A Novel Fault Classifier and Locator using One-End Current Spectrum and Minimal Synchronized Symmetrical Components for Transmission Lines

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Abstract— **Nowadays the utilisation of electrical power is increasing exponentially in the present modern living style. In order to meet the consumer load demand, expansion in the power system network is essential. To provide continuous and reliable power supply, a smart power system needs to identify any abnormal conditions on overhead transmission lines such as line faults in minimum time. The fault detection, fault classification and its location on the overhead transmission system is still a major area of research for the secure and reliable operation of the power system. In this paper, minimal synchronised symmetrical components based fault locator for overhead transmission lines is proposed. Prior to fault location, classification of the fault is also given importance by utilising one end current data. The overhead transmission line network is modelled in PSCAD software environment. Various simulations have been performed by taking 100km and 300km long line cases. The simulated data is processed through the proposed fault classification and location algorithms developed in MATLAB environment. The simulation results enumerate the accuracy of the proposed algorithm based on the error percentage.**

Keywords— Electrical power; Fault Classification; Fault Location; Overhead Transmission lines; Synchronization; Symmetrical components.

I. Introduction

Modern power system network is designed to meet the consumer load demand with safety and reliability. The power system operation and control engineers who are working to transmit the efficient power to the respective consumers, concentrates on various optimal solutions to keep the grid smart enough for detecting, classifying and mitigating the fault as soon as possible [1-3]. It is evident that fault should be identified within less time, the circuit breaker should operate in the transient zone and fault should be cleared within a short span of time. However, in this paper, the emphasis is specially made on fault classification and location which are equally important to clear the fault once it occurs.

In the past literature, many researchers have concentrated on either fault classification or fault location techniques. In the previous literature of fault classification, many people studied on wavelet transform techniques or knowledge-based techniques, especially fuzzy logic and artificial neural network (ANN) based techniques. Though the wavelet transform is effective in generating transient signals it may not be sufficient to complete the whole process of fault classification and location. The artificial neural network techniques suffer from the requirement of large training data. So, many researchers currently utilise the combinations of both wavelet transform and fuzzy logic or wavelet transform and ANN [4-5]. However, these methods are hard to implement practically. If the fault can't be identified quickly, it will produce many ill-effects such as line outages during the period of peak load leading to severe economic losses. There may be a chance for the entire grid to collapse which is called as blackout and the reliability of the system would be affected. Hence all these complex situations made the researchers focus on fault location studies and fault location algorithms [6-17]. The algorithm presented in [6] was simple but the accuracy is less. Girgis,G. Hart and Peterson proposed a fault location technique for two and multiple terminal lines based on voltage and current phasors [7]. J.A. Jiang *et al.* proposed a technique utilising phasor measurement units (PMUs) in [8]. Gopalakrishnan *et al.* proposed a different fault location technique that requires synchronised data sampling from both ends of the line [9]. Morcos & Tawfik proposed fault location technique based on travelling waves [10]. All the above two-end fault location algorithms must have knowledge of online parameters and line length. Y. Liao proposed a method without requiring line parameters but this method was unable to identify the symmetrical faults correctly [11]. Liu C.W.et *al.* proposed a fault location algorithm for multi-section compound transmission lines using synchronised phasor measurements [12]. M.Korkali *et al.* proposed a fault location algorithm using synchronised voltage measurements [13]. I.Niazy and J. Sadeh proposed a new fault location algorithm by taking fault clearing transients [14]. H.Livani & C.Y.Evrenosoglu [15] proposed a method based on wavelets which require a higher sampling frequency. In[16] the previous fault location techniques using synchronised measurements are presented. V.Terziza, Z.M.Radojevic, G.Peterson [17] proposed a fault location algorithm for short lines. However, validation of the algorithm for long lines could also be carried out and the algorithm can also be nurtured well for classification of the fault prior to fault location.

