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Implementation & simulation of fault locating algorithm and localization of fault for linear transmission lines on PMU based two terminal systems.

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Abstract
The demand of electricity is increasing rapidly. Among all, electricity is most reliable and sustainable source. With the growth in demand, power system will be more complex and sophisticated. Transmission lines are backbone for supplying electricity to every consumer. Transmission line are mostly prone to faults. So, clearing the fault of transmission in least possible time is most important to reduce the damage occurred due to fault. The protection of the transmission line could benefit tremendously from the capacity to locate and identify the issue. The Phasor Measurement Unit is used in this work to offer a contemporary method of fault localization and detection. The PMU transmission line and fault have been modelled using MATLAB/Simulink. The detection of fault uses discrete wavelet transform, PMU uses discrete Fourier transform and the localization of fault is done using Universal algorithm. In general, this paper provides the concept of PMU and its application in fault detection and locating the fault point in transmission as well as distribution line. The approach taken in this paper has been tested for different line length, source impedance and different types of faults.

***Keywords*—** Phasor Measurement Unit (PMU), Decomposition wavelet, Discrete Fourier Transform (DFT), Wide Area Monitoring System (WAMS)

Introduction

With the increase in use of electricity, the power transfer capability of transmission increases and in return the fault associated with these components also increases gradually. Thus, it is necessary to detect and isolate the fault from the healthy system in order to maintain stability and increase efficiency during transmission. To increase power system stability and reliability during and after disturbances, new strategies for enhancing operator situation, awareness and power grid controls must be developed [1], [2].

Advanced power-grid monitoring systems is a combination of power supply monitoring, load balancing, protection and metering functions to enable safe and efficient power delivery. The PMU is a complex electronic and electrical apparatus developed for the purpose of measuring the phasor quantity of electrical parameter such as voltage and current using a time source with universal reference commonly provided through the GPS Satellite [3]. General purpose PMU has high temporal resolution compared to traditional SCADA, which enable engineers in analysing dynamic events in the interconnected grid.

An electric power system is a large and complex network spread over a wide range of geographical area consisting of generator, transformer, transmission line and load. Various abnormalities such as breakage of

transmission conductors, switching failure, insulation failure and other human error might occur and such abnormalities are called faults.
Faults are generally categorized into two group:

1. Open Circuit
2. Short Circuit

Apart from this short circuit fault can be classified as symmetrical and unsymmetrical faults. As seen in fig.1.

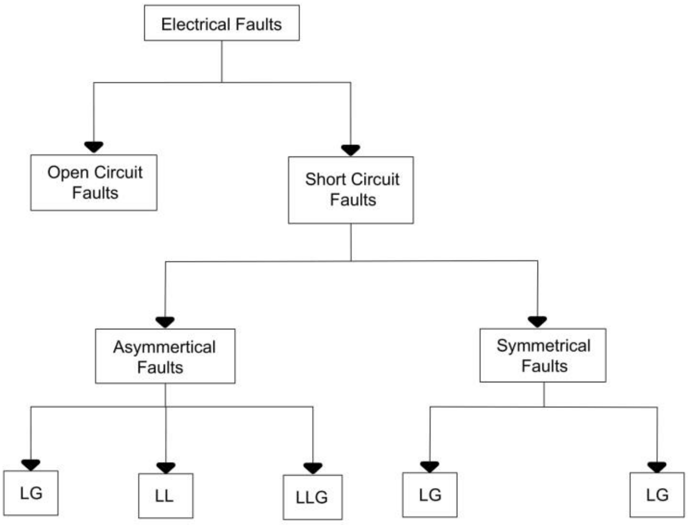

Figure 1: Fault Classification

Faults are unwanted in an electrical grid and have significant impacts in the system. Some impacts of faults in a medium grid system are listed below:

1. Heating & excess electric field.
2. Imbalance & cause of loss of synchronism.
3. Unwanted sparks.

Literature Review

The calculation of phasor using PMU's can be performed by various methods and algorithms like Fourier transform method, zero-crossing detection method, Kalman filtering method, recursive algorithm, and non-recursive algorithm [4], [5]. Among all available methods and algorithm, the MATLAB/Simulink model developed is based on Discrete Fourier Transform (DFT). Fundamental ideas on the application and significance of DFT for the creation of PMU are cited by the authors in [6], [7]. In conclusion, DFT method has the best harmonic suppression among the available methods.

