DETECTION AND LOCALIZATION OF FAULT IN AN ELECTRICAL POWER TRANSMISSION LINE USING SUB-TRANSIENT CURRENT MEASUREMENT AND WAVELENGTH CALCULATION METHOD

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Abstract: *This paper proposes two methods of fault assessment in an electrical power transmission line based on sub-transient current measurement and wavelength calculation method. Accurate localization and quick detection are the two most important parts of fault analysis of electric power transmission line. The fault location can be accurately or precisely evaluated by taking the vantage of current that flows immediately after the occurrence of fault. The fault curve is drawn from sub-transient currents for faults at different locations in the transmission line which acts as a characteristic fault curve for the transmission line. In addition to the former, by decently selecting the sampling time of the signal, fault location can be exactly localized by observing the first bursting point. In this study a 1000km, 230kV, 50Hz electrical power transmission line model was used and simulations were carried out in MATLAB/SIMULINK environment.*

Key words: *Fault Detection, Fault location, Sub-transient current, Transmission line, Wavelength calculation.*

1. Introduction

Fault detection and localization are very important from the view point of improving system availability and reliability. The diagnosis of faulty region is necessary in order to maintain continuity of power supply to the customers with minimum interruption. This is absolutely essential for reliable operation of power equipment and satisfaction of the customers. In the earlier stages there were many methods used to perform this operation and they have their own advantages and limitations. Travelling wave methods [1-5] and line impedance based methods [6-9] were popular for locating a fault. When faults occur close to the bus, travelling wave schemes have some difficulties. Accuracy of impedance measurement based methods are not good for precise fault location as error can be as high as 10% of line length. Recently, high frequency components rather than traditional methods have been used [10]. Fourier transform based analysis is used for extracting information about fundamental frequency components. But Fourier transform has the limitation that it cannot be used for required accuracy in certain cases. S-Transform for fault locating is discussed in [11]. Nowadays, Discrete Wavelet Transform (DWT) is popular and used for estimating fault locations with desired accuracy [12-20]. In [21], DWT is employed with travelling wave to find the fault location for overhead lines combined with underground cables, sparse wide-area measurement based fault location method for untransposed and transposed transmission lines is discussed in [22]. In DWT method for desired accuracy, it needs more complex calculation which is very much difficult to design and implement in the hardware or software. In this paper, very simple and easy concepts and methods for localizing a fault are shown with very good accuracy which eliminates tedious calculations and complexities. Fault detection is carried out by paying close attention at the wave shapes as anomaly signal is produced due to fault in the power system network.

This paper depicts the current measurement and sampling time based fault locator algorithm. The performance of the developed methodology is evaluated by modeling a 1000km, 230kV, 50Hz electrical power transmission line using the MATLAB/SIMULINK software.

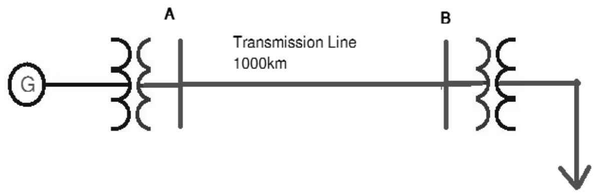

Fig. 1. Single line diagram of the simulated system.

This paper describes two methods to perform the process of fault detection and localization. The proposed techniques are based on the current measuring that flows immediately after the occurrence of a fault and its wavelength calculation method. Single line diagram of the simulated system is given in Fig. 1.

A three phase generator is used to generate electrical energy to supply power to the load centre through transformer and transmission line.

2. Sub-Transient Current Measurement Method

This method is actually works on the percept of measuring impedance from the terminal to the fault point. As terminal voltage is almost fixed, then fault current depends upon the impedance. This fault current is employed as a fault locating element.

Faults can involve any phase(s). A new fault type indentification technique is discussed in [23]. In developing the fault location procedure using proposed sub-transient current measurement method, an assumption is made that the fault is symmetrical.This procedure consists of three stages,

- Detection of anomaly signal.
- Measure the maximum single phase current.
- Match this current with the fault curve and measure the distance from it.

