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Fault Locating in Transmission Networks Using Transient Voltage Data

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Abstract

Generally, short circuit faults are the most important disturbances in power transmission lines. Accurate and fast finding of fault location, are the main characteristics of a proper fault locating system during transient and stable faults. In this paper, after a short review on current methods and techniques in the field of fault locating in transmission networks, a new method has been introduced using the data obtained from single terminal transient input voltage. The Wavelet Transform is used for identification of the transient wave receiving time in associated terminals. The performance of the proposed method has been tested on a standard network against various fault types, different fault resistances, and for several fault initial angles, using MATLAB simulation tools. The obtained results showed proper accuracy and correctness of the proposed technique.

Keywords: Transmission line; Transient and stable faults; Wavelet Transform; Fault locating; Traveling Waves;

1. Introduction

Remaining of the short circuit faults on transmission lines and elimination of the electrical torque against the mechanical torque of generation units causes serious problems for the stability of power systems. In this situation, isolation of the faulty part from the rest of power system in a minimum possible time is the main task of the protection system. Sometimes the outage of a transmission line leads to interruption of some loads and in order to improve the availability and security of power system it is essential to find fault location in a short time and perform the essential actions to eliminate the fault. Fault Locator is a device which is able to determine the location of faults fast and accurately. In addition to the possibility of quick fault clearance and fast returning of the faulty line, the application of fault locators

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helps utilities to find week and damageable points in power systems. Fault locating has several benefits such as time and energy saving, improvement of system readiness in electricity supply, future planning modification and economical factors improvement and finally leads to customers satisfaction and reliability increase in system. Generally, fault locators are classified in two major categories: 1) Methods based on impedance measuring and 2) Methods based on traveling waves.

1.1. Fault Locating with the impedance measuring method

In these methods the fault location is determined using the calculation of the main voltage and current phasors. These methods are also divided in two categories: methods which use the voltage and current information from one of transmission line terminals and methods which use the information from both of line terminals.

The first category methods are more economic, as there is no need to the communication channels between line terminals. However; in some presented algorithms, the negative effects resulting from the lack of data about the fault resistance and source parameters are unavoidable. Actually, the need to do some assumptions causes some errors in these methods [1-3]. The accuracy of these methods is dependent on how the line and loads are modeled.

Because most of the methods which uses single terminal data, have some errors resulting from the changes in some parameters such as the equivalent Thevenin impedance of sources in line sides, the fault initial angle, the line asymmetry, the fault resistance and the load condition; in order to improve the fault locating accuracy, the application of data from both terminals of transmission lines has been proposed and the modern communication technologies have prepared the possibility of receiving data from both sides of the line [3,4]. This group of methods has been introduced with two viewpoints in data sampling:

- Synchronous data sampling from both sides of the line
- Asynchronous sampling from both sides of the line

Impedance techniques require the separation and removal of DC and harmonics components of the waveforms. The elimination of these components is generally associated with some problems which could be solved using the equations governing the transmission lines in transient states, because various harmonics and DC components in the voltage and current waves also satisfied these equations and there is no need to remove them [5]. Impedance techniques were also very sensitive to fault resistance and the interaction between phases, so they were modified to overcome these problems.

1.2. Fault locating using the traveling waves

While enough data are available, another viewpoint which allows high-speed and more accurate locating of faults is the traveling wave method. These methods are based on the calculation or measurement of the time which is needed for the traveling of electrical waves from the position of the fault locator to the location of the fault. In traveling wave fault locating methods, the correlation between the waves passing the line from the fault location to the line sides is investigated and the fault distance is determined using the high frequency voltage and current signals recorded in one or both line terminals.

In the following sections, the methods and techniques which have been presented in the field of fault locating are reviewed and a new method using the single terminal transient input voltage data is introduced. The receiving time of the transient voltage to the terminal is determined using the wavelet transform and the fault distance is calculated using the principles of the traveling waves. The proposed method is also tested on a standard network.

