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Traveling wave method for analysis of faults in a high voltage transmission line

Método de las ondas viajeras para el análisis de fallas en una línea de transmisión de alta tensión

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This paper presents an analysis of the error presented in the location of faults by the traveling wave method, and the traveling wave method analyzing reflected waves. This analysis arises from the results of the simulation of a high voltage transmission line in the ATP-EMTP software that allows us to simulate faults in a very graphical way and gives, as a result, the waveform presented at the measurement points. The results show similar behavior between theoretical behavior and simulation.

Keywords: ATP-EMTP, fault location, high voltage, transmission line, traveling wave

En este artículo se presenta un análisis sobre el error presentado en la ubicación de fallas por el método de ondas viajeras, y el método de ondas viajeras analizando ondas reflejadas. Este análisis surge de los resultados de la simulación de una línea de transmisión en alta tensión en el software ATP-EMTP que nos permite simular fallas de una forma bastante gráfica, y da como resultado la forma de onda presentada en los puntos de medición. Los resultados muestran comportamientos similares entre comportamiento teórico y simulación.

Palabras clave: Alta tensión, ATP-EMTP, línea de transmisión, localización de fallas, onda viajera

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Introduction

Nowadays, one of the main drawbacks of power systems is when a fault occurs (Li et al., 2020; Saber et al., 2020). Whether its source is natural, or due to bad execution of work in the power system, these failures cause supply problems (Afrasiabi et al., 2020; Ren et al., 2020). One of the most worrying faults is those that occur in the lines, whether transmission or distribution, since the exact location of the fault is not known (Wang & Dehghanian, 2020). The entire section of the line to find it could take a long time, making the service inefficient. To estimate the place of occurrence of the fault there are a variety of methods that reduce the search space, and therefore maintenance costs. To mention some of these methods we have the application of the differential principle in the traveling wave method to determine the locations of faults in overhead lines with branches using the navigation approach (Barman & Hazarika, 2020; Gafoor & Rao, 2006). The least-squares method is used to determine the wave propagation velocity.

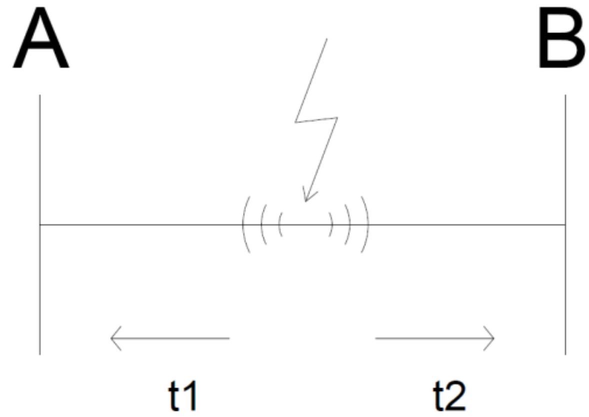
Another interesting method for estimating the location of a fault in the network is based on traveling wave analysis. The tasite advantage of this strategy is that it does not require the use of GPS global positioning systems for the synchronization of the system. In this case, to extract the transient wavelet from the wavelets recorded on the bus bars, wavelet elimination using the Wavelet transform is used (Abubakar et al., 2020; Cherif et al., 2020). The residual signal in this procedure has a large amount of information about the fault. The algorithm uses the statistical analysis parameters of the traveling wavelet as the input to a categorization system, which in our case is an artificial neural network (Rafique et al., 2021).

In this study, to perform fault studies on the different types of faults, and the performance of each strategy, type faults are generated using the ATP-EMTP software tool (Adly et al., 2020; Torres et al., 2020). The results obtained for each case are then categorized and discussed. The proposed network has a reliable response, an average error of 0.92% shows the power of the algorithm against the one based on reactance techniques. In contrast, this is a higher error than that obtained with the traveling wave-based fault location strategy, which uses GPS synchronization.

Regardless of the strategy used to estimate the location, the fault location method is costly because the measurement is associated with the value of the equipment to be used (Huang et al., 2020; Rivas & Abrão, 2020). This is because it is required to quantify fairly small time differences, and therefore, the equipment must have quite demanding accuracy characteristics. However, the benefits of locating a fault on a major transmission line outweigh this value (Yousaf et al., 2020).