A model of 1000km transmission line length is simulated by MATLAB/SIMULINK software to perform this method to investigate the perfomance. At regular condition i.e. when there is no distubance in the transmission line, the current level is within the tolerable limit. A fault curve is drawn by taking the sub-transient current for fault at the different points. This fault curve is used to locate the fault location. The complete SIMULINK model for detecting as well as locating fault using sub-transient current measurement method is shown in Fig. 2.

While building the SIMULINK model, a three phase source, bus bar, three phase measurement, transformer, transmission line and three phase series RLC load blocks are used.

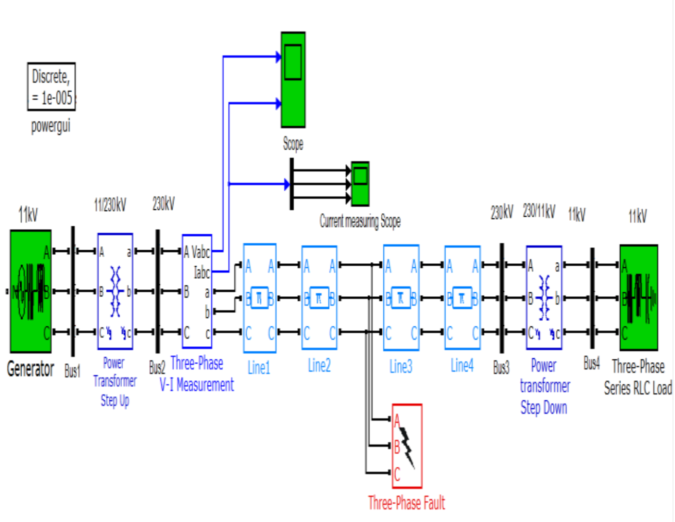

Fig. 2. Complete SIMULINK model for detection and localization of a symmetrical fault using sub-transient current measurement.

3. Wavelength Calculation Method

This method delineates the process of locating fault in a very simple manner. The indispensible part of this method is sampling of current wave shape in such a way that it represents the actual travelling of electrical signal which is indicated by plotting the current wave in space domain.

It is known that the velocity of the signal through pure conductor is almost 98% of the velocity of light. In MATLAB/SIMULINK the velocity of signal used is 2.9415×10^{8} ms^{-1} which is 98% of the velocity of the light.

For the 50Hz signal, wavelength of the signal is 5883km, i.e. it passes 5883km in a complete full cycle. This concept is used for measuring a fault. If a fault occurs in the transmission line it respond instantly at the point of fault but take a time to respond at the sending end measuring unit. Since the measuring instrument is connected at the sending ends which is far away from the fault position. This respond time depends upon the location of fault. If fault occurs at the far end from the sending end, the respond time will be higher and vice versa. Although this responding time is very little in value but this little time variation is considered for measuring a fault.

In the MATLAB/SIMULINK this feature is used in another way. The sampling time in the scope is set in such a way that the current or voltage wave shape travel 5883km in a complete full cycle of revolution. For this consequence sampling rate will be 3.4×10^{-6}. The following MATLAB/SIMULINK model indicates the typical power system network with complete set up for detecting fault and measuring fault location using the method of wavelength measurement. The complete SIMULINK model for locating a fault using wavelength calculation measurement method is shown in Fig. 3.

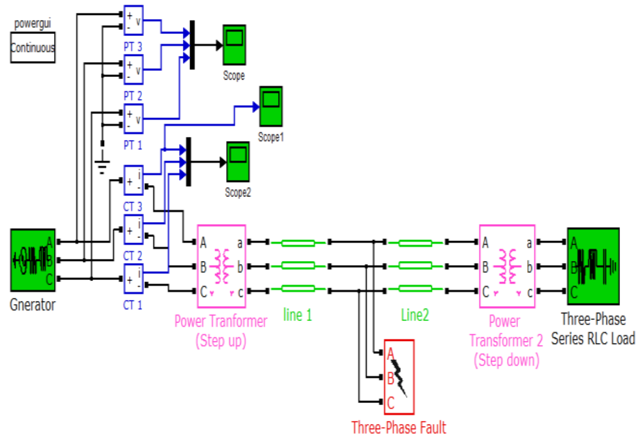

Fig. 3. Complete SIMULINK model for detection and localization of a fault by wavelength measurement.

Here also while building the complete SIMULINK model, a three phase source, current transformer, potential transformer, power transformer, transmission line and three phase series RLC load are used.