2. Different types of fault locating with traveling waves

Because of several reasons such as high fault resistance, feeding from two sides and existence of series capacitors in transmission lines, the impedance fault locating methods did not work well. Therefore; the traveling wave methods have been applied since 1950. These kinds of fault locators are classified in four categories: A, B, C and D. At the beginning the high price of the products prevented utilities from vast usage of traveling wave fault locators, but nowadays with fast and economical microprocessors and computers, the A and D types are not very expensive but reliable enough. The auxiliary pulses and signals are not used in the methods A and D and only the transient states of faults are applied in these two methods. However; methods B and C use auxiliary signals in fault locating [2, 6].

2.1. Using of the Wavelet Transform in fault locating

The display of transient state using the Wavelet transform was first showed by Robertson et al. In that paper the application of the wavelet transform in power system protection was described [7].

At the same time Bo et al. presented a method based on traveling waves which found the location of faults with no need to auxiliary tools such as filters. The key point in this paper is the sampling of transient voltage or current using the proposed tools with enough accuracy. The traveling wave's roles in transmission lines have been used, and the fault detection and locating has been done by transient wave analysis in two line terminals [8]. One year later Bo et al. presented another method for fault locating in overhead lines and cables using the traveling wave theory [9]. The effect of busbar capacitance in reflection and depletion of the waves was also considered and a minimum sampling rate according to line length was finally presented in a table.

At the same year Yibin et al. showed that the Wavelet transform can be used to extract the main frequency component. The fault location determined using the main component and the wavelet method was compared with the results obtained from the standard Fourier transform method [10]. Lee and his colleagues also showed some of wavelet transform applications in power system analysis. It was showed that wavelet transform is useful in fault detection and locating, determination of fault type, comparison of data and system analysis under short circuit condition [11].

Yan et al. used discrete wavelet packet transform in finding the faulty parts, fault detection and accurate fault locating in networks containing LV branches [12]. In this method a characteristic matrix is developed using the fault signal local energies and the faulty part is identified by comparison of energies with a standard margin. The accurate location of the fault is then determined by identification of the faulty part and the wave reflection time.

Following the developments in the field of fault locating, Elhaffer et al. used the wavelet transform and sampled the input data from the outputs of current transformers (CT), because the capacitive voltage transformers (CVT) do not pass the high frequency components. They tested their method on transposed and in-transposed lines and proper fault locating was observed in 2nd and 3rd modes [13]. Some almost similar methods were also presented in [14-18].

3. The proposed method

Figure 1 shows the lattice diagram which is used to describe the proposed method. Suppose that a fault occurs in a point with distance x from busbar R. The traveling waves generated due to the fault are published toward the busbars.
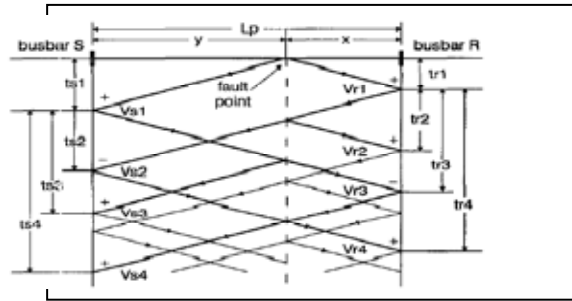
Fig. 1. The Lattice Diagram for a lossless single phase overhead line

Measuring the receiving time of high frequency transients to the location of busbars, the method of finding the location of fault is described below.

3.1. Installation of fault locator in busbar R

According to Figure 1, the signal V_{r2}, which is the reflected wave of V_{r1} from the location of the fault, is identified at busbar R after $t_{r2}=2*t_{r1}$ from receiving of the first wave (V_{r1}) to the same busbar. Therefore; the distance of the fault from busbar R is calculated from the following equation:

$$x = \frac{v \times t_{r2}}{2} \tag{1}$$

where v is the wave propagation speed.