Figure 1

Traveling waves produced on a fault.



Fault location principles

Traveling waves

This strategy is based on electromagnetic pulses of current and voltage signals with very high frequencies that are produced by a transmission line fault. These disturbances can occur due to atmospheric phenomena, connection, or disconnection maneuvers of the equipment, such waves propagate in both directions of the line from the fault (Fig. 1).

The propagation speed of this wave is the speed of light, i.e. 300,000 km/s. Thus, with a simple calculation, taking the time difference in which this wave arrives at the ends of the line, it is possible to calculate the distance at which the fault is located (Eq. 1).

$$d = \frac{L - v\,(t_2 - t_1)}{2} \tag{1}$$

Where:

- d = distance of the fault from node 1 [km].
- L = total length of the line [km].
- v = speed of light = 300,000 [km/s].
- t_2 = wave arrival time at node B [s].
- t_1 = wave arrival time at node A [s].

For the application and execution of the procedure of this method, quite precise equipment is required, since a variable such as speed, its precise measurement requires precise and quality equipment, and therefore expensive.

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Reflected traveling waves

The analysis of the traveling waves is complemented with the analysis of the reflected traveling waves, which shows how the reflection of the wave, an event that occurs at each node and the point of the fault, allows a redundant calculation to be made, since by using the reflection and refraction of the wave in the case of the point of the fault, a second distance calculation can be made, calculating the time it takes to travel the distance of the fault again.

Fig. 2 shows different waveforms corresponding to faults at different distances from node A (red wave) and node B (green wave). Thus we see that in signal (a) corresponding to a 50 km fault on a 200 km line, the traveling wave between the fault point and node A is reflected a couple of times before the fault is detected by node B. On the other hand in waveform (b) corresponding to a fault 30 km from node A, the wave is reflected between the fault and the node a total of 7 times. Waveform (c) corresponds to a fault very close to the study node, the wave is reflected many times in very small times compared to the two previous examples. Finally, the waveform (d) simulates a fault distance that corresponds to half of the line, being easy to notice that the times in which the waves and their reflections and refractions are the same in both nodes.

To record the times we can resort to the Lattice time-space diagram, where the movement of the reflected and transmitted waves are represented at any time, this diagram has the following considerations (Eq. 2).

- All waves start in a positive direction from left to right.
- The potential at any instant of time is the superposition of all the waves from which they arrive at the point until the instant of time, displaced in the position of each one by time intervals, is equal to the time difference of their arrival.
- The test values change in 10 km sections starting at node A and in the direction of the node, thus allowing a stepwise analysis of the results.
- The percentage error of the calculated distance concerning the actual distance calculated with the following equation is presented.

$$Error\,[\%] = \frac{\text{Calculated Distance} - \text{Actual Distance}}{\text{Total Line Length}} \qquad (2)$$

Methods

The study proposes a simple structure, where the methods selected at the beginning will be explained and an analysis of their use, advantages, and disadvantages will be made. A simple transmission line and two substations at the ends are used. For the ATP simulation, it will be simulated as if it were two lines of different lengths, and the fault will be simulated at the junction of these two. Signals are recorded to detect the variables necessary to perform the calculation by the traveling wave method.

These simulations will be performed with the fault in different sections of the line, thus changing the distance to be detected as a result. With the real distance, which would be the one entered in the line parameters, and the calculated distance, a percentage error calculation will be performed, which will be compared with other methods at the end.

A more complete version of this method will also be performed, which consists of adding the analysis with the reflected wave, a method that in theory gives better results. The different simulated faults will be performed with the element called splinter in the simulator, which serves to divide the three-phase scheme into three single-phase connections, thus allowing to simulate of a large number of faults. It will be possible to simulate single-phase ground fault, single-phase fault with impedance to ground, two-phase line-to-line fault, and two-phase line-to-ground fault.

Results

The transmission line is simulated with a length of 200 km with two generators at each end, with voltage at nodes A and Bus 2 of 230 kV. For the simulation of the fault, this section is divided with the element called *splinter* which serves to divide the three-phase scheme into three single-phase connections and thus make ground connections through timed switches, the design of the fault is presented with two lines in both directions which have the same model and occupy length values that together equal the 200 km.

The data resulting from the test are summarized in Table 1. The last column shows the comparative error compared to the theoretical values.

The average error for this method where no reflected wave analysis is performed is 0.2833%, thus demonstrating that it provides fairly accurate values considering the importance of the fault location in a real case.

Conclusion

When applying the method it can be observed that as the distance of the fault is greater the error decreases considerably, having an initial error of 0.5% and reaching an error of 0.025%, which suggests that the method is not accurate in short distances. Since the propagation speed of the wave corresponds to the speed of light, it can be deduced that the times measured by this method will be the same for any type of fault, a fact that was verified at the time of performing the simulation, which does not indicate that the method is indifferent to the type of fault and gives us the location of this regardless of its nature.

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Figure 2

Characteristic behaviors of reflected traveling waves. a) waveform for a fault at 50 km, b) waveform for a fault at 30 km, c) waveform for a fault at 10 km and d) waveform for a fault at 100 km.

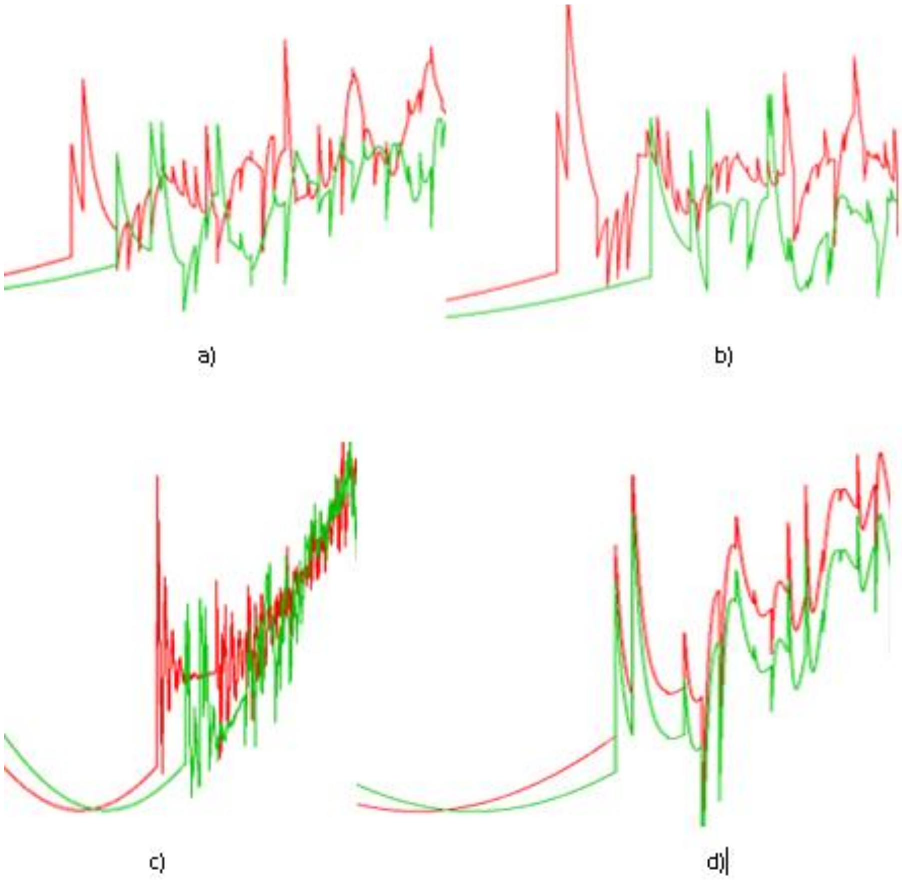

Table 1

Test data summary

Actual distance [km]	Measured time in A [s]	Measured time in B [s]	Calculated distance [km]	Error [%]
10	0.010034	0.010641	8.95	0.525
20	0.010068	0.010607	19.15	0.425
30	0.010101	0.010573	29.20	0.400
40	0.010135	0.010540	39.25	0.375
50	0.010169	0.010506	49.45	0.275
60	0.010202	0.010472	59.50	0.250
70	0.010236	0.010438	69.70	0.150
80	0.010270	0.010405	79.75	0.125
90	0.010304	0.010371	89.95	0.025
100	0.010337	0.010337	100.00	0.000