In this paper, novel fault classification and location algorithms have been presented by using the one end current data and minimal synchronised symmetrical components

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from both ends respectively. The effectiveness of the proposed algorithms is demonstrated using simulation studies with 100km and 300km long lines.

II. Network Model

A. Network Configuration:

The overhead transmission line network configuration for evaluating the proposed algorithms is shown in Fig. 1(a). Here two areas are considered which is denoted as A and B, where the fault is occurred at a distance *l,* in a transmission line of total line length *D.* In Fig. 1(b). S and R represent the sending & receiving end sides of the transmission line. E and I denote the corresponding voltage and current of the phases a, b and c respectively.

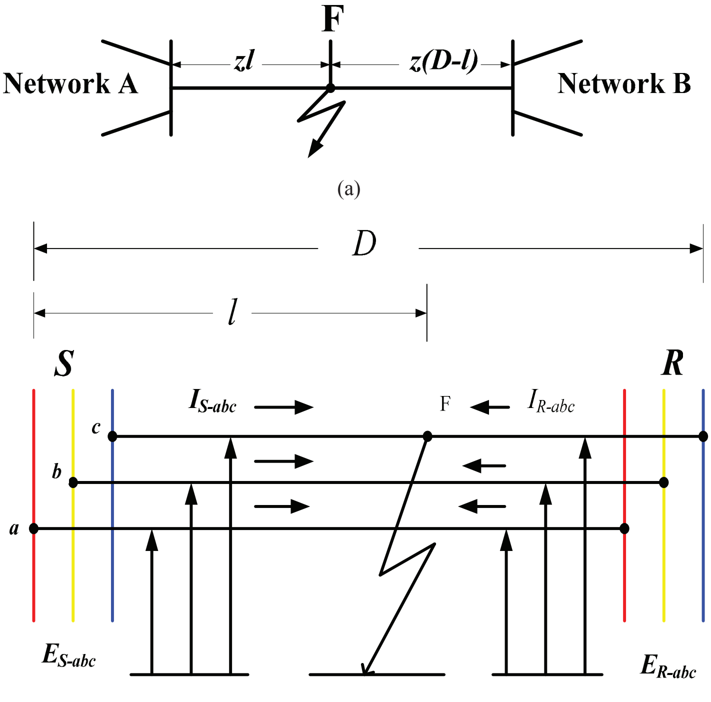


Fig. 1. (a) Single line representation of the faulted line (b). Three phase representation of the faulted line

The source parameters of the two areas are presented in Table. I. The distributed overhead transmission line model parameters are tabulated in Table. II.

TABLE I. Parameters of Two areas

Parameter	Sending End	Receiving End
RMS Voltage (kV)	416	400
Phase angle,(ø°)	0	-20
Frequency (Hz)	50	50
Resistance, R_L(Ω)	1.0185	0.6366
Inductance, L(H)	0.0509	0.0318
Resistance, R_o(Ω)	2.0371	1.2732
Inductance, L_o(H)	0.1018	0.0636

Here the simulations are performed for 100 km and 300 km long lines. Though the proposed fault location algorithm is independent of line length, electrical line parameters were solved for 100 km long line by using a tower configuration shown in Appendix.

TABLE II. Line Parameters

Parameter	Positive & Negative sequence	Zero sequence
Resistance(Ω/km)	0.03206	0.284
Inductance(mH/km)	1.2857	4.79
Capacitance(nF/km)	11.468	6.859

III. Proposed Fault classification and location Algorithm

The detailed flowchart of the proposed novel algorithm for classification and location of the fault is shown in Fig.2. Initially, the sending, receiving end voltages and currents are extracted using PSCAD simulations.

