LOCALIZATION OF FAULTS ON POWER TRANSMISSION LINES USING TRAVELING WAVE THEORY

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ABSTRACT

Transmission lines are designed to transfer electric power from source locations to distribution networks. However, their lengths are exposed to various faults. Protective relay and fault recorder systems, based on fundamental power frequency signals, are installed to isolate the faulty line and provide the fault position. However, the error is high especially in transmission lines. This work investigates the problem of fault localization using traveling wave current signals obtained at a single-end of a transmission line and/or at multi-ends of a transmission network.

Keywords: power transmission lines, faults, traveling wave theory.

INTRODUCTION

An electric power system comprises of generation, transmission and distribution of electric energy. Transmission lines are used to transmit electric power to distant large load centers. The rapid growth of electric power systems over the past few decades has resulted in a large increase of the number of lines in operation and their total length. These lines are exposed to faults as a result of lightning, short circuits, faulty equipments, mis-operation, human errors, overload, and aging. Many electrical faults manifest in mechanical damages, which must be repaired before returning the line to service. The restoration can be expedited if the fault location is either known or can be estimated with a reasonable accuracy. Faults cause short to long term power outages for customers and may lead to significant losses especially for the manufacturing industry. Fast detecting, isolating, locating and repairing of these faults are critical in maintaining a reliable power system operation. When a fault occurs on a transmission line, the voltage at the point of fault suddenly reduces to a low value. This sudden change produces a high frequency electromagnetic impulse called the Traveling wave Theory (TWT). These traveling waves Propagate away from the fault in both directions at speeds close to that of light. The paper reports work on analyzing traveling waves, which may occur on power transmission lines using Bewley Lattice Diagram (BLD) [l]. High Speed Fault clearance is an effective method of increasing power transfer and improving the transient stability of a power system [2, 3].

TRAVELING WAVE THEORY (TWT)

The transmission line conductors have resistances and inductances distributed uniformly along the length of the line. Traveling wave fault location methods are usually more suitable for application to long lines. A representation of an overhead transmission line by means of a distributed section has been implemented by using MATLAB. Traveling waves along transmission lines of power systems has been of interest since the last century. Having advanced simulation tools which can be executed on powerful computers allows more flexible and advanced visualization of these waves, not only along a single transmission line, but also for regions containing several interconnected lines and other equipment.

Electromagnetic transient's simulators typically provide numerical solutions for the voltages at specified buses in the power system. Plotting these solutions over a time interval of interest will reveal the details of voltage transients at these buses. These plots can be described as the signatures of the traveling wave transients [4, 5] along transmission lines on their terminal buses. However, they do not necessarily provide the variation of the voltage along a given transmission line, i.e., its voltage profile. In principle, once the terminal voltages are known as a function of time, the voltage profile along the transmission line can be obtained by using the transmission line equations. Time variation of the traveling waves along the line can be observed by calculating this profile at discrete time steps.

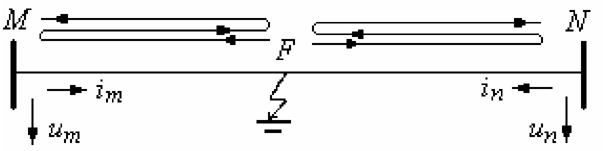


Figure-1. Fault generated traveling wave on a single- phase transmission line.

Figure-1 shows a diagram for a solid fault on a single-phase transmission line. The voltage and current traveling wave at both ends of the line 'M' and 'N' can be expressed as:

$$\begin{cases} u_m(t) = e(t-\tau_m) + \alpha_m e(t-\tau_m) - \alpha_m e(t-3\tau_m) - \alpha_m^2 e(t-3\tau_m) + ..., \\ i_m(t) = \dfrac{-e(t-\tau_m) + \alpha_m e(t-\tau_m) + \alpha_m e(t-3\tau_m) - \alpha_m^2 e(t-3\tau_m) + ...}{Z_C}, \\ u_{m+}(t) = \alpha_m e(t-\tau_m) - \alpha_m^2 e(t-3\tau_m) + ..., \\ u_{m-}(t) = e(t-\tau_m) - \alpha_m e(t-3\tau_m) + ... \end{cases} \quad -----(1)$$