4. Simulation Results

The system studied is composed of 230kV transmission line with total length of the system is 1000km which connected to three phase series RLC load. The transmission line is simulated with distributed parameter line model using MATLAB/SIMULINK as shown in Fig. 2 and Fig. 3.

4.1. Sub-Transient Current Measurement Method

At normal condition when continuous power flows from the sending end to the receiving end, their corresponding three phase voltage and current wave shapes are shown in Fig. 4 and Fig. 5. From these figures it is observed that voltage and current wave shapes are in balanced condition which indicates the stableness of the power system.

Since line current wave shapes are used to analyze, hence for the simplicity they are shown separately for each phase in Fig. 5.

If a three phase symmetrical fault occurs in the transmission line, the disturbances or abnormalities occur in the transmission line is observed by the scope. The disturbed signal indicates the fault in the power system. The sending end three phase voltage and current wave shapes after fault are shown in Fig.6.

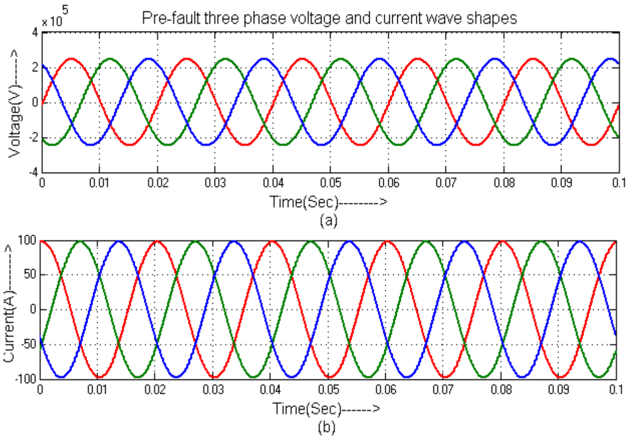

Fig. 4. Pre-fault wave shapes at sending end.

(a) Voltage. (b) Current.

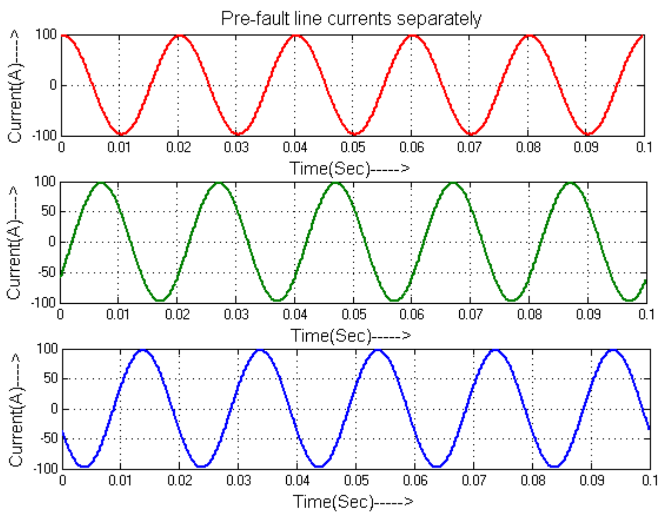

Fig. 5. Each phase pre-fault current wave shapes at sending end.

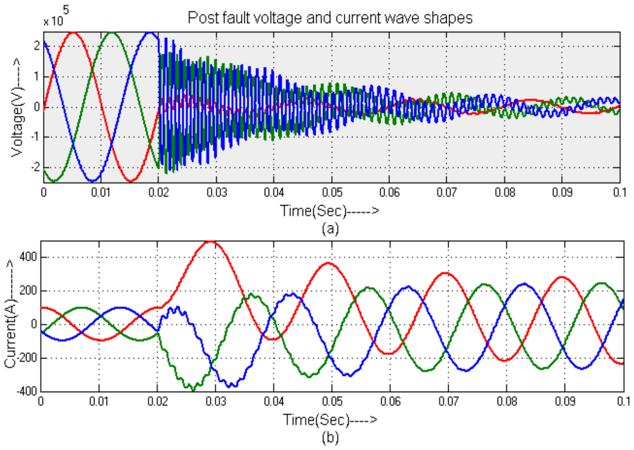

Fig. 6. Post fault wave shapes at sending end.