The higher order frequency components in currents are eliminated by using Butterworth filter and the required sequence components of currents and voltages were estimated by using FFT. Later the fundamental sequence components were utilised in estimating the fault location. Prior to fault location, fault classification was also done using the sending end current data, the RMS values of currents prior and during the fault is calculated for one cycle. The current difference during and prior to the fault are calculated. If the difference is less than 0.3 then the line is healthy and there is no fault in the transmission line. When all phase currents difference during and prior to the fault is greater than 0.3 then the fault is symmetrical. When any one phase current difference during and prior to the fault is greater than 0.3 then the fault is unsymmetrical. When the fault is unsymmetrical obtain the values of zero sequence components of sending end RMS values of currents over a window of one cycle from the fault instant. If the obtained RMS value is greater than 0.0001 then the fault is unsymmetrical and grounded, else the fault is unsymmetrical ungrounded.

The location of the unsymmetrical fault is calculated by using (6) and the symmetrical fault location is obtained by using (11).

IV. Derivation of Proposed Fault Location Algorithm

The proposed algorithm uses the one-end current spectrum and minimal synchronised symmetrical components. since in this algorithm the fault location was estimated by using positive and negative sequence components for asymmetrical fault and positive sequence only for symmetrical fault location estimation with proper synchronization assuming that the data from the source and receiving ends are coming at a proper time stamp with no communication delay, hence the term "*minimal synchronized symmetrical components*" has been used.

A. Unsymmetrical Fault Case:

An unsymmetrical fault case is considered here, where the fault has occurred at a point F on the transmission line as shown in Fig.1. The equivalent circuits of positive sequence and negative sequence components are shown in the below Fig.3. and Fig.4. Here to reduce the computational burden the fault resistance is ignored.

