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Fault Location Techniques in Power System based on Traveling Wave using Wavelet Analysis and GPS Timing

***Abstract**. In this paper two approaches are proposed based on Discrete Wavelet Transform (DWT) and traveling wave to locate the fault of the three phase transmission line. The exact fault position is determined according to the instances in time when the fault waves arrive at each locator location and wave speed calculated on the basis of the proposed algorithms. To achieve actual data, synchronized sampling is needed which can be made possible by precise time receivers based on Global Positioning System (GPS) time reference. All the possible fault types are generated using the ATP-EMTP and results using the two methods are discussed. Extensive simulation studies indicate that the proposed approaches are reliable for rapid and correct identification of various fault cases.*

***Streszczenie.** Przedstawiono system do badania trójfazowej lini transmisyjnej. Metoda wykorzystuje falę wędrująca i dyskretną transformatę falkową oraz system GPS. Badania wykazały przydatność systemu do lokalizacji uszkodzeń sieci.(Technika lokalizacji uszkodzeń linii przesyłu energii wykorzystująca analize falkową i system GPS)*

Keywords: Power System, Fault Location, Traveling Wave, Wavelet Transform, GPS Timing.
Słowa kluczowe: lokalizacja uszkodzę, sieć transmisyjna, transformata falkowa.

Introduction

Transmission line faults are the most common faults, triggered by falling trees across lines, lightning strikes or insulator strings to flash over. Economic and reliable operation of a power system requires fast fault location and fast fault clearing. Concepts of availability, efficiency and quality have an increasing importance nowadays due to the new marketing policies which can be directly interpreted as a cost reduction or a profit increasing.

Conventional methods use measurements of voltage and current at the substations. Fundamental component during pre-fault and fault are used in these methods to estimate the apparent impedance viewed from the measurement point and then fault location. However, the estimation of fundamental components of voltage and current signals requires application of robust algorithms against the undesired effects of generated transient components after occurrence of the fault. This is the essential problem which limits the operation speed of conventional techniques for identification of the faults [1-4].

Traveling wave algorithms are based on the fact that an abrupt change of voltage and current at the fault point results in transient waves which propagate along the transmission line in both directions away from the fault point close to the light velocity. These high frequency waves carry useful information associated to the relevant fault location. Information refers to the sequence of reflection-transmission phenomena and can be useful for rapid identifying the fault location [5-8].

In traveling wave-based method, the fault location can be found by comparing the arrival time of the transient signals at a single end or multi-ends of the line terminals. Although the single-ended fault location method is less expensive than the multi-ended method, since only one unit is required per line and a communication link is not required, but the errors remain high. In this method the arrival times of the initial and reflected traveling waves at a single end of the line are used [9,10].

The fault location can be calculated by comparing the arrival time of the initial transients at two substations A and B using the known propagation speed of the traveling wave transient signals. The crucial issue in this method is the provision of accurate time synchronization and telecommunication. The Global Positioning System (GPS) which provides inexpensive, but highly-accurate timing and synchronization capability over a wide area as covered by a power system network, has always been a subject of interest for power system engineers. Fig. 1 shows a simplified block diagram of GPS-based time tagging for fault location.

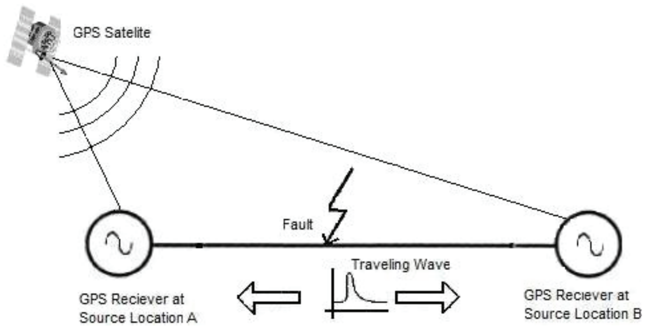

Fig. 1. Simple block diagram of GPS-based time tagging

Reference [11] presents methods which were designed and implemented to predict GPS receivers timing errors. GPS timing RMS error reduced to less than 38 nanoseconds which can be ignored against the other errors occurring in fault location procedure [12,13].