$$\begin{cases} u_n(t) = e(t-\tau_n) + \alpha_n e(t-\tau_n) - \alpha_n e(t-3\tau_n) - \alpha_n^2 e(t-3\tau_n) + ..., \\ i_n(t) = \dfrac{-e(t-\tau_n) + \alpha_n e(t-\tau_n) + \alpha_n e(t-3\tau_n) - \alpha_n^2 e(t-3\tau_n) + ...}{Z_C}, \\ u_{n+}(t) = \alpha_n e(t-\tau_n) - \alpha_n^2 e(t-3\tau_n) + ..., \\ u_{n-}(t) = e(t-\tau_n) - \alpha_n e(t-3\tau_n) + ... \end{cases} \quad ------(2)$$

Where

M, n represent voltage and current quantities at end M and N respectively;
α_m and α_n are the reflection coefficients at ends 'M' and 'N' respectively.
τ_m and τ_n are the time for the wave to travel to the ends 'M' and 'N' respectively.
Z_c is the wave resistance. Positive is the forward wave and negative is the reverse wave, e(t) is the super-imposed voltage source of the fault network as shown in Figure-1.

A fault occurring on a transmission line will generate both voltage and current travelling waves. These will travel along the line until they meet a discontinuity on the line such as fault point and bus bar. At this point, both reflection and a refraction of the wave will occur. This generates additional waves which will propagate through the power system.

Traveling wave fault location theory

The voltage and current at any point x obey the partial differential equations:

$$\frac{\partial e}{\partial x} = -L\frac{\partial i}{\partial t} \tag{3}$$

$$\frac{\partial i}{\partial x} = -C\frac{\partial e}{\partial t} \tag{4}$$

Where *L* and *C* are the inductance and capacitance of the line per unit length. The resistance is assumed to be negligible. The solutions of these equations are:

$$e(x,t) = e_f(x - vt) + e_r(x + vt) \tag{5}$$

$$i(x,t) = \frac{1}{z}e_f(x - vt) - \frac{1}{z}e_r(x + vt) \tag{6}$$

Where $Z = \sqrt{\dfrac{L}{C}}$ the characteristic impedance of the transmission is line and $V = \dfrac{1}{\sqrt{LC}}$ is the velocity of propagation.

Forward (e_f and i_f) and reverse (e_r and i_r) waves, as shown in Figure-2, leave the disturbed area "x" traveling in different directions at "v", which is a little less than the speed of light, toward transmission line ends.

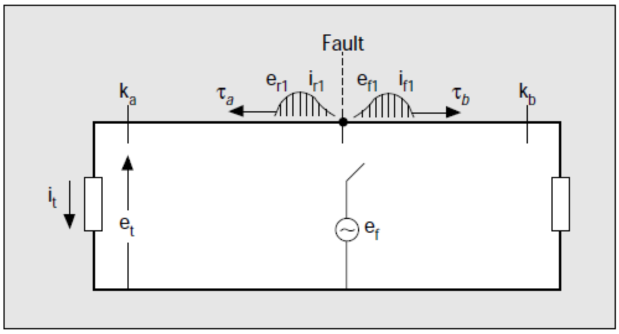


Figure-2. Traveling voltage and current waves.

Transmission line ends represent a discontinuity or impedance change where some of the wave's energy will reflect back to the disturbance. The remaining energy will travel to other power system elements or transmission lines. The basic characteristics of fault generated traveling wave transients [7] can be summarized as:

a) The wave characteristics change suddenly with the arrival of successive waves at the bus bar. This marks the occurring of the fault and the traveling time for the journey from the fault to bus bar etc;
b) The magnitude of the sudden change depends on the magnitude of the voltage at the fault instant - e(t). For later waves, it also depends on the reflection and refraction coefficients at the discontinuity and the attenuation characteristics of traveling wave [2]; and
c) The polarity of the sudden change depends on the polarity of the fault voltage at the fault instant and the discontinuous characteristics of the wave impedance.

Generally speaking, the polarity of traveling wave [9] has the following characteristics:

a) Reflected voltage and current waves from the fault point will have the same polarity as the incident waves;
b) The initial voltage or current waves have the same polarity at both ends of the line; and
c) For the reflected positive wave from the bus bar and the reflected negative wave from the fault point, their initial wave and reflected wave have the same polarity. The above basic characteristics lay the foundation for the TWT protection.

For a transmission line with inductance L and capacitance C, the propagation velocity of traveling wave is,

$$V = \frac{1}{\sqrt{LC}} \tag{7}$$

SIMULATION MODELS

Simulation system

For evaluating the performance of the proposed algorithm, the authors adopt MATLAB/ Simulink for fault data generation and algorithm implementation.

Figure-3 depicts the single-line diagram of the simulated system, which is a 500kV, 50Hz, Transmission Line Length: 200Km, Distributed Line.

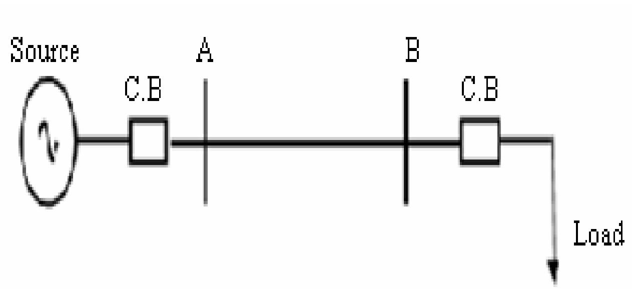


Figure-3. The single-line diagram of the simulated system (single area).

Figure-4 depicts the single-line diagram of the simulated system, which is a two area system interconnected by a 230kV, 50Hz, Transmission Line Length: 200Km, Distributed Line.

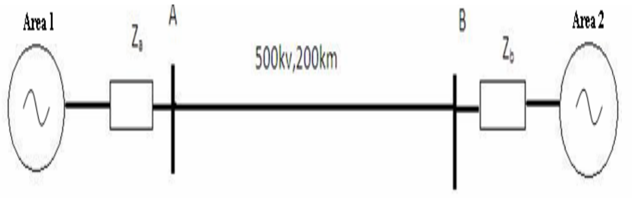


Figure-4. The single-line diagram of the simulated system (two area).

Case studies

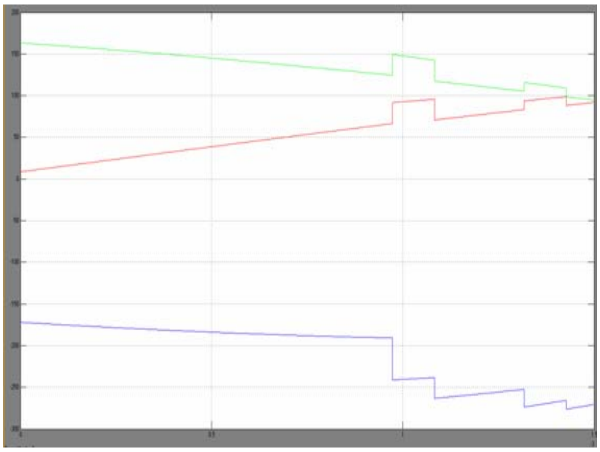


Figure-5. The current waveforms for a fault created at 50Kms at t = 0.0008sec (two area).

Fault is created at 0.0008 Seconds.

But the fault appeared at 0.0009724 Seconds.

Difference in Time = (0.0009724 - 0.0008)
Δt = 0.0001724 Seconds

$V = \frac{1}{\sqrt{LC}}$ is the velocity of propagation

$$V = \frac{1}{\sqrt{0.9337 * 10^{-3} * 12.74 * 10^{-9}}}$$

$$V = 2.899 * 10^{5} \, Km \, / \sec$$

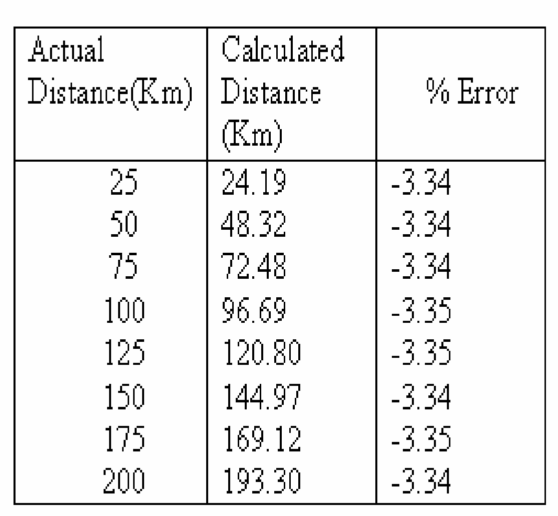
Distance = Velocity * Time

Here, Distance = $2.899*10^{5}*0.0001724$

Distance = 49.9Kms.

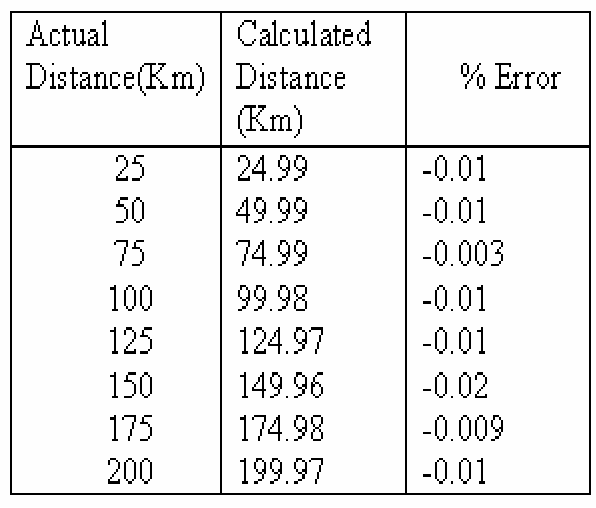
For the faults even with small variation in distances we can identify it very accurately. This is shown in Figure-6. Where distance variation is only 1 km i.e. for 50, 51, 52, 53 km. And the shift between any two fault is constant for equal shift in distance.

Table-1. Single Area Network.



Actual Distance(Km)	Calculated Distance (Km)	% Error
25	24.19	-3.34
50	48.32	-3.34
75	72.48	-3.34
100	96.69	-3.35
125	120.80	-3.35
150	144.97	-3.34
175	169.12	-3.35
200	193.30	-3.34

Table-2. Two Area Network.



Actual Distance(Km)	Calculated Distance (Km)	% Error
25	24.99	-0.01
50	49.99	-0.01
75	74.99	-0.003
100	99.98	-0.01
125	124.97	-0.01
150	149.96	-0.02
175	174.98	-0.009
200	199.97	-0.01

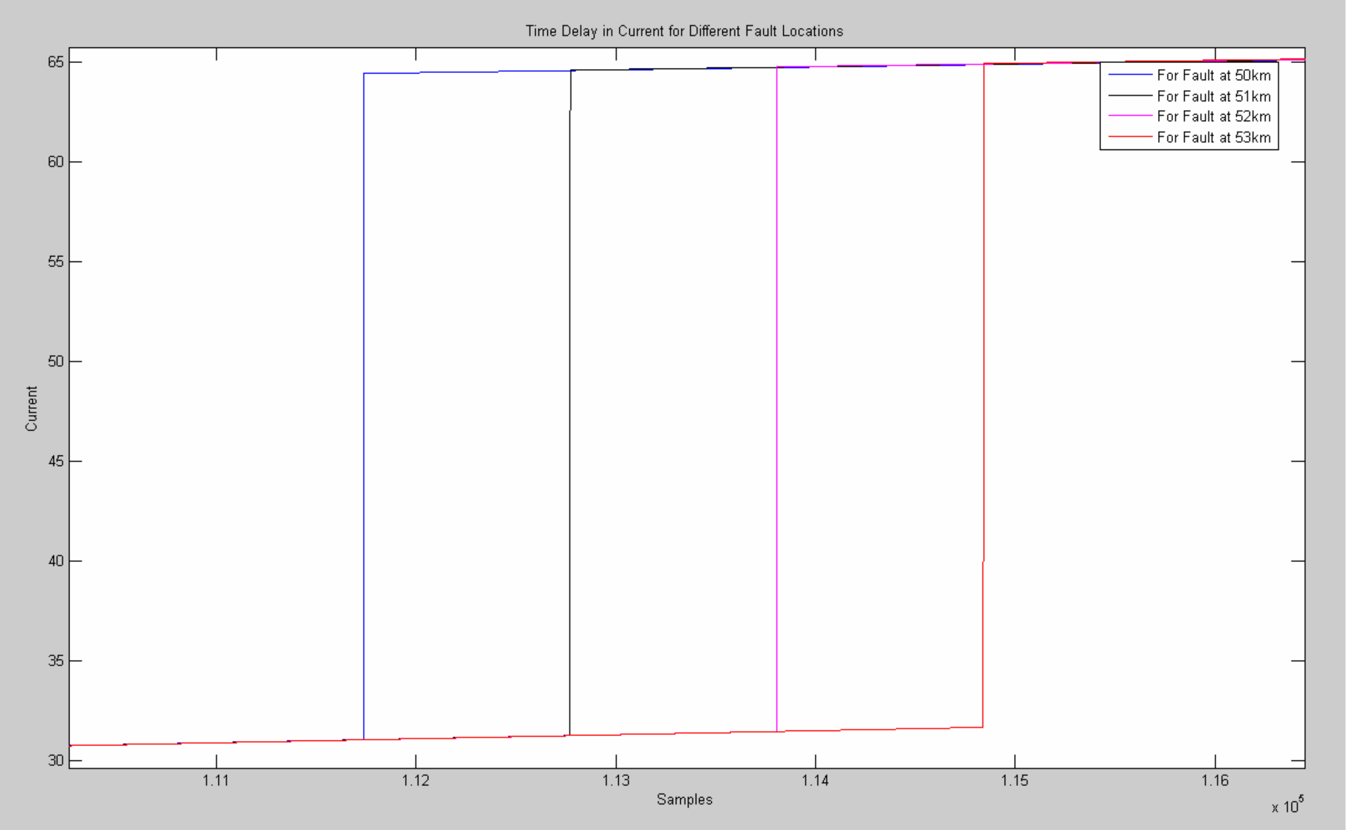


Figure-6. The shift in current waveforms for a fault created at 50, 51, 52, 53 km (two areas).

CONCLUSIONS

In the present work, fault location based on the characteristics of the traveling waves is tested using MATLAB. The error in fault location estimation is a function of the sampling rate and the speed of propagation. The technique was tested using data generated by executing various cases in MATLAB.

REFERENCES

[1] L.V. Bewley. 1951. Traveling waves on transmission systems. Wiley, New York.

[2] D. Spoor and J. G. Zhu. 2006. Improved single-ended traveling-wave fault-location algorithm based on experience with conventional substation transducers. IEEE Transactions on Power Delivery. 21: 1714-1720.

[3] T. Takagi, Y. Yamakoshi, M. Yamura, R. Kondow and T. Matsushima. 1982. Development of a new type fault locator using the one terminal voltage and current data. IEEE Trans. Power Apparent. Syst. Vol. PAS-101: 2892-2898.

[4] Wiszniewski. 1983. Accurate fault impedance locating algorithm. IEE Proc. 130(6): 311-314.

[5] N. Chen, X. Zeng, X. Tang, Y. Wang, Z. Liu. 2006. Software for Power Grid Fault Location with Traveling Wave. International Conference on Power System Technology, Power Con. pp. 1-5.

[6] Elhaffar M. Lehtonen. 2005. An improved GPS current traveling-wave fault locator in EHV transmission networks using few recordings. International Conference on Future Power System.

[7] Elhaffar N. I. Elkalashy, M. Lehtonen. 2007. Experimental Investigations on Multi-end Fault Location System based on Current Traveling waves. Power Tech 2007. Lausanne, Switzerland.

[8] Elhaffar M. Lehtonen. 2004. Traveling waves based earth fault location in 400-kV transmission network using single-end measurement. Large Engineering Systems Conference on Power Engineering 2004, LESCOPE-04. pp. 53-56.

[9] L. M. Wedepohl. 1963. Application of matrix methods to the solution of traveling-wave phenomena in poly phase systems. IEE Proceedings. 110(112): 2200-2212.