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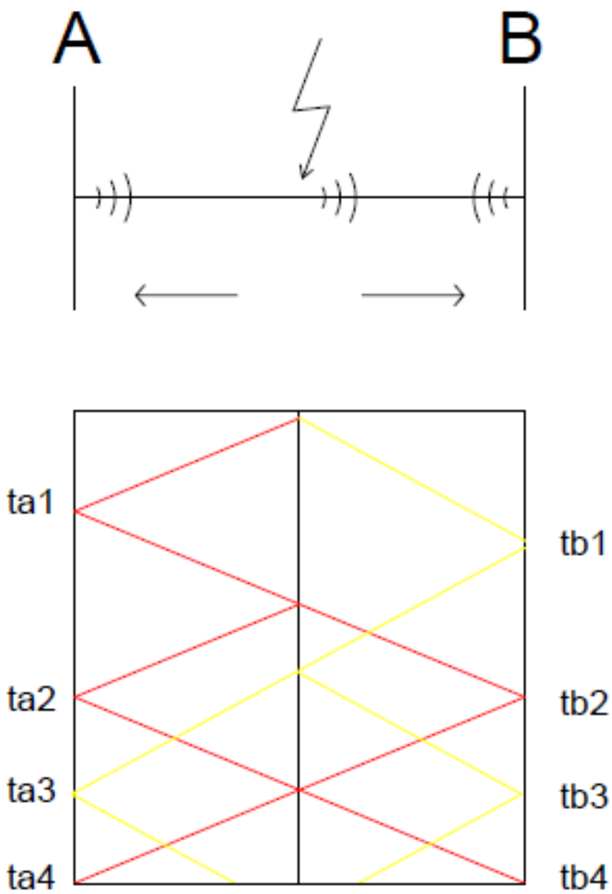
Figure 3

Traveling waves, fault model.



At the time of making the simulation, it was found that the equation with which distance is calculated gives us data very similar to the theoretical ones, it can also be said that the ATP program is a program that has many tools that help us to solve this type of problems, despite being free software, if it has some difficulties, it lacks aids, but for the same reason of being free to use.

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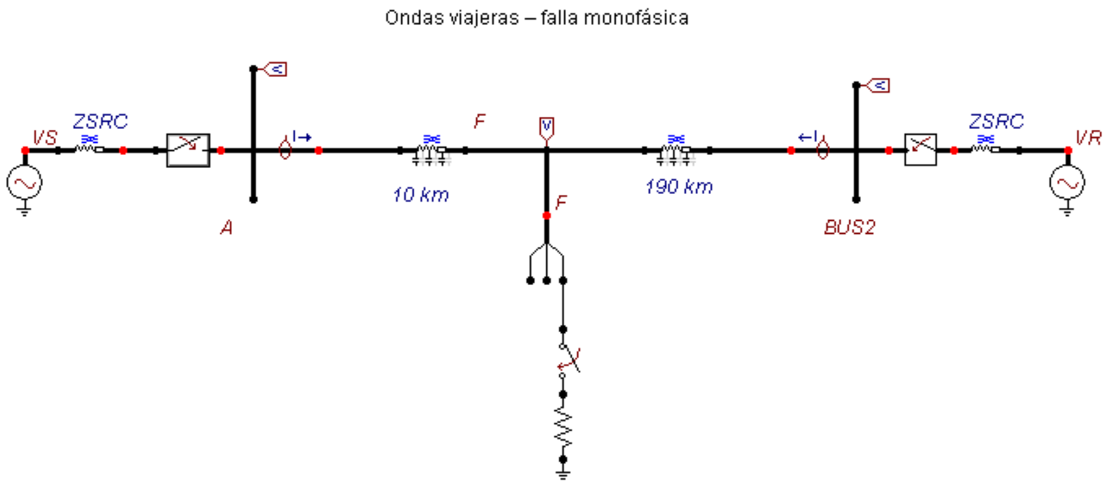
Figure 4

Traveling waves, single-phase fault.



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