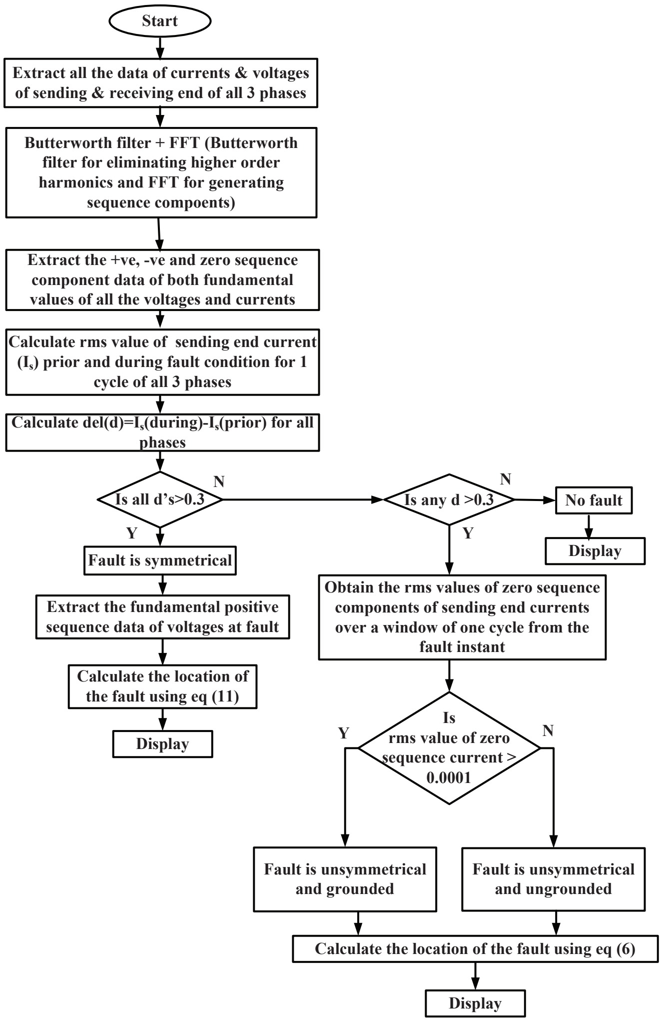


Fig. 2.Flow Chart of the proposed algorithm

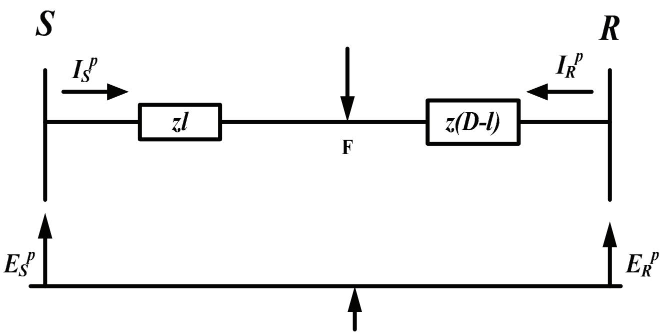


Fig. 3. Equivalent circuit of the faulted line with positive sequence components

From the above Fig. 3 and Fig. 4. the following equations are derived where p & n denotes the positive & negative sequence components of the sending and receiving end.

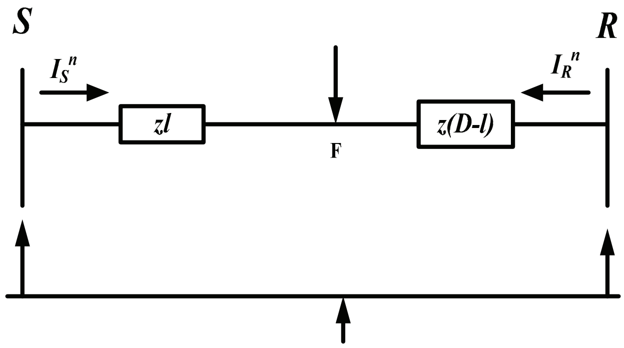


Fig. 4. Equivalent circuit of the faulted line with negative sequence components

$$E_S^p - zlI_S^p = E_R^p - z(D-l)I_R^p \quad (1)$$

$$E_S^n - zlI_S^n = E_R^n - z(D-l)I_R^n \quad (2)$$

Solving for *zl* & *z(D-l)*

$$zl = \frac{(E_S^p - E_R^p)I_R^n - (E_S^n - E_R^n)I_R^p}{I_S^p I_R^n - I_S^n I_R^p} \quad (3)$$

$$z(D-l) = \frac{(E_S^p - E_R^p)I_S^n - (E_S^n - E_R^n)I_S^p}{I_S^p I_R^n - I_S^n I_R^p} \quad (4)$$

By solving the distance to fault *l*, expressed as a percentage of total line length, *D,*

$$\%l = \frac{l}{D} * 100 \quad (5)$$

From (3) & (4),

$$\%l = \frac{(E_S^p - E_R^p)I_R^n - (E_S^n - E_R^n)I_R^p}{(E_S^p - E_R^p)(I_S^n + I_R^n) - (E_S^n - E_R^n)(I_S^p + I_R^p)} * 100 \quad (6)$$

B. Symmetrical Fault Case:

Here for the derivation of fault location, only positive sequence components network is sufficient since there would be no negative and zero sequence components if the fault is symmetrical. Hence, here the fault resistance is considered for obtaining the accurate results as shown in Fig. 5. F represents the fault point. The equations for symmetrical fault case are as follows:

$$E_S^p - zlI_S^p - E_F^p = 0 \quad (7)$$

$$E_S^p - z(D-l)I_S^p - E_F^p = 0 \quad (8)$$

Solving for *zl* & *z(D-l)*

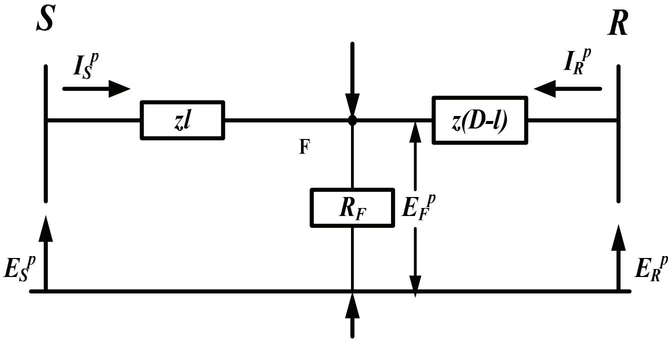


Fig. 5. Positive sequence equivalent circuit for symmetrical faults

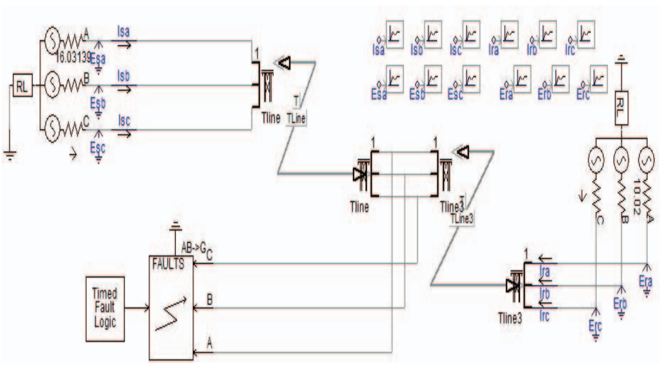
$$zl = \frac{E_S^p - E_F^p}{I_S^p} \tag{9}$$

$$z(D-l) = \frac{E_R^p - E_F^p}{I_R^p} \tag{10}$$

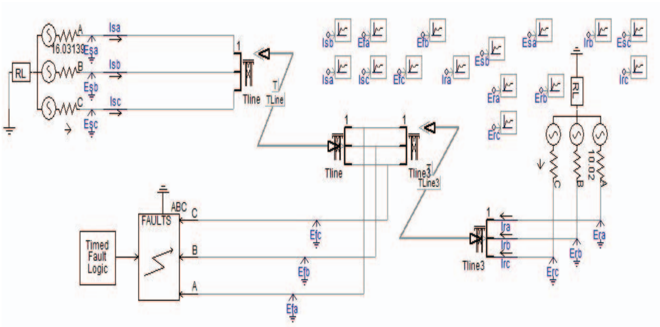
From (9) & (10)

$$\%l = \frac{(E_S^p - E_F^p)I_R^p}{(E_S^p - E_F^p)I_R^p + (E_R^p - E_F^p)I_S^p} * 100 \tag{11}$$

Hence from the above derivations of this algorithm, fault location can be identified without prior knowledge of line length and line parameters. Also for symmetrical faults, the only positive sequence equivalent circuit is utilised.



(a)



(b)

Fig. 6.(a) Simulation diagram in PSCAD for Unsymmetrical fault (b) Simulation diagram in PSCAD for symmetrical fault

V. Results And Discussion

Various simulation studies are performed in PSCAD [18] by taking 100 km & 300km line length and implemented the proposed procedure shown in above flow chart in Fig.2. The three phase currents and voltages are captured with a sampling frequency of 6.4 kHz and are given as input to the proposed algorithms.

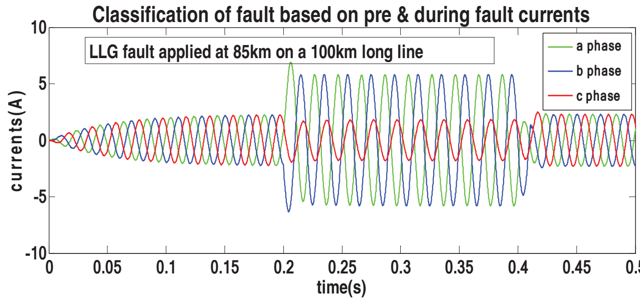


Fig 7. Currents of individual phases during the LLG fault

From the Fig.7. It is clear that the variations in amplitudes of a and b phase currents are high at the instant of fault. Here, 4th order Butterworth filter is used to filter out the unwanted high-frequency component. The Butterworth filter has better performance when compared to other anti-aliasing filters as shown in Fig.8.

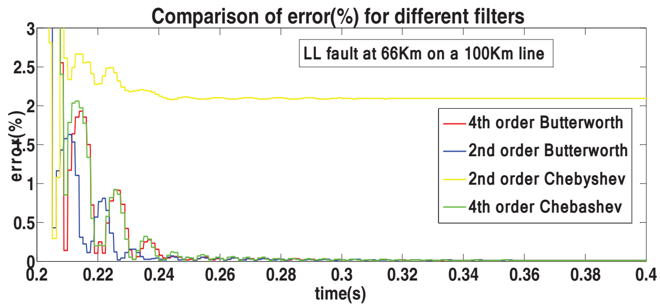


Fig. 8.Comparison between different filters.

Hence from this, taking the RMS value for 1 full cycle prior to a fault & during the fault, the fault has been classified. But in real time, to detect it as LLG fault, the utilisation of zero-sequence component should be taken to differentiate from LL. Fig. 9. indicates the presence of zero-sequence component for the LLG fault

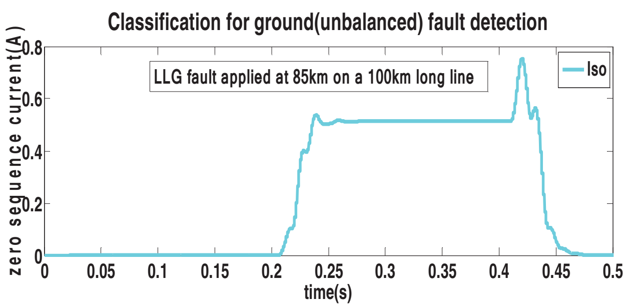


Fig. 9. Differentiating between LL & LLG through zero sequence components.

TABLE III. % ERRORS AT VARIOUS FAULT LOCATIONS FOR A 100KM LINE

Fault type	Error(%) at various locations(in km)				
	15	*24*	*36*	*64*	*85*
LG	0.429	0.299	0.109	0.01	0.17
LL	0.27	0.147	0.138	0.03	0.15
LLG	0.23	0.109	0.201	0.06	0.205
LLL	0.174	0.221	0.196	0.043	0.008
LLLG	0.211	0.312	0.401	0.334	0.095

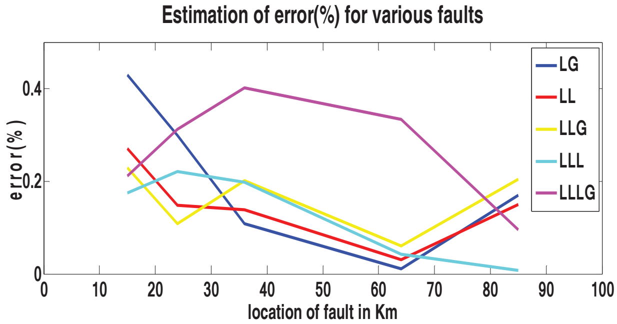


Fig. 10. Error(%) and fault location graph for 100km line

Various types of faults have been applied over 100 km long line at various locations and estimated the percentage error. From the Table III, the results are superior based on error percentage when compared to previous fault location algorithms for a higher fault resistance of 100 ohms. Fig.10. shows the variation of percentage error with respect to the length of the overhead transmission line.

