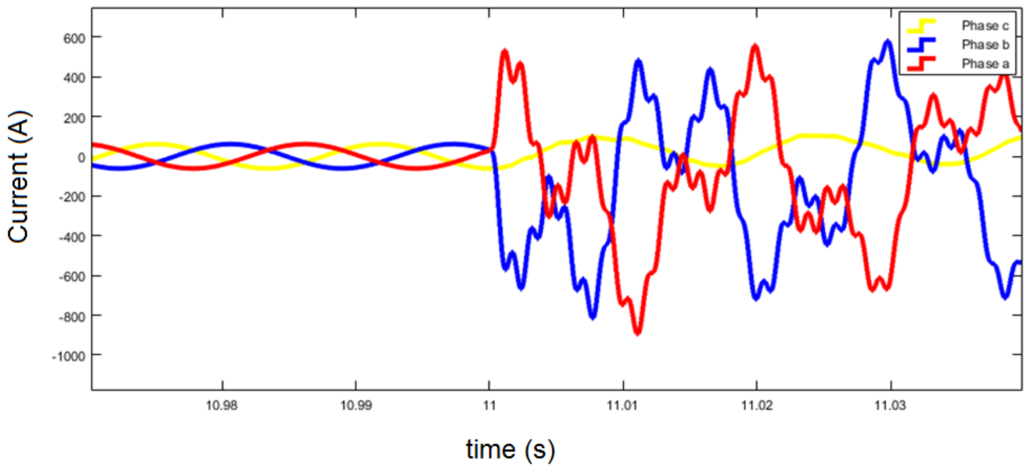

Fig 9. Current output waveforms in line T1 when line (ab) connected to the ground

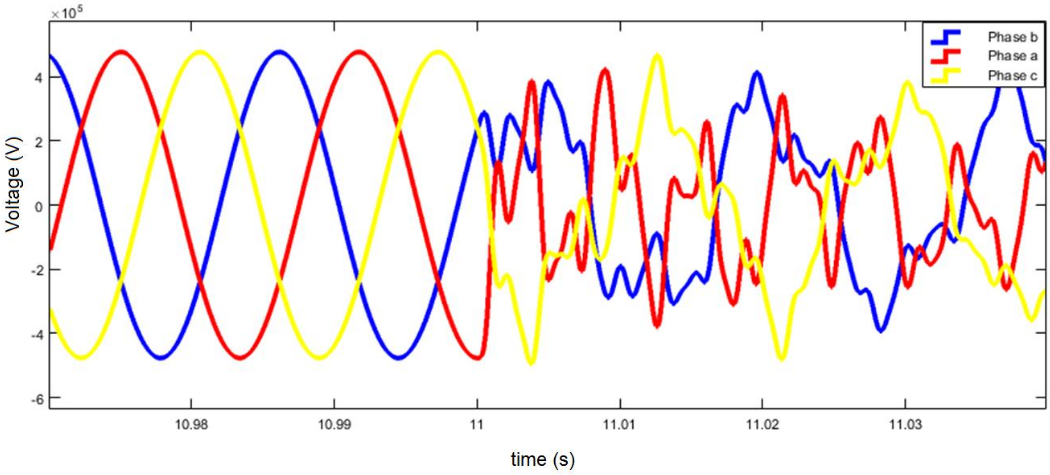

Fig 10. Voltage output waveforms in line T1 when line (ab) connected to the ground

The figure 11 shows the line a - line b fault current output wave characteristics between Bus 4 to Bus 5. It was observed that the line a line b were unstable while line c is stable at that particular point of fault occurrence at a distance 113 km between Bus 4 to Bus 5. The figure 12 shows the voltage output at T1 for phase (a)-phase (b) fault waveform characteristics between Bus 4 to Bus 5. It was observed that the line a line b were unstable less than line c at that particular point of fault occurrence at a distance 113 km between Bus 4 to Bus 5, and the entire length is 225 km. The figure 13 shows three phase fault current output wave characteristics between Bus 4 to Bus 5. It was observed that all the phases were unstable at that particular point of fault occurrence at a distance 113 km between Bus 4 to Bus 5, while the entire length of T1 is 225 km. The figure 14 shows the voltage output at T1 fault waveform characteristics between Bus 4 to Bus 5. It was observed that all phases were unstable but line c rises higher than line a and line b at that particular point of fault occurrence.