The power system encounters large disturbances and sudden changes in power output which is specified in [8]. For successful monitoring of the grid, it is important to be able to detect disturbances and events based on measured data. Methods such as mean, variance, correlation, residual modelling, STFT, and linear regression can be used for screening PMU data [9].

For fault detection, authors in [10] uses two stage detection method that uses the data acquired from the optimal PMU locations. It facilitates discrimination between the faults and other minor disturbances by using the available positive and zero sequence voltage measurements. The first stage which is used to distinguish major fault, receives positive and zero sequence measurement. The knee voltage is extracted from p-v curve analysis to discriminate between a fault and other disturbances. Hence, comparison is made between voltage deviation and threshold value. In the second stage, the zero-sequence voltage deviation is compared with its set value. If positive and zero sequence voltage deviation are greater than positive and zero sequence threshold value, then the algorithm detects the fault otherwise just a disturbance.

The methods and algorithms for localization of fault in transmission line can be classified into one-terminal and multi-terminal method. To calculate location of fault using one terminal method is difficult when there is change in system impedance while in multi-terminal method the change in the systems impedance doesn't affects the outcome [11], [12]. Any sort of multi-terminal transmission line, including double-circuit lines, non-homogeneous lines, short lines, long lines, and any multi-terminal lines with arbitrary configuration, can use the fault localizing technique in [13] because it is a universal approach. The fault locator uses positive sequence component of electrical parameters for calculating the fault location.

Methodology

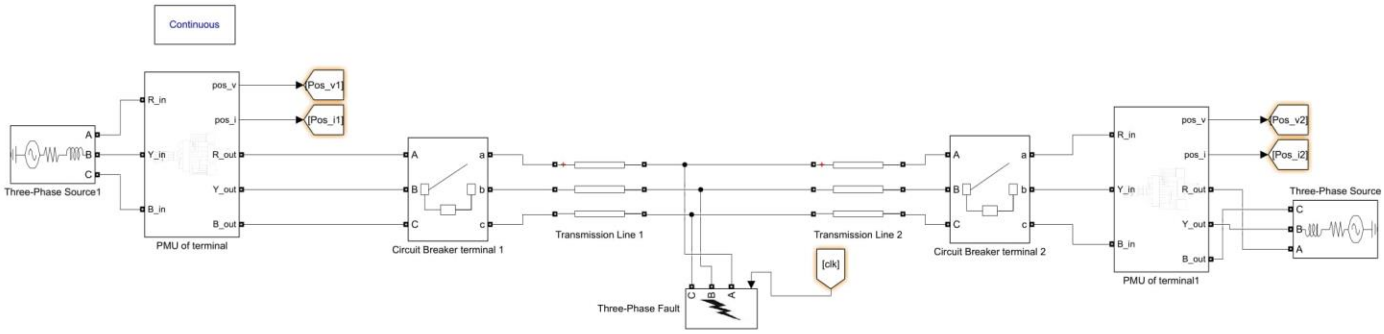

Figure 2: MATLAB model of two terminal transmission line.