(a) Voltage. (b) Current.

Each phase currents are shown separately in Fig.7. The maximum current that occurs in any phase of the transmission line is recorded and compared with the fault curve to attain the fault location.

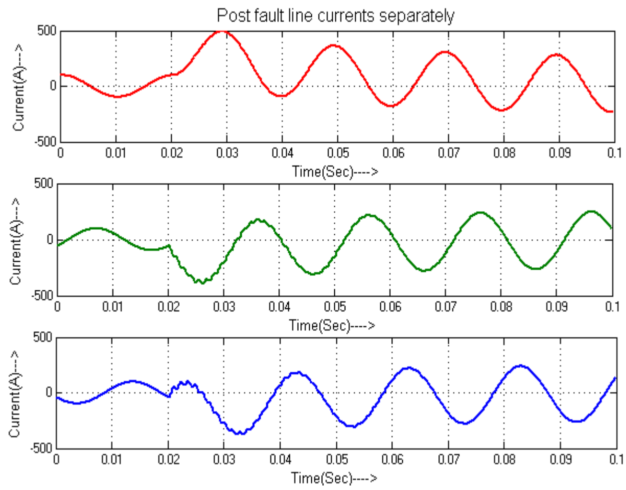

Fig. 7. Each phase post fault current wave shapes at sending end.

The current flowing immediately after the occurrence of a fault and that flowing few a cycles later differ considerably [24]. Fault curve is obtained by taking the highest peak of the sub-transient current for the fault at the different positions. At every point of fault the corresponding sub-transient current is recorded. The fault curve is drawn from that data. This fault curve will act as a characteristic curve for the transmission line. Since the fault is symmetrical, the phasor summation of three phase current is zero at any instant. The fault curve is shown in Fig. 8.

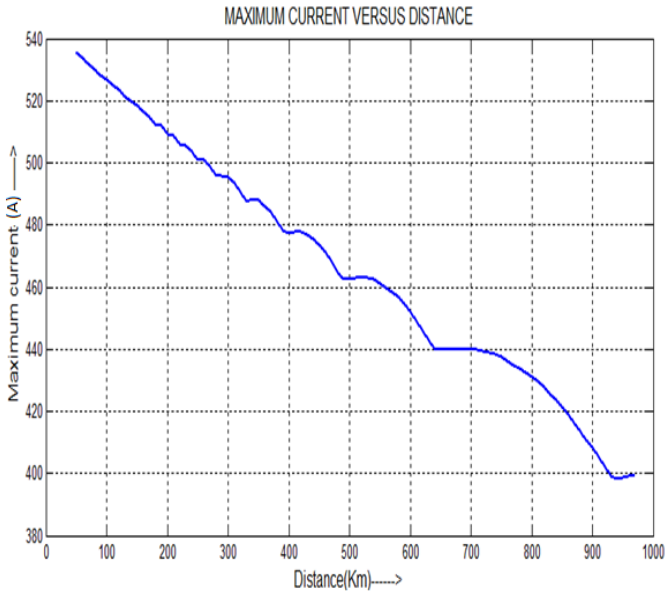

Fig. 8. Maximum current versus distance curve (Fault Curve).

From the fault curve it is encountered that initially it follows a straight line but with increasing of the distance it follows rising undulate.

Let us now consider a situation that a three phase symmetrical fault occurs at a distance 300km from the sending end. The wave shapes of voltage and current and their process of measuring fault location is described sequentially. The post fault line current wave shape is shown in Fig. 9. From the figure maximum current is recorded and compared with the fault curve shown in Fig. 10.

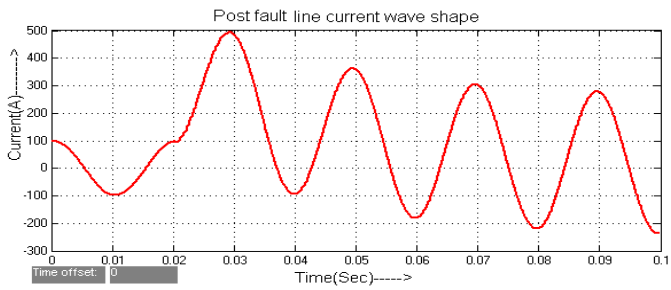

Fig. 9. Post fault line current wave shape.