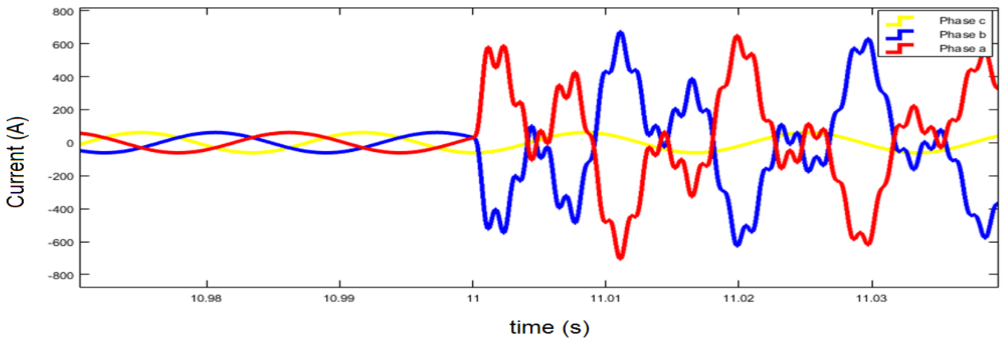

Fig 11. Current output waveforms in line T1 when phase (a) connected to phase (a)

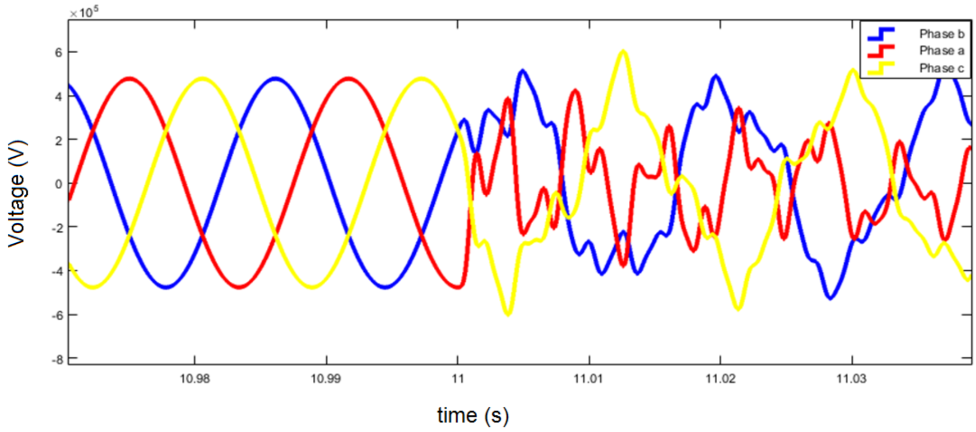

Fig 12. Voltage output waveforms in line T1 when phase (a) connected to phase (a)