TABLE IV. % ERRORS AT VARIOUS LOCATIONS FOR A 300KM LINE

Fault type	Error(%) at various locations(in km)				
	20	*30*	*60*	*100*	
LG	1.406	1.40	0.83	0.35	
LL	1.52	1.26	0.84	0.43	
LLG	1.52	1.22	0.96	0.45	
LLL	0.75	1.06	1.12	0.63	
Fault type	**Error(%) at various locations(in km)**				
	160	*210*	*270*	*280*	*290*
LG	0.07	0.23	0.588	0.78	0.63
LL	0.03	0.034	0.583	0.76	0.65
LLG	0.39	0.04	0.64	0.78	0.65
LLL	0.09	0.172	0.223	0.19	1.36

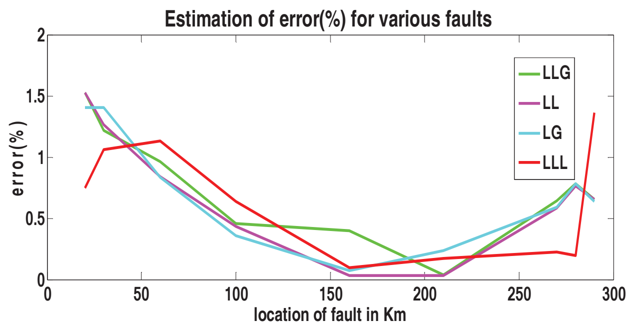


Fig. 11. Error(%) and fault location graph for 300km line

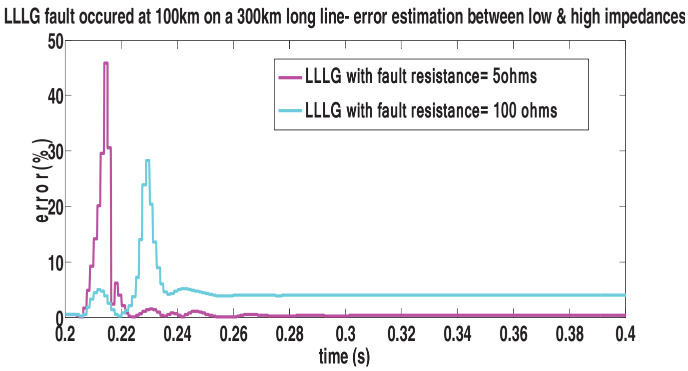


Fig. 12. Error(%) with high & low fault resistances for 300km line

The simulation results of the 300km overhead transmission line for various faults by considering fault resistance is depicted in Fig.11. and Fig. 12.

TABLE V. % ERROR WITH DIFFERENT FAULTS & RESISTANCES FOR 100KM LINE

Fault type	Fault Resistance	Actual value	Estimated value	Error(%)
A-G	10	0.56	0.5598	0.02
AB-G	0.1	0.45	0.450024	0.0024
ABC	10	0.4	0.3997	0.03
B-G	5	0.85	0.85158	0.158
A-G	5	0.64	0.63996	0.004
AB	5	0.64	0.63994	0.006
AB-G	5	0.64	0.6399	0.01
ABC-G	1	0.5	0.499	0.01
ABC	1	0.2	0.1996	0.04
ABC-G	1	0.2	0.19958	0.042
AB	0.1	0.15	0.15309	0.309

The above table proves the superiority of the proposed algorithm for fault location with lower values of fault resistances.

VI. CONCLUSION

Novel algorithms are proposed for identifying the type of fault and its location on an overhead transmission line. For classification, one end current data is used. To identify the location, a minimal synchronised symmetrical components data is utilised. From the results, it is observed that the estimated % error is less than 1.5%. Hence the proposed algorithms are classifying and locating the fault on an overhead transmission line effectively.

APPENDIX

The tower configuration used in this paper for fault classification and location is shown in below Fig.13.

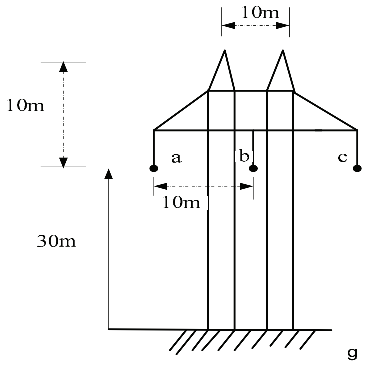


Fig. 13. Tower configuration

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