Most notable power signals include a combination of impulse-like events such as spikes and transients for which Fourier Transform (FT) and Short Time-Fourier Transform (STFT) and other conventional time-frequency methods are not as suitable for analysis. The identification of the characteristic frequencies should be therefore accomplished by using appropriate signal analysis techniques that allow the adjustment of the signal spectrum versus time. In this respect, the wavelet analysis is one of these techniques.

The Wavelet Transform (WT) has been found to be particularly useful for analyzing transient signals. Its ability to examine the signal in both time and frequency in a distinctly different way from the traditional STFT has spawned a number of sophisticated wavelet-based methods for signal manipulation and interrogation. On the other hand, the WT windowing is automatically altered according to frequency. Therefore wavelet analysis is suitable for rapid alterations in transient signal analysis. The capacity to show the local features of a specific area of a large signal demonstrates the strength of wavelet analysis [14,15].

This paper presents two fault location methods. The principles are explained and finally their validity will be proved by simulation results in last section.

Power System Simulation

For evaluation of the performance, a power system with 400 KV using ATP-EMTP is simulated according to Iran distribution management company and various types of faults are modeled [16]. The 200km one-line diagram of the studied system is shown in Fig. 2. Also, the fault current waveforms from ATP are shown in Fig. 3.

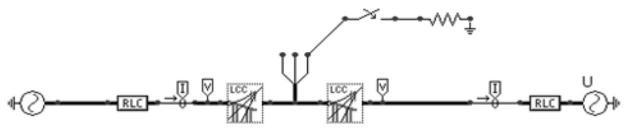

Fig. 2. Simulated 400-kV transmission line

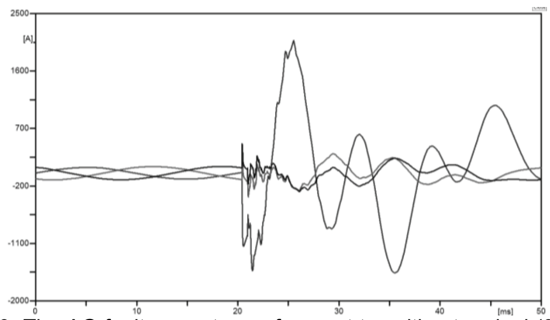

Fig. 3. The AG fault current waveforms at transition terminal (80km from transmitter)

The sampling frequency is considered to be 1 MHz. This way, close-in faults can be identified more accurately. Reducing this sampling frequency should be based on the frequency spectrum of the traveling waves [17].

Basic Principles

Traveling waves propagate along the line in both directions away from the fault point close to the light velocity. If we rely on the linear equation for the non-linear relation between fault location and traveling wave arrival times, we can have equation (1):

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

Where d is the fault distance from left source to fault location, L is the transmission line length (200km), t_2 is the time from fault distance to right relay, t_1 is the time from fault distance to left relay and v is wave velocity. Times are detected on the basis of high scale WT coefficients. The wavelet can be manipulated in two ways. It can be moved to various locations on the signal and it can be stretched or squeezed. If the wavelet matches the shape of the signal well at a specific scale and location then a large transform value is obtained. If however the wavelet and the signal do not correlate well, a low value of the transform is obtained. Different types of mother wavelet can be used for analyzing traveling wave. In this paper, the Daubechies 4 (db4) is used with five scales in order to separate the high frequency components [18].

Time of the first scale-one coefficient which is higher than a special threshold is recorded as the arrival time of the traveling wave. Allocating the correct value for transient wave velocity is very crucial in fault location accuracy according to equation (1). Any changes in this parameter can make the result completely different.

This paper presents two methods to calculate the traveling wave speed more accurately and therefore achieving better results.

The Effect of Fault Resistance

All the simulations are repeated by replacing the fault resistance 10 ohms by 50. Although the waveform will be changed because of fault resistance varying, but the fault location results are the same. It is believed that the algorithm performance will remain insensitive to variations in the fault resistance because of using appropriate WT.