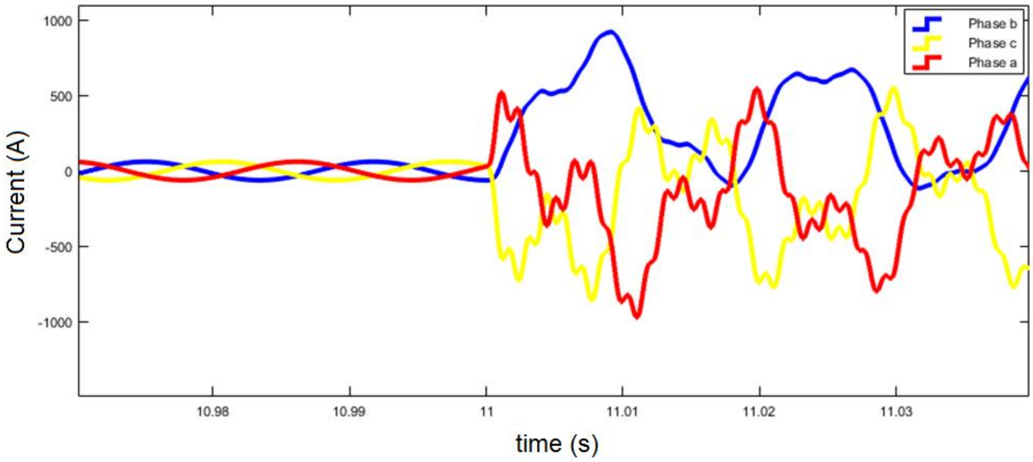

Fig 13. Current output waveforms in line T1 in three-phase fault

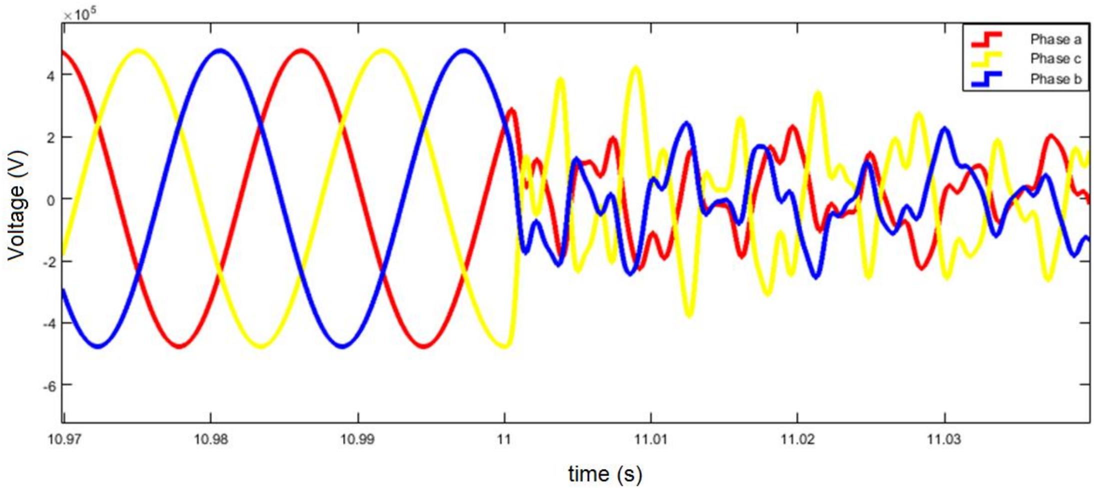

Fig 14. Voltage output waveforms in line T1 in three-phase fault

Accordingly, for all cases the simulation results have been obtained and presented in tables 2, 3, 4 and 5. From the results, in most cases the double-end techniques are more accurate and errors are lower that single-end techniques. However, close-in techniques are more accurate in compare with remote-end techniques. A comparison of the accuracy of different techniques for different fault types at different lines are presented in Figs 15 to 20. In these figures the aforementioned traveling waves techniques are supposed to be: Technique 1: single ended (close in fault), Technique 2: single ended (remote end fault), Technique 2: double ended (close end) and Technique 4: double ended (remote end). In general, the accuracy of traveling wave techniques to find the fault locations on transmission system depends on the actual distance of fault location, fault type and transmission line characteristics.

Table 2. Results of Single Ended (Close in) technique

Name of Line	Length of Line (km)	Actual Distance of Fault Location (km)	SLG Fault		LLG Fault		LL Fault		3-Phase Fault	
			Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)
T1	225	113	112.87	0.12	112.78	0.19	112.62	0.34	112.82	0.16
T2	186	93	93.21	0.23	93.10	0.11	92.69	0.33	93.26	0.28
T3	112	55	56.39	2.53	55.56	1.02	55.72	1.31	54.83	0.31
T4	60	31	30.95	0.16	31.14	0.45	30.91	0.30	31.23	0.75
T5	138	69	69.13	0.19	69.23	0.33	69.96	1.39	68.76	0.35
T6	80	40	40.46	1.15	40.37	0.92	40.40	2.00	39.13	2.17