3.2. Installation of fault locator in busbar S

In this case, according to Figure 1, due to a fault occurrence at a point with distance y from busbar S, the signal V_{r1} receives at busbar S at the time t_{s1}. This signal then reflects and after reaching the fault location, returns again toward busbar S (signal V_{s3}) and at the time of t_{s3} it receives at busbar S. But the wave V_{s2} which is reflected from busbar R, reaches the busbar S at the time of t_{s2}, before receiving of V_{s3}. In such condition the application of Equation (1) leads to incorrect responses in fault locating. Thus, the correct location of the fault can be calculated using the following equation:

$$x = \frac{v \times t_{s2}}{2}$$
$$y = L - x \tag{2}$$

Before applying the Equation (2), it should be determined whether the receiving signal at busbar S has been reflected from busbar R or fault location. This is done by identification of the transient wave polarity at busbar S. The waves which are reflected from the fault location have positive polarity, while the waves reflected from terminal R toward busbar S have negative polarity (Figure 1). In this method, it is critical to determine the receiving time of the traveling waves accurately. Recently the wavelet transform has been applied to detect the fault times due to its ability in analysis of identification systems. For using wavelet, db4 wavelet is selected for mother wavelet and the results (received times) is earned from level1 of db4 wavelet.

4. The simulation results

In order to evaluate the proposed algorithm in this paper, a 220 KV, 3-phase case study network including a combined line (overhead and cable) has been simulated using Sympowersystem toolbox in the

MATLAB software. The studied line has a length of 100 km and is supposed to be completely transposed. The parameters of this line are shown in Table 1. The line has been connected to a 3-phase 220 KV network with a capacity of 500 MVA.

Table 1. The parameters of the overhead line and the cabel

Parameter name	Positive and negative sequences	Zero sequence
L [mH/km]	4.595	1.326
C [μF/km]	0.004762	0.008688

Figure 2 shows the simulated system in MATLAB. As is observed in the figure, the sampling is done at the sending terminal of the line. The sampling frequency is 1 MHz and the time interval has been considered one micro second.
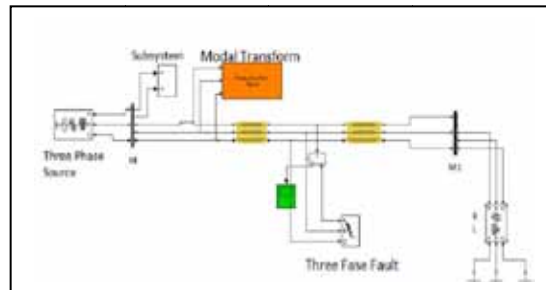

Fig. 2. The simulated system in MATLAB

The performance of the proposed algorithm has been simulated and investigated under different system conditions, various fault types, and several fault resistances and fault initial angles. The calculation error can be defined using Equation (3).

$$e = \frac{\left| x_{estimated} - x_{actual} \right|}{l} \times 100 \quad \%$$

(3)

While the estimated and actual fault location is considered from the sending end of the overhead line.

The simulations were run for faults occurred at the distance of 5 and 25 km from the beginning of the line, with fault resistance values of 0, 10 and 50 ohms, and initial angles of 0, 30 and 60 degrees for different types of faults such as single phase to earth, two phases to earth, three phases to earth, two phases to each other and three phases to each other. For example, for a three phase to earth fault at 15 km from the beginning of the line, with a 50 ohms resistance and 0° initial angle, t_1 and t_2 were measured 0.00679s and 0.00107s respectively. The calculated fault distance for this fault is 15.076 km which shows an acceptable calculation error of 0.076 %. The outputs of modals 1, 2 and 0 for voltage and the partial component of the modal 1 wavelet have been shown in Figure 3.

Other fault types with different fault resistances and various initial angles have been tested in the same way. Some results have been presented in Tables 2 and 3. Table 2 shows the fault locating calculation results for single phase to earth fault while Table 3 presents the results for two phase to earth faults at distances of 5 and 25 km, with fault initial angles of 0°, 30° and 60° .The effect of the value of fault resistance and fault initial angle on the calculation of fault location can be observed from the presented results.
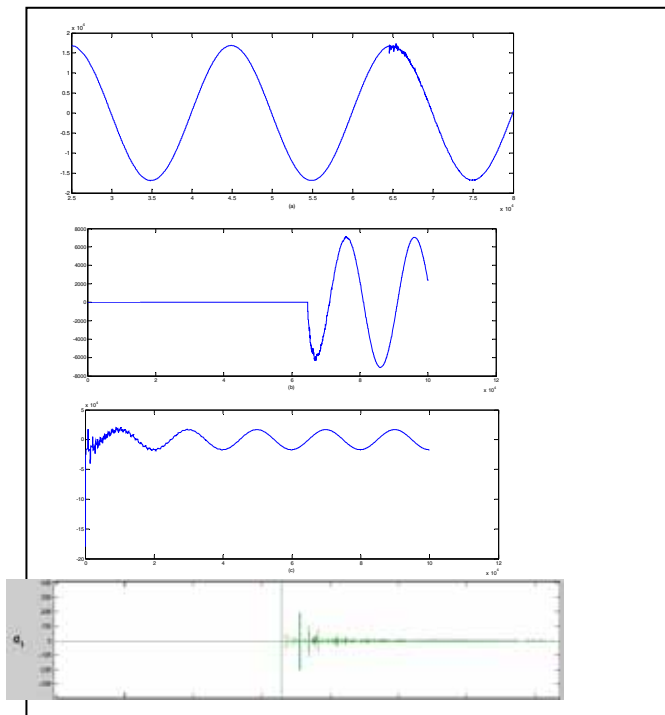
Fig. 3. The outputs of modals 1, 2 and 0 for voltage, and the partial component of the modal 1 wavelet

5. Conclusion

In this paper a new technique for fault locating in transmission lines was introduced using the Wavelet Transform. The quality and accuracy of the proposed method was evaluated. Considering the test results under different conditions (different fault types, various fault resistances and different initial angles), the proposed method has several advantages in fault locating such as:

a) no need to harmonic elimination
b) high accuracy and low sensitivity to variations in fault initial angle
c) high accuracy and low sensitivity to variations in the value of fault resistance
d) high accuracy and low sensitivity to variations in fault location
e) no need to the information of the fault type and the fault occurrence time
f) no need to the information about the fault location resistance
g) no need to the information about the fault beginning initial angle
h) no need to the information of load characteristics

Table 2. Fault locating results for a single phase to earth fault with different fault distances and various initial angles

Fault Type	Fault Resistance	Initial Angle	Actual Location of Fault	Calculated Location of Fault	Calculated Error %
Single phase to Earth	0	0	5	5.019	0.38
	0	0	25	24.91	0.36
	0	30	5	5.013	0.26
	0	30	25	24.92	0.32
	0	60	5	5.0213	0.426

0	60	25	24.98	0.08
10	0	5	5.0009	0.018
10	0	25	25.0008	0.0032
10	30	5	5.003	0.06
10	30	25	24.997	0.012
10	60	5	5.00287	0.0574
10	60	25	24.997	0.012
50	0	5	5.009	0.18
50	0	25	24.997	0.012
50	30	5	5.003	0.06
50	30	25	24.994	0.024
50	60	5	5.00287	0.0574
50	60	25	24.9925	0.03

Table 3. Fault location results for a two phase fault with different fault distances and various initial angels

Fault Type	Fault Resistance	Initial Angle	Actual Location of Fault	Calculated Location of Fault	Calculated Error %
	0	0	5	4.9975	0.05
	0	0	25	24.99	0.04
	0	30	5	4.998	0.04
	0	30	25	25.002	0.008
	0	60	5	4.994	0.12
	0	60	25	24.998	0.008
	10	0	5	4.991	0.18
	10	0	25	24.998	0.008
Two Phase to Earth	10	30	5	4.995	0.1
	10	30	25	25.005	0.02
	10	60	5	5.0008	0.016
	10	60	25	25.007	0.028
	50	0	5	4.9996	0.008
	50	0	25	24.9997	0.0012
	50	30	5	5.0007	0.014
	50	30	25	24.9998	0.0008
	50	60	5	5.00071	0.0142
	50	60	25	25.00082	0.00328

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