Proposed Protection Algorithm I

In this approach traveling wave speed is calculated according to pre-measurements. To do so, some faults on the known locations are imposed to the line and after recording the arrival time of the transient wave, according to equation (1), v can be achieved. Because of using a linear equation for estimating non-linear relation, again if we calculate the fault distance by equation (1), some error will happen. The velocity average of the cases with better result and less error will be used as the traveling wave speed.

To examine this method of speed calculation, faults on the specific distances in different modes such as SLG, DLG, LL, 3-P (AG, BG, CG, ABG, BCG, CAG, AB, BA, CA and ABC) with two different fault resistances are simulated. The traveling wave arrival times are recorded and velocity average is calculated. For averaging, the cases with the errors less than 0.5% are chosen. Accuracy of the obtained results is very good and the error average of fault location is less than 0.16%. The calculated speed for simulated line was v = 2.966989416E8.

Proposed Protection Algorithm II

After fault occurring, traveling waves propagate along the line and at the discontinuities, a part of the energy is let through and a part of the energy is reflected and travels back. This reflected wave can be used for the purpose of speed calculation.

$$v = \frac{2L}{\Delta t_1 + \Delta t_2} \quad (2)$$

where v is the traveling wave speed for imposed fault, L is the line length and Δt_1 and Δt_2 are the differences of the arrival time of the main and reflected waves. Meanwhile, it should be considered that for close-in faults, detection of reflected wave times is not easy; because the reflected wave high frequency scale coefficients will be mixed with the main wave coefficients. So faults with suitable distances should be chosen for this algorithm. The traveling wave speed is the average of calculated speeds. Simulation for the proposed line results in v=2.94117647058824E8 which shows very high accuracy and leads to the error less than 0.06%.

Simulation Results

The simulation results of above-mentioned methods are discussed in this section and several test cases are compared. The fault resistances of 10 and 50 ohms are used, but the results are very close because of using the appropriate mother wavelet. The error percentage also is computed as:

(3) $$Error(\%) = \frac{|\text{Calculated Distance - Actual Distance}|}{\text{Line Length}} \times 100$$

Table 1 shows the results according to the first proposed fault location algorithm for LG faults. In the specified fault locations the distances and the error percentages have been calculated. The error average is less than 0.16% which is very good result for especially long transmission line.

Table 1. First protection algorithm response (for LG Type)

Actual distance (km)	Calculated distance (m)	Error (%)
10	9506.82	0.247
20	19594.59	0.203
30	29385.65	0.307
40	39473.42	0.263
50	49561.18	0.219
60	59945.64	0.027
70	69736.71	0.132
80	79824.47	0.088
90	90208.93	0.104
100	100000.00	0.000

The results obtained in the case of LG fault according to second proposed method are presented in Table 2. This table shows that for many cases the fault location method has a very good result with the least error. These high accuracy figures are due to using appropriate pre-measurements so the error average is less than 0.06%.

Table 2. Second protection algorithm response (for LG type)

Actual distance (km)	Calculated distance (m)	Error (%)
10	10294.12	0.147
20	20294.12	0.147
30	30000.00	0.000
40	40000.00	0.000
50	50000.00	0.000
60	60294.12	0.147
70	70000.00	0.000
80	80000.00	0.000
90	90294.12	0.147
100	100000.00	0.000

A plot for comparison of error in percent vs. Location in kilometer for LG fault is shown in Fig. 4.

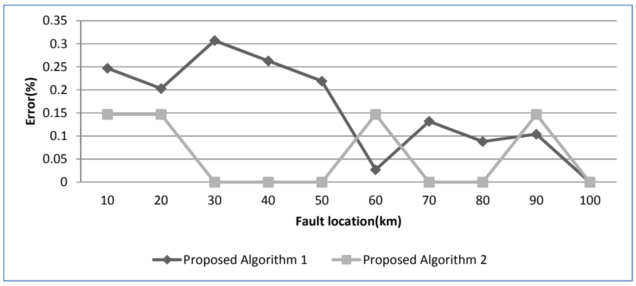

Fig. 4. Error comparