Steady State versus Transient Signal for Fault Location in Transmission Lines

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Abstract. This paper focuses on determination of suitable time interval of features extraction either during steady state signal or transient signal of impedance based method to estimate the location of fault using Artificial Neural Network (ANN). Simulation studies have been carried on power system model using MATLAB & SIMULINK. The faulted current signal taken at single-ended of transmission lines are used as input in the proposed scheme. Different types of faults at different operating condition have been considered to this study. This studies extracted five features that are delta minimum to maximum, amplitude, standard deviation, energy and mean of the signal for both condition. The proposed studies is evaluated by Mean Square error (MSE) from ANN. Most researchers using steady state signal as their input and there also have researchers used transient signal as the input but there have no study or reason for choosing the signal at that condition. However, by carrying out this studies, it shows that not all features are suitable to extract during one time signal condition.

1. Introduction
Transmission Line need to deliver energy from power supply to consumer but physically it exposed to the environment, therefore it would facing high possibility to fault due to several causes such as tree falls, lightning, storms and insulation breakdown. At the meantime the requirement on providing a continuous power supply without significant cost urging to have modern technology of power system protection and fault location considered as crucial needed. The restoration can be expedited if the location of the fault is either known or can be estimated with reasonable accuracy.

When a fault occurs on a transmission line it causes a sudden change in the current and voltage signals as well as measured impedances at the relay location (1). Basically fault location method are broadly classified as traveling wave technique and impedance based technique as shown in Figure 1. Traveling wave based on the arrival time of fault signal using the reflected wave measurement meanwhile the impedance based technique used the current or voltage signal measurement (2–4).
Figure 1 Types of Fault Location Technique

Figure 2 presents the time interval for pre-fault, fault and post-fault and one can distinguish. Pre-fault signal is signal recorded before fault occurs or at normal signal without fault. It recorded within the pre-fault interval. The steady state signal called as post-fault signal is a signal recorded during the fault occurs up to detected steady state signal instant or within the fault interval meanwhile transient signal called as fault signal is signal recorded after the fault occurs or within the post-fault interval. (5)

Nowadays fault location in transmission line using the intelligence system becoming a trend to many researchers due to capability of the system to estimate fault location with high accuracy. The selection input data is important for ANN to estimate the location correctly. Therefore, the data collection approach would influence the performance of system developed. Iżykowski et al. said there is another possibility which concerns post-fault analysis program with fault location algorithm included. It is shows post-fault data have been used for estimate fault location (6). Most researchers have chosen to use post-fault data for their study on fault location in transmission line such as (7–9). Ray and Mishra also uses post-fault of current waveform to estimate fault location and develop a system with error less than 0.29% (10) while Ghimire used post-fault voltage and current from two end method to estimate fault location (11) with less than 3.9% for impedance based method. In contrast, researcher (12–14) studies fault location in transmission line using faulted current signal. There are no significant reason of choosing post-fault signal or fault signal. Moreover, there have no study on the suitable selection time interval to collect the data for fault location.

This paper aims to determine the appropriate time to extract features of impedance based technique for fault location in transmission lines using ANN. Thus, comparing the result to have the suitable features for fault location in transmission line. This paper are limited to 10 types of faults using single-ended of impedance based method. The 900 experimental data generated using MATLAB SIMULINK for data training, validation and testing as input for ANN. All the data have been developed under MATLAB environment. The length of transmission line is 300km with voltage of 500KV, 50Hz.
2. Methodology
Figure 3 describe the chronology of the work carried out for this study. After simulation of transmission lines, two types of data collection method will be explored which are during fault condition and post-fault condition. Then the data will be normalized. Next features will be extract as input into ANN to perform fault location and lastly evaluate the performance of the system.

Figure 3 Flow Chart of the Study.

2.1. Transmission Line Model
This study generate the data by using type single-ended of impedance based technique to perform the simulation of fault in transmission line. The transmission line model considered is single line diagram with total length of 300km as shown in Figure 4. The model was developed using MATLAB/SIMULINK. The study is tested with varying fault location, fault types, fault resistance and inception angle as mentioned in Table 1.