Table 3. Results of Single end (Remote end) technique

Name of Line	Length of Line (km)	Actual Distance of Fault Location (km)	SLG Fault		LLG Fault		LL Fault		3-Phase Fault	
			Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)
T1	225	113	112.83	0.15	112.74	0.23	112.58	0.37	112.78	0.19
T2	186	93	93.18	0.19	93.07	0.08	92.66	0.37	93.23	0.25
T3	112	55	55.60	1.09	54.78	0.40	54.94	0.11	54.06	1.71
T4	60	31	31.07	0.21	31.26	0.84	31.03	0.10	31.35	1.13
T5	138	69	69.06	0.09	69.16	0.23	69.89	1.29	68.69	0.45
T6	80	40	39.53	1.18	39.44	1.39	39.00	2.49	39.01	2.47

Table 4. Results of Double Ended (Close in) technique

Name of Line	Length of Line (km)	Actual Distance of Fault Location (km)	SLG Fault		LLG Fault		LL Fault		3-Phase Fault	
			Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)
T1	225	113	113.25	0.22	113.16	0.14	113.05	0.04	113.20	0.18
T2	186	93	93.43	0.46	93.32	0.34	92.91	0.10	93.48	0.52
T3	112	55	55.79	1.44	54.97	0.06	55.13	0.23	54.25	1.37
T4	60	31	30.45	1.77	30.64	1.17	30.41	1.90	30.73	0.89
T5	138	69	69.26	0.38	69.36	0.52	70.09	1.58	68.89	0.16
T6	80	40	40.93	2.33	40.84	2.10	40.38	0.96	40.39	0.98

Table 5. Results of Double end (Remote end) technique

Name of Line	Length of Line (km)	Actual Distance of Fault Location (km)	SLG Fault		LLG Fault		LL Fault		3-Phase Fault	
			Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)	Estimated Distance of Fault Location (km)	Error (%)
T1	225	113	111.74	1.12	112.25	0.66	112.37	0.56	112.60	0.35
T2	186	93	92.56	0.47	92.45	0.59	92.04	1.03	92.61	0.42
T3	112	55	55.20	0.36	54.39	1.11	54.54	0.83	54.42	1.05
T4	60	31	30.54	1.48	30.73	0.88	30.50	1.61	30.82	0.59
T5	138	69	68.73	0.39	68.83	0.25	69.56	0.80	68.36	0.92
T6	80	40	39.06	2.35	39.46	1.35	39.54	1.15	39.75	0.63

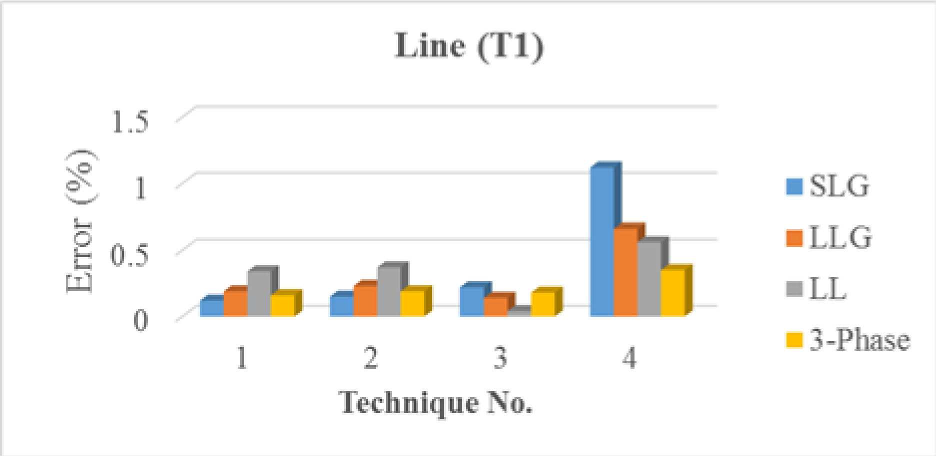

Fig 15. Comparison of the accuracy of different techniques for different fault types at line T1

