Power Transmission Line Fault Location Estimation Using The Traveling Wave Method

Eyakeno Luke¹
Department of Electrical/Electronic and Computer Engineering, University of Uyo, AkwaIbom, Nigeria

Kalu Constance²
Department of Electrical/Electronic and Computer Engineering, University of Uyo, AkwaIbom, Nigeria

Udofia, Kufre³
Department of Electrical/Electronic and Computer Engineering, University of Uyo, AkwaIbom, Nigeria

Abstract— In this paper, power transmission line fault location estimation using the traveling wave method is presented. Specifically, the double terminals traveling wave fault location method is used. The method determines the fault location by using precisely measured arrival time of the traveling wave at each end of the line. Importantly, the method uses the propagation time of the high frequency traveling wave created whenever a fault occurs on a transmission line to detect and also to locate the fault. The relevant mathematical expressions pertaining to the model are presented. The model was simulated using Simulink and the input data from a case study three phase transmission line with the following parameters: wave propagation speed is 299,792 km/s, the sampling time is 10 µs and the total length of the transmission line is 46 Km. During the simulation, different three phase faults are simulated at different locations along the transmission line. The results on the fault location distance and the percentage error in fault location calculation for the different fault locations show that the maximum percentage error is 1.13 % and it occurred for a fault at a distance of 12.2 km. The r-squared value between the actual and the estimated fault location is 0.9993. In all, the results show that the traveling wave method is effective in estimating the location of faults on the case study transmission line.

Keywords— Transmission Line, Fault Location, Fault Detection, Traveling Wave, Power Transmission, Propagation Speed, Three Phase Transmission Line

I. INTRODUCTION
According to experts in the power industry, faults are inevitable on power transmission lines [1,2,3,4]. As such, experts and operators are developing measures to address the faults when they occur. Notably, the location of transmission line fault is needed so that the fault can be corrected and the power system restored to normal operating condition [5,6,7]. In practice, manual determination of the fault location is difficult especially for large power networks covering several kilometers of distance. As such, operators use different methods to assist in the determination of fault location.

Normally, whenever a fault occurs on a transmission line, transient voltage and current will be generated and these waves will travel both directions from the fault location towards the terminals where the transmission line is connected [11,12]. One method used to determine the fault location is the traveling wave method [13,14,15]. Basically, the traveling wave method works by obtaining the arrival time of the traveling waves and then use the traveling times along with other pertinent information about the transmission line to determine the location of the fault [16,17,18]. Specifically information on the length of the line and wave propagation velocity are used along with the traveling wave arrival times to the line terminals are used to analytically determine the fault location. In this paper, the traveling wave method is used and sample transmission line is modeled in MathLAB for different fault types and fault locations. The traveling wave method is then employed in the MathLAB simulations to determine the fault locations.

II. METHODOLOGY
When a fault occurs on a power transmission line, there will be a sudden change in voltage or in the current. This sudden change at the fault point generates high frequency electromagnetic signal which is referred to as traveling wave. From the fault location, the traveling wave will propagate in both directions towards the two ends (terminals) of the line. The time it takes the two traveling waves to reach the end of the terminals are used to determine the fault location. In that case, assuming a lossless transmission line length is d (in km), the travelling wave velocity is denoted as \( v \) (in km/s), the fault occurred at a distance of 'x' km from terminal A of the line, capacitance and inductance per unit length of the line are denoted as 'L' and 'C' and the characteristic impedance of the line is \( Z_c \), then, the voltage and current values are given as [19]:

\[
\frac{\partial e}{\partial x} = L \frac{\partial i}{\partial t} \tag{1}
\]

\[
\frac{\partial i}{\partial x} = C \frac{\partial e}{\partial t} \tag{2}
\]

www.scitechpub.org
The solutions to the two differential equations are given as:

\[ e(x, t) = e_f(x - vt) + e_c(x + vt) \]  \hspace{1cm} (3)

\[ i(x, t) = \frac{e_f}{Z_c}(x - vt) + \frac{e_c}{Z_c}(x + vt) \]  \hspace{1cm} (4)

The time the travelling waves will travel from the fault location to terminal A and terminal B are denoted as \( \tau_A \) and \( \tau_B \) respectively. Then, the location of the fault, denoted as \( x \) in km is determined as follows:

\[ x = d - \frac{(\tau_A - \tau_B)v}{2} \]  \hspace{1cm} (5)

Where \( v \) is the wave propagation speed which is 299,799 km/sec.