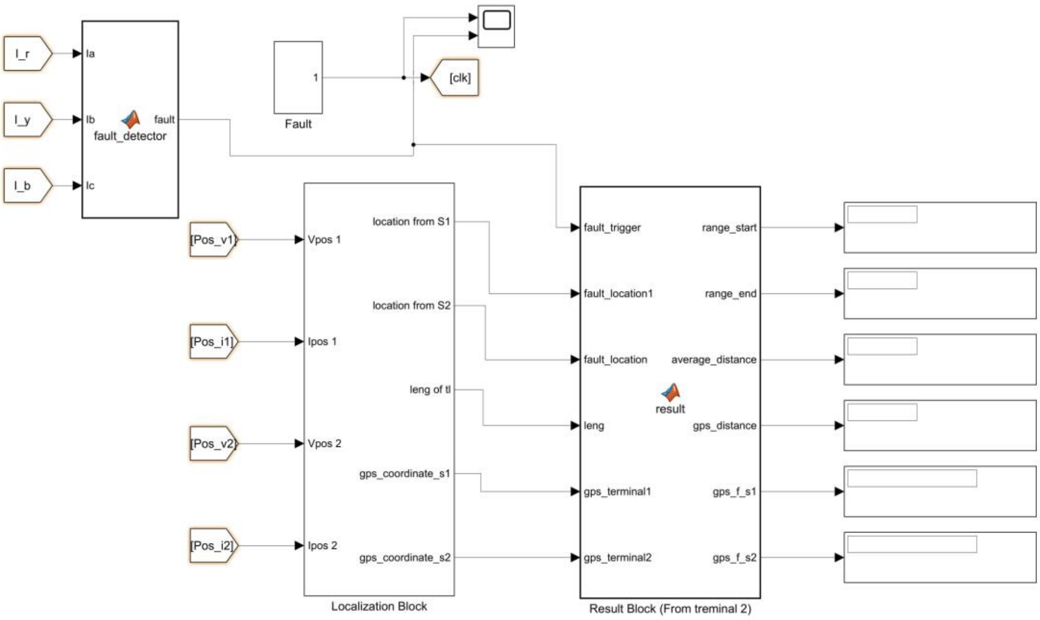

Figure 3: MATLAB model of the fault generator, detection and localization blocks.

The project focuses on the localization of fault through the positive sequence component of voltage and current obtained through PMU. The digital model of two terminal transmission line along with their respective PMU were developed in MATLAB, that uses direct Fourier transform. The model was developed such that the parameters of transmission line such as length, position of fault occurrence instance and duration of fault can be controlled easily and varied as required.

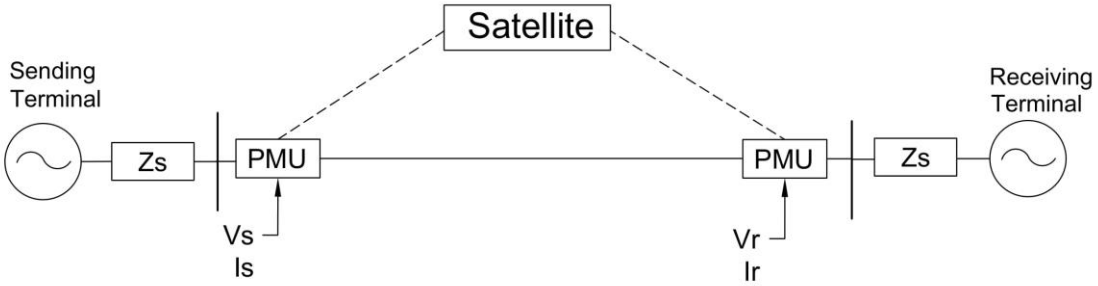

Figure 4: Developed digital twin.

For the purpose of detection and localization of fault in transmission line, digital models of detection and localization block were developed which uses wavelet decomposition algorithm for detection of fault occurrence. Whereas, the localization algorithm used is Universal algorithm [14]. The phasor of three phases were determined and the sequence components were calculated using eq. (1) and (2) by the PMU. Also, the working algorithm followed by the PMU model is shown in fig. 5.

$$X_{real} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \left(cos\left(\frac{2\pi n}{N}\right)\right)$$

$$X_{imag} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \left(sin\frac{2\pi n}{N}\right) \tag{1}$$

$$X_{mag} = \sqrt{X_{real}^2 + X_{imag}^2}$$

$$X_\theta = atan2\left(\frac{X_{real}}{X_{imag}}\right) \tag{2}$$

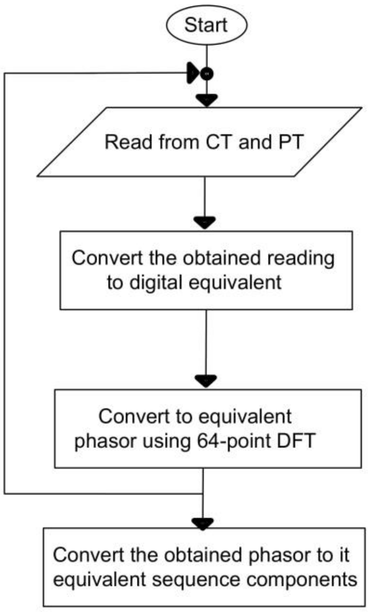

Figure 5: PMU algorithm

The fault locator uses the phasor measurement obtained from the PMU. The purpose of the fault locator is to use the electrical parameters obtained during fault condition via PMU for the calculation of location index. The expression used for calculation of the location index is expressed in eq. (3).

$$D = \frac{\log_e\left(\frac{N}{M}\right)}{2\tau l}$$

$$M = \frac{1}{2}e^{-\tau l}[V_s + Z_c I_s] - \frac{1}{2}[V_r + Z_c I_r] \tag{3}$$

$$N = \frac{1}{2}[V_r - Z_c I_r] - \frac{1}{2}e^{-\tau l}[V_s - Z_c I_s]$$

where,
D = Location index
V_s = Positive seq. voltage of sending terminal
I_s = Positive seq. current of sending terminal
V_r = Positive seq. voltage of receiving terminal
I_r = Positive seq. current of receiving terminal