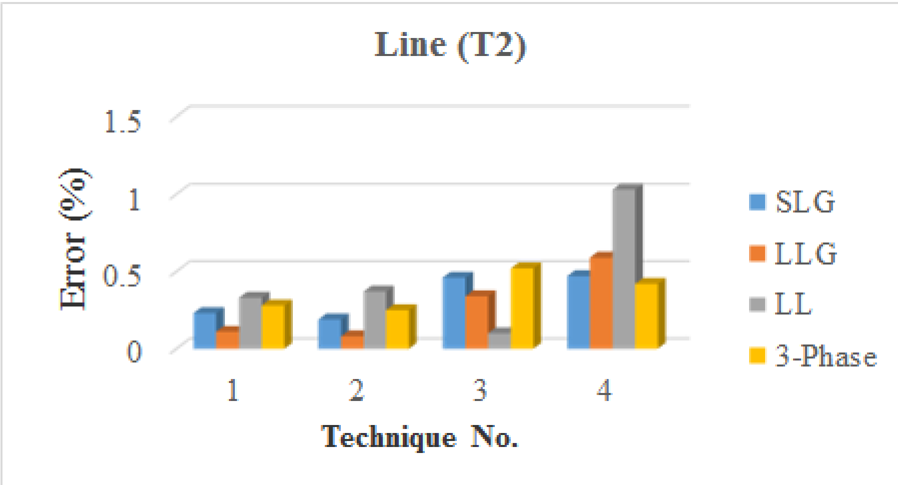

Fig 16. Comparison of the accuracy of different techniques for different fault types at line T2

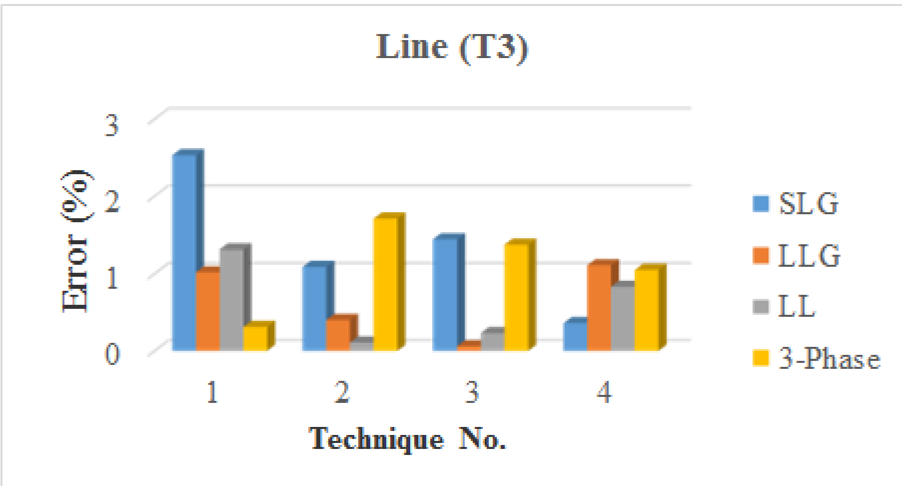

Fig 17. Comparison of the accuracy of different techniques for different fault types at line T3

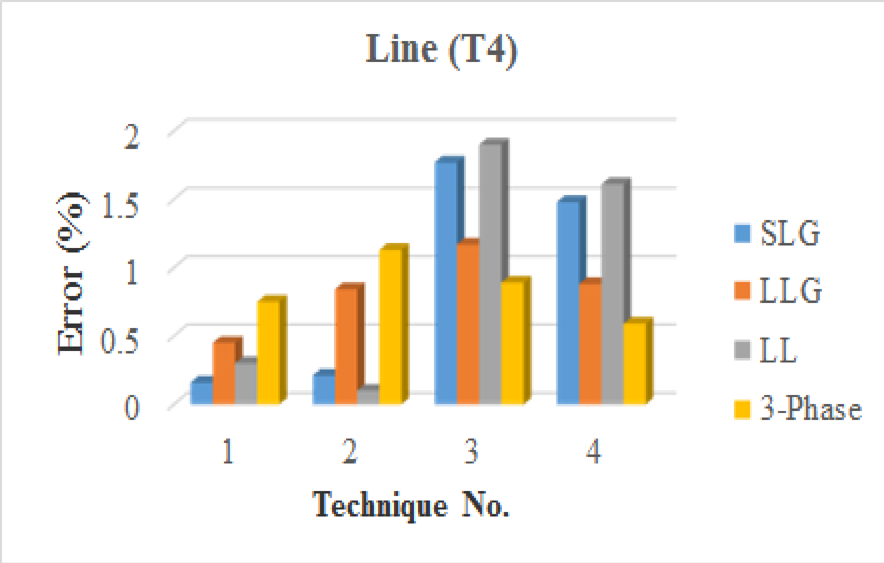

Figure 18. Comparison of the accuracy of different techniques for different fault types at line T4