Figure 4 Single Line Diagram for Single Ended Transmission Line Model

The fault is created at 0.023s with sampling frequency of 1.25 MHz and the parameter setting for:

\[
R_1 = 0.01273 \ \Omega/km; \ \ R_0 = 0.3864 \ \Omega/km; \\
L_1 = 0.9337e^{-3} \ \text{H/km}; \ \ L_0 = 4.1264e^{-3} \ \text{H/km}; \\
C_1 = 12.74e^{-9} \ \text{F/km}; \ \ C_0 = 7.751e^{-9} \ \text{F/km}
\]


Table 1 Varies Parameters Value

| Parameters                      | Value        |
|--------------------------------|--------------|
| Fault Location, L (km)         | 0-500        |
| Fault Resistance, Rf (Ω)       | 0.01, 1, 10, 50, 100, 200 |
| Fault inception angle, Ft(degree) | 0, 90       |

2.2. Data Collection Method

This paper conducted 10 types of fault that are three types of single line to ground fault (AG, BG, CG), three types of double line fault (AB, AC, BC), three types of double line to ground fault (ABG, ACG, BCG) and lastly a three phase fault (ABCG). This fault location scheme using one faulted current signal as data collection reference. The current signal was chosen because current is sensitive to any changes especially during fault. The data was collected for one cycle of fault interval and post-fault interval for next process.

Figure 5 presents the example waveform of three-phase current signal recorded using scope in SIMULINK for fault occurs at 187km. Fault incipience is the starting time to collect the data for fault interval while fault clearance is the starting time to collect the data for post-fault.

![Figure 5 Specification of time intervals according to position for 187km fault](image)

2.3. Features Extraction

This study were extracted five features from both interval condition that are delta minimum to maximum, amplitude, standard deviation, energy and mean of the current signal. The features extracted use as input into ANN to estimate the location of fault. Features is an important element to ANN determine the output of the system. The suitability of the features are considered to have better fault location system.

Delta minmax is peak to peak amplitude of waveform while the amplitude is the maximum point of the waveform from origin. The features extracted using formulae of mean by equation (1)

$$
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
$$

(1)

Formulae of standard deviation by equation (2)
\[
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2}
\]

Formulae of energy by equation (3)

\[
E = \frac{1}{n} \sum_{i=1}^{n} |x_i|^2
\]

2.4. Fault Location using ANN

There are several processes for ANN to determine the fault location as shown in Figure 6. Since the values of data were too high, normalization process is needed to avoid ANN taking too much time to calculate and estimate the output. Next several features need to be extracted as input into ANN. Lastly, ANN will estimate the location based on data given.

![Figure 6: Main Process toward ANN](image)

Basic algorithms used in fault locators are intended to make distance to fault calculation as accurate as possible. A structure of ANN called MLP is developed that consists of three layers which are input layer (Features extracted from faulted current), hidden layer and output layer (fault location). The NN are performed independently based on types of fault as in Figure 7. The MLP network was selected because the model displayed an efficient learning environment where each layer is connected with weight and bias for minimizing error between target and obtained value. The process of training, validation and testing are performed using neural network toolboxes in MATLAB with suitable number of hidden layers. Lavenberg-Marquardt backpropagation is used as training algorithm. The transfer function of the hidden layer and output layer are respectively sigmoid and linear function. The suitable number of hidden layer used is within 1 to 20 hidden layers.

![Figure 7: ANN structure](image)
2.5. **Performance Evaluation**

The performance of system are evaluated by calculating performance indicator. Performance indicator chosen is MSE of ANN for testing data. The Mean Square Error, MSE is an indicator for the quality of the estimated data from targeted output. Best results of MSE is 0. The formulae is on equation (4).

\[
MSE = \frac{1}{n} \sum_{i=1}^{n} (Output\ ANN_i - Output\ Target_i)^2
\]

Where \( n \) represent the number of data.