Fault detection also uses the positive sequence current for detection of fault in transmission and distribution line. The detector performs discrete wavelet transform of the sequence current, which decomposes a signal into sinusoidal basis functions of different frequencies. No information is lost in this transformation; in other words, we can completely recover the original signal from its DFT (FFT) representation. The discrete wavelet transforms as mentioned in [10], helps in analysing the high-frequency components of current or voltage during transient conditions like faults. The mathematical relation used for the calculation of DWT are expressed in eq. (4).

$$DWT(p,q) = \sum_{a_0}^{-p/2} x\,[k]h * \left[\left(k - q a_o^p b_0\right)/a_0^p\right]$$

$$c_1[q] = \sum h\,[k-2q].x[k] \tag{4}$$

$$d_1[q] = \sum h\,[k-2q].x[k]$$

where,
$c_1[q]$ = is the original signal’s $\{i.e.\ x[n]\}$ low frequency coefficient.
$d_1[q]$ = is the original signal’s $\{i.e.\ x[n]\}$ high frequency coefficient.

The combination of these three components helps in detection of fault in transmission and distribution line. The working of the combined model is shown in fig. 6.

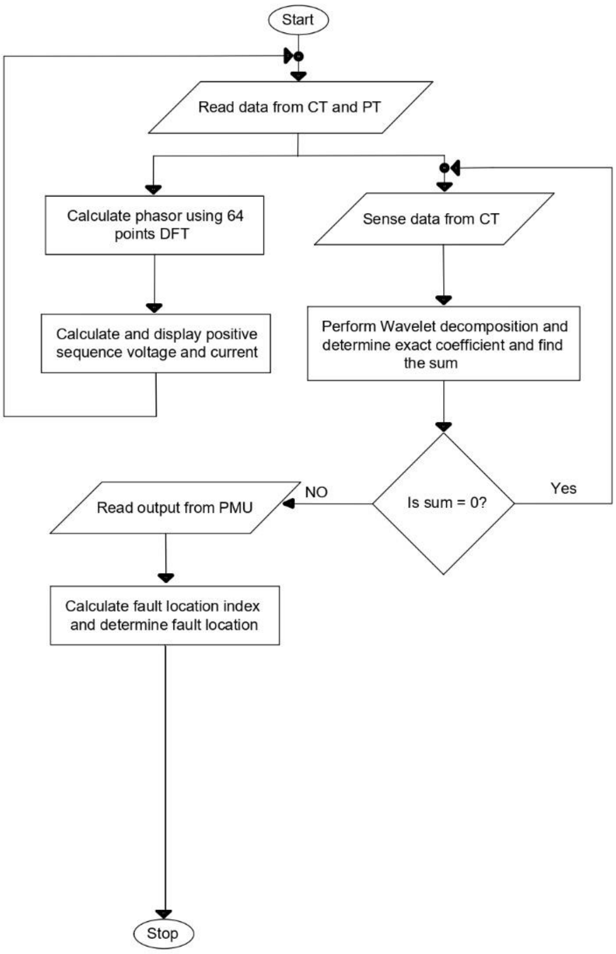

Figure 6: Algorithm flowchart.

Results

After development of the MATLAB model the distance and type of fault were varied for different line length, the inputs were given manually and the output of the algorithm was compared with input and the accuracy of the model was tested. In addition, the source impedance, line length, and other line parameters were varied, as well as the fault type, to investigate the effects of these changes on the algorithm's accuracy.

The phase current is used to detect the fault occurred in the line. During the fault the current in the phase increases beyond its original value at normal condition. Figs. 7 and 8 shows the profile of phase current during normal & L-L-G fault condition respectively.

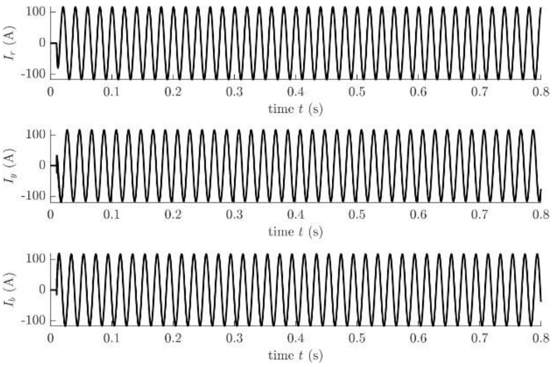

Figure 7: Phase current during normal operating condition

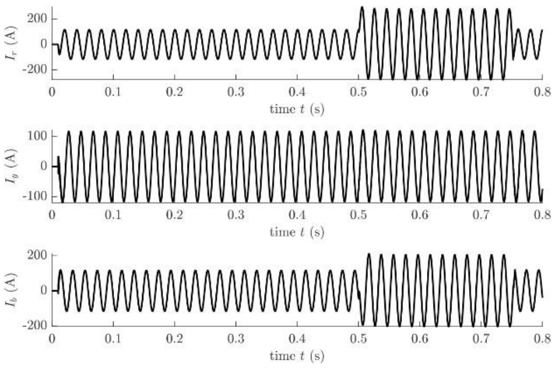

Figure 8: Phase current during faulted condition.

The relation of magnitude of fault current during occurrence of fault can be generalized using mathematical expression in: eq. (5)

$$I_r^{fault} = -\frac{j * \sqrt{3}E}{Z_1 + Z_2 + Z_f}$$
$$I_b^{fault} = \frac{j * \sqrt{3}E}{Z_1 + Z_2 + Z_f} \tag{5}$$

where,
I_r^{fault} = Current in the R phase during faulted condition
I_b^{fault} = Current in the B phase during faulted condition
Z_1 = positive sequence impedance of the system
Z_2 = negative sequence impedance of the system
Z_f = fault impedance

When the fault detector model finds a fault, the detection trigger value is toggled, and the model continuously verifies the occurrence of line fault as long as the detection trigger value is high. Fig. 9 shows status of detection trigger during fault.

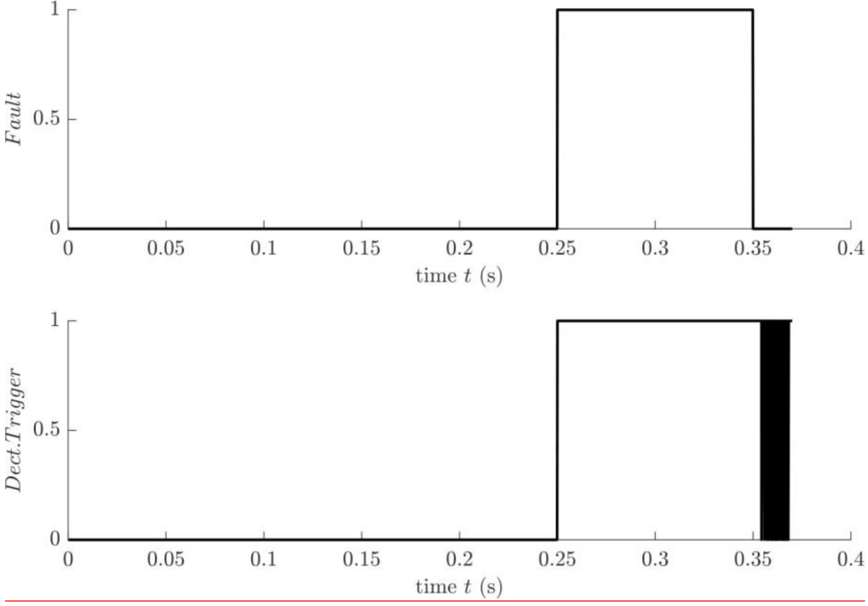

Figure 9: Fault trigger during faulted condition

The developed model was tested for different line length as a function of % error and calculated for different voltage levels like (11kV, 132kV and 220kV). During the testing of the model the nature of change in the error percentage of fault location was found similar for all three voltage levels which can be justified from fig. 10.