If the post fault line current is plotted in space domain with the fault curve, it is seen that the sub-transient current cuts the fault curve at 304.8982km.

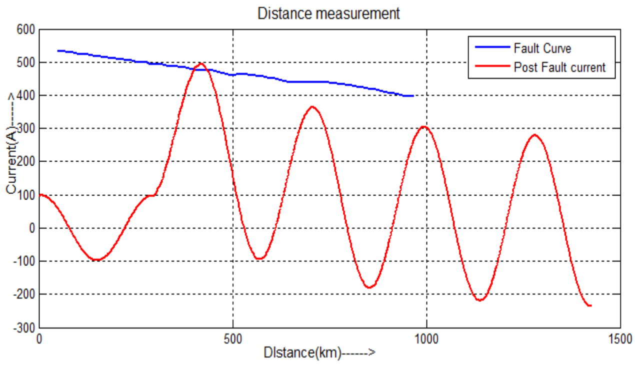

Fig. 10. Distance measurement from fault curve.

The measured distance is 304.8982km.

$$\text{Percentage of error}(\%) = \frac{300 - 304.8982}{300} \times 100$$

= -1.63%.

Table 1. shows the results for symmetrical fault at different locations in the transmission line.

Table 1.
Fault Location Results for Fault at Different Points

SL No.	Actual Distance(km)	Measured Distance(km)	Error(%)
1	100	100.2155	-0.22
2	200	200	0
3	300	304.8982	-1.63
4	400	385	3.75
5	500	484	3.2
6	600	600	0
7	700	720	-2.86

4.2. Wavelength Calculation Method

At normal condition, current wave shapes in time domain and space domain are shown in Fig. 11-Fig. 14.

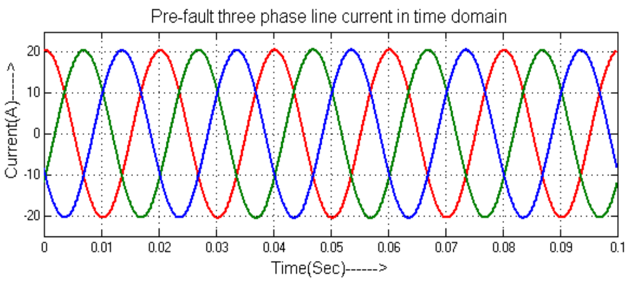

Fig. 11. Pre-fault three phase line current in time domain.

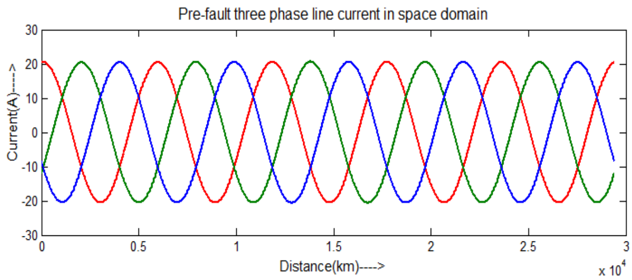

Fig. 12. Pre-fault three phase line current in space domain.

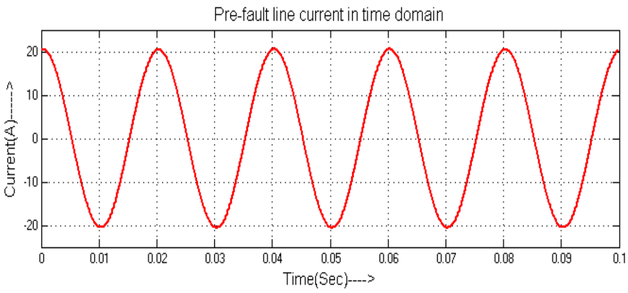

Fig. 13. Pre-fault single phase line current in time domain.

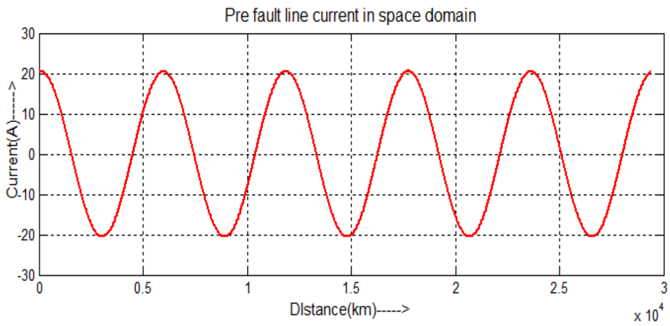

Fig. 14. Pre-fault single phase line current in space domain.

It is seen from the above figures that, 20ms in time domain is equal to the 5883km in space domain. For the simplicity of the calculation and graphical representation only five cycles are shown.

If a fault occurs in the transmission line the corresponding first disturbing point is observed at the scope. When the input current wave shape is plotted in space domain the disturbing point indicate the fault point. For simplicity of calculations the fault is considered at time 20ms. As it is known current wave travels 5883km in 20ms, while measuring this faulty point, this 5883km is subtracted from the disturbing point because time of fault is 20ms. After subtracting we get the required faulty point. The following figures show the different wave shapes of current in both time domain and space domain at faulty condition.

Let us now consider the situation that a three phase fault occurs in a transmission line at a distance 500km from the sending end. The corresponding three phase line current in time domain and space domain are shown in Fig. 15 and Fig.16 respectively.

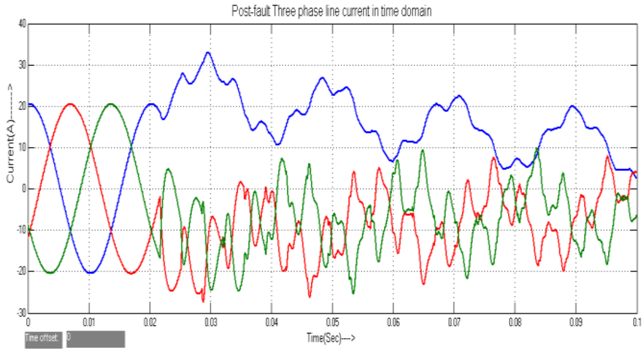

Fig. 15. Post fault three phase line current wave shape in time domain.

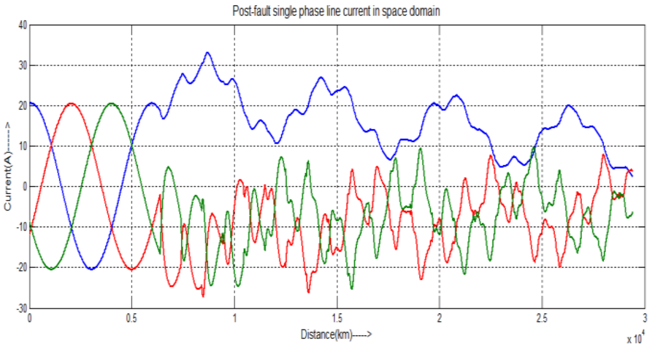

Fig. 16. Post fault three phase line current wave shape in space domain.

While measuring the distance only a single phase line current wave shape is used. Fig .17 and Fig .18 show the single phase line current in time domain and space domain respectively.

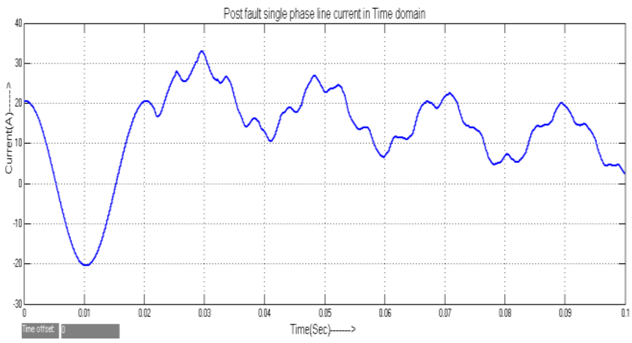

Fig. 17. Post fault single phase line current in time domain.

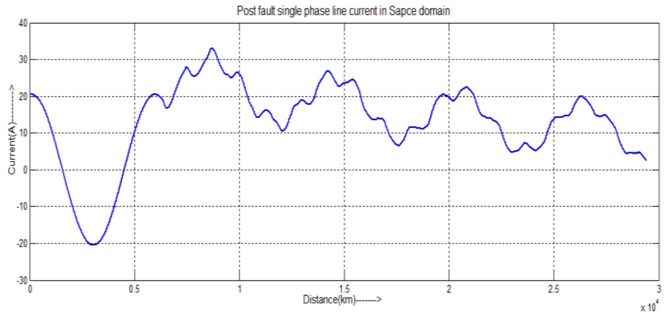

Fig. 18. Post-fault single phase line current in space domain.

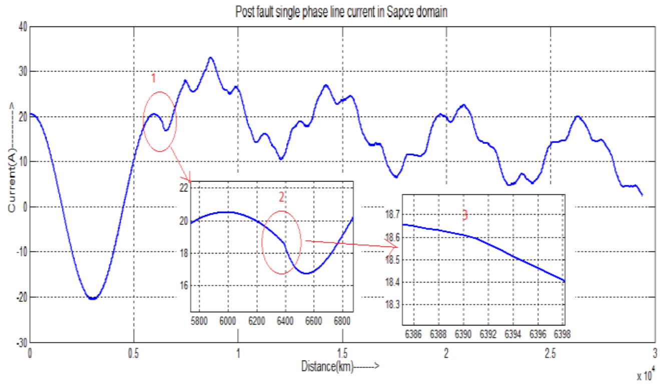

Fig. 19. Fault measurement from single phase line current curve in space domain.

From the post fault line current curve in space domain, fault location can be measured. For the simplicity a three phase fault is considered at 500km and the time of fault is 20ms. During the faulty condition, those disturbed wave shapes obtained from the Fig. 15- Fig. 18 are observed very closely.

While magnifying the disturbing point and taking a close look at the disturbing point, it is seen from the Fig. 19 that the fault occurs at the point 6391km. The points 1, 2, 3 in that figure indicates the magnifying procedure.

As the fault occurs at 20ms (space domain 5883km) and disturbed observed at 6391km, the fault position on the transmission line is = 6391-5883 = 508km.

Percentage of error (%) = $\frac{500-508}{500}$ ×100= -1.6%.

Table 2. shows the results for different types of fault those occur in the transmission line at a distance of 300km from the sending end.

Table 2.
Fault Location Results for Different Types of Fault

SL No.	Type of fault	Actual Distance (km)	Measured Distance (km)	Error (%)
1	Single line to ground fault (L-g)	300	305	-1.67
2	Double line fault (L-L)	300	305	-1.67
3	Double line to ground fault (L-L-g)	300	305	-1.67
4	Symmetrical three phase to ground fault (L-L-L-g)	300	304	-1.33

Table 3. shows the results for symmetrical fault at different locations in the transmission line.

Table 3.
Fault Location Results for Symmetrical Fault at Different Points

SL No.	Actual Distance(km)	Measured Distance(km)	Error(%)
1	100	100.5	-0.5
2	200	203	-1.5
3	300	304	-1.33
4	400	404	-1
5	500	508	-1.6
6	600	605.5	-0.92
7	700	706	-0.86

4.3. Comparison of Two Proposed Methods

A comparison is made between these two proposed methods in Table 4.

Table 4.
Comparison of Two Proposed Methods

SL No.	Wavelength calculation method	Sub-transient current measurement method
1	Accuracy above 98%	Accuracy above 97%
2	Applicable in any types of fault.	Applicable in symmetrical fault only.
3	Sampling rate should be accurate.	Sampling rate is not necessary.
4	There is no need to consider the effects of terminal voltage, power factor, line impedance or some other factors. Only the first bursting point is necessary.	The effects of terminal voltage, power factor, line impedance or some other factors should be considered.
5	Fault occurring time should be known.	It is not necessary to know the fault occurring time.

5. Conclusions

Two new methods are proposed in this paper named sub-transient current measurement method and wavelength calculation method which describe the concepts and methodologies of detecting and locating a fault in an electrical power transmission line. Sub-transient current measurement method can be used for symmetrical fault and wavelength calculation method is feasible for any kind of faults. Accurate sampling rate is needed for the later one, but not for the former one. The concept of sub-transient current and its wavelength calculation methods are explored during the study of fault analysis. After observing the simulation results, it is clear that the proposed methods are accurate enough and it is concluded that the proposed methods can be the effective solutions to detect and locate a fault in transmission line.

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