The prediction percentage error, \( P_e(\%) \) is given as

\[ P_e(\%) = \frac{(Actual\ distance\ of\ fault\ location - Predicted\ distance\ of\ fault\ location)}{Total\ Length\ of\ the\ transmission\ line} \times 100 \]  \hspace{1cm} (6)

III. SIMULATION, RESULTS AND DISCUSSION

A program written in MATLAB syntax was used for the simulation. The dominant frequency was extracted from the transient wave through the use of wavelet transform. Also, the Daubechies wavelet is used both to detect and also to locate the disturbance event. Among the different Daubechies wavelet filter coefficients, the modal signals are decomposed using the Daubechies 4 wavelet filter coefficients [20].

Figure 1 shows that when the Daubechies 4 method was used the disturbance occurred at level one. In Figure 7, S is the input signal (current phase A signal) \( a_1 \) and \( d_1 \) are the decomposed residual plots which was passed through the spectral signal to generated the energy with other statistical parameters as shown in Figure 2; the energy values (under the plot of energy against frequency) was then used to determine the fault location via traveling wave method. The same process was done for phase B (in Figure 3 and Figure 4) and for phases (in Figure 5 and Figure 6).

![Figure 1; Phase A current Signal](image-url)
Figure 2: The spectral analysis of the decomposed signal of current of phase A.

Figure 3: Phase B current Signal
Figure 4: Spectral Analysis of the decomposed signal of Current of Phase B.

Figure 5: Phase C current Signal
Figure 6: Spectral Analysis of the decomposed signal of Current of Phase C.

During the simulation, different three phase faults are simulated at different locations along the transmission line. The line parameters are $v = 299,792$ km/s, the sampling time is $10 \mu$s and the total length ($d$) of the transmission line is 46 km. The results of the measured propagation times, $\tau_A$ and $\tau_B$ for the different fault types and fault location are given in Table 1. In Table 1, the fault location based on traveling wave is calculated using Equation (5); for the first row, $\tau_A = 1.75$ ms = 0.00175 s, $\tau_A = 1.85$ ms = 0.00185 s, $d = 46$ km and $v = 299,792$ km/s, then:

$$x = \frac{46 - (0.00175 - 0.00185)299792}{2} = 7.78 \text{ km}$$

The prediction percentage error, $P_e(\%)$ is computed from Equation (6) as follows:

$$P_e(\%) = \frac{(8.20 - 7.78)100}{46} = 0.913\%$$

The results on the fault location distance by the travelling wave method and the percentage error in fault calculation for all the other fault locations are given in Table 1. In all, the maximum percentage error is 1.13 % and it occurred for a fault at a distance of 12.2 km. The $r$-squared value between the actual and the estimated fault location is 0.9993.

<table>
<thead>
<tr>
<th>Actual fault location distance km</th>
<th>$\tau_A$ (ms)</th>
<th>$\tau_B$ (ms)</th>
<th>Fault location distance by the travelling wave method (km)</th>
<th>Percentage error in fault calculation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.20</td>
<td>1.75</td>
<td>1.85</td>
<td>7.78</td>
<td>0.91</td>
</tr>
<tr>
<td>12.20</td>
<td>1.30</td>
<td>1.38</td>
<td>11.68</td>
<td>1.13</td>
</tr>
<tr>
<td>22.00</td>
<td>0.07</td>
<td>0.07</td>
<td>22.43</td>
<td>0.93</td>
</tr>
<tr>
<td>25.00</td>
<td>0.18</td>
<td>0.17</td>
<td>24.58</td>
<td>0.91</td>
</tr>
<tr>
<td>35.50</td>
<td>1.38</td>
<td>1.30</td>
<td>35.00</td>
<td>1.09</td>
</tr>
</tbody>
</table>

$r$-squared = 0.9993

IV. CONCLUSION

Travelling method of fault location on a transmission line is presented. The method used the propagation time of the high frequency traveling wave created whenever a fault occurs on a transmission line to detect and also locate the fault. The key mathematical expressions pertaining to the model are presented. The model was simulated using Simulink and input data from a case study three phase transmission line. The results show that the traveling wave method is effective in estimating the location of faults on a transmission line.

REFERENCES