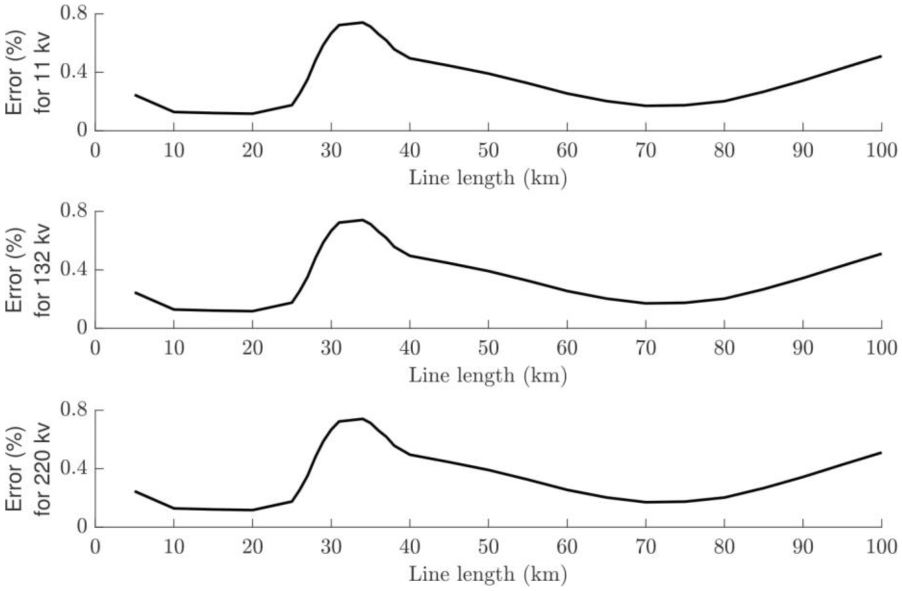

Figure 10: Percentage error vs line length

The impact of change in impedance (±7.5%) was tested and it was found that the accuracy of the model was dependent on the source impedance. The fig. 11 shows the impact of impedance on the acquired error percentage. It can be seen that when the impedance of the source is increased the error percentage also increases relatively to the normal condition. However, when the source impedance is decreased, error percentage also increases relatively to the normal condition but the increment in the error percentage is not that high as in the case when there is increment in the source impedance. But in both cases, it can be seen that the error percentage is minimum for line length of 80 km and the nature of the curve is identical.

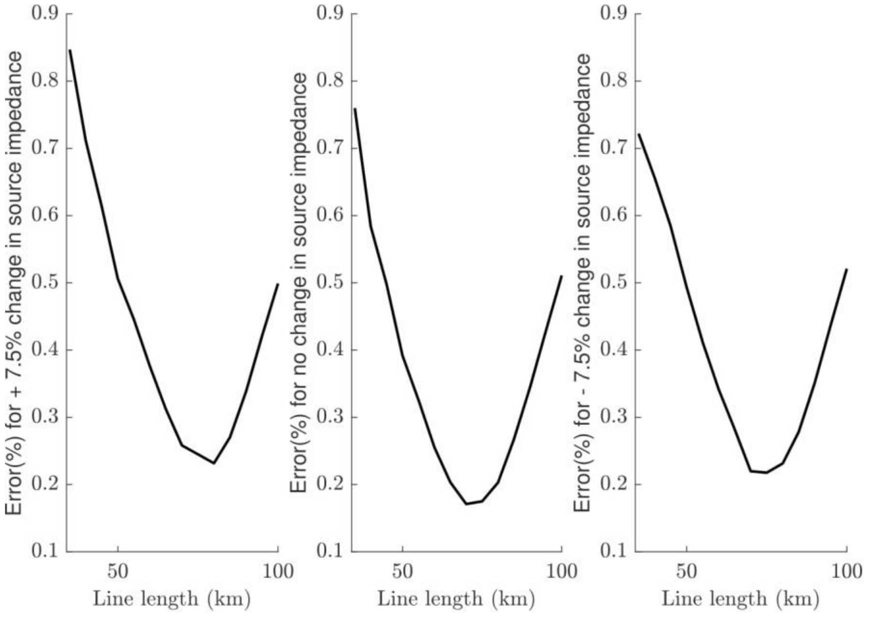

Figure 11: Impact of change in impedance to the avg. error.

Conclusion

This paper provides modern techniques for detection of faults in transmission lines based on DWT whereas the localization of the faults is based on Universal algorithm. The conversion of electrical parameters to phasor sequence components using DFT. Upon testing the model for different line parameters, the accuracy of fault location was found to be 1% which is within acceptable range than that of other techniques of fault localization. The voltage level and line length were found to have negligible dependency on the accuracy of the model, however during the course of the study the impact of voltage level on the line parameters such as line inductance, line capacitance and line resistance has been neglected. The model has been tested for 100 km and had high accuracy for 80 km line length. In future, the purposed model can be tested in the transmission line of INPS (Integrated National Power Supply) for feasibility study of the proposed PMU based system in context of Nepal.

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