3. **Results and Discussion**

3.1. **Transmission Line Model**

Figure 8 shows the design of single-ended of single line diagram using SIMULINK MATLAB. All the setting parameters followed the setting describe in methodology.

![Figure 8 Transmission Line Model using MATLAB SIMULINK](image)

3.2. **Features Extraction**

Figure 9 shows the example of training distribution data from features extraction of AG fault for fault condition and post-fault condition. Each figure illustrated the graph of normalized current, \( I_{\text{norm}} \) against fault location. The features extracted into five features that are delta minmax, amplitude, mean, standard deviation and energy from both condition. The features were used as input for ANN to estimate the location. As can be seen, when the fault location is increase, the \( I_{\text{norm}} \) will decrease exponentially. From the figure, the pattern of data for fault condition and post-fault condition is almost the same except for mean features.
Figure 9 Data Training of AG Fault
(a) Delta MinMax (b) Amplitude (c) Mean (d) Standard Deviation (e) Energy
3.3. Performance of Features Extracted

All the five features performance at the fault condition and post-fault condition was determined based on MSE results and the results are presented in Table 2.

| Types of Fault | Delta MinMax | Amplitude | Mean | Standard Deviation | Energy |
|----------------|--------------|-----------|------|--------------------|--------|
|                | Fault        | Post-Fault| Fault| Post-Fault          | Fault  |
| AG             | 27.79        | 0.56      | 56.14| 4.41               | 1450.30|
| BG             | 10.09        | 2.61      | 22.35| 17.11              | 538.66 |
| CG             | 6.27         | 2.43      | 36.42| 1.81               | 943.78 |
| AB             | 2.95         | 0.55      | 4.29 | 2.41               | 2576.78|
| AC             | 1.57         | 0.35      | 2.20 | 3.91               | 0.031  |
| BC             | 18.58        | 6.22      | 1.71 | 5.11               | 2150.63|
| ABG            | 5.36         | 2.55      | 33.10| 3.28               | 1944.51|
| ACG            | 15.03        | 1.20      | 2.95 | 10.95              | 0.639  |
| BCG            | 15.13        | 8.43      | 6.73 | 6.24               | 0.864  |
| ABCG           | 9.41         | 3.42      | 2.38 | 1.06               | 0.739  |
| Average        | 27.79        | 0.56      | 16.83| 5.12               | 745.640|

In view of the results obtained, the MSE value for post-fault condition are lower for delta minmax and amplitude but higher for mean, standard deviation and energy based on the average results. Delta minmax and amplitude were reduced about 27.23 and 11.71 each for MSE value by choosing post-fault condition compared to fault condition. In contrast, MSE value for mean, standard deviation and energy were reduced by 1200, 0.07 and 8.2 each by choosing fault condition compared to post-fault condition. Among all the features, mean features was found to be highest of MSE and have significant reduction for fault condition and post-fault condition. It can be seen contribution of features extraction data has the greatest influence to the results of MSE.

The table was interpreted in figure as in Figure 10. The figure shows the MSE results from testing data ANN against the types of faults on both cases for all the features that are (a) delta minmax, (b) amplitude, (c) mean, (d) standard deviation of the signal and, (e) energy. From the figure, it can be seen that each types of fault have different criteria for MSE results for each features. The ANN shows more difficult to estimate fault location for single phase to ground fault since MSE values is higher during this types of fault except for energy features.
Figure 10 MSE results for all features
(a) Delta minmax (b) Amplitude (c) Mean (d) Standard Deviation (e) Energy
4. Conclusion
In this paper, fault location is calculated using single-ended impedance based method. From the results, certain features are suitable collected during fault condition such as standard deviation, energy and mean of signal meanwhile the rest is suitable collected during post-fault condition such as delta minimum to maximum and amplitude. The performance evaluation is based on the MSE results of each features. Therefore, the suitable features for fault location by rank is standard deviation of fault condition (MSE=0.299), delta minimum to maximum of post-fault condition (MSE=0.560), energy of fault condition (MSE=1.091), amplitude of post-fault condition (MSE=5.118) and lastly mean of fault condition (MSE=745.640).

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