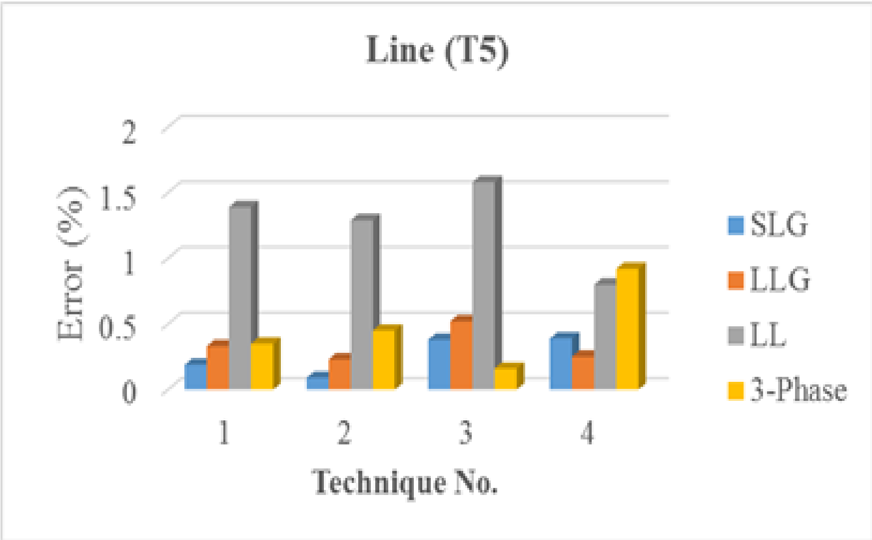

Fig 19. Comparison of the accuracy of different techniques for different fault types at line T5

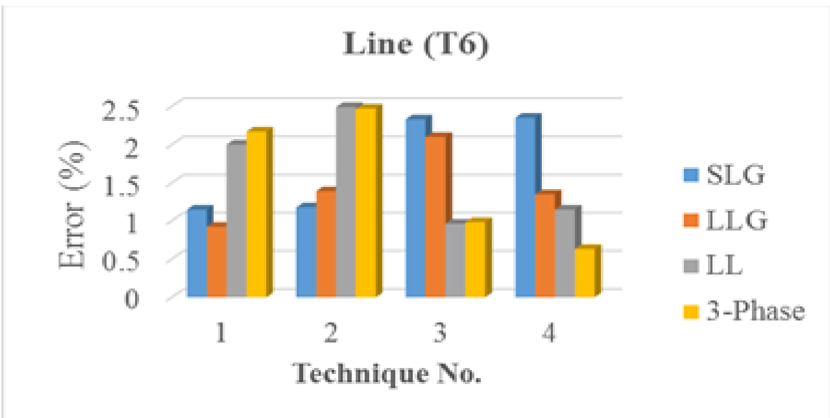

Fig 20. Comparison of the accuracy of different techniques for different fault types at line T6

V. Conclusion

This study presented a fault location estimation method by means of a traveling wave on transmission lines. A three-phase voltage and current measuring device was modelled at the sending and receiving ends of each line to capture the output waveform, and similar cases were performed for each line. A wavelet transform was used to decompose the signals to their modal components and to transform these components into a time frequency domain. Different types of faults on the transmission lines were simulated at different locations and tested on a 9-bus power system modelled on MATLAB Simulink. The travelling wave technique was found to be capable of locating faults in transmission systems. After applying various travelling wave techniques in the power system, the multi-ended techniques were found to have greater accuracy than the single-ended techniques, and the close-in techniques were found to be more accurate than the remote-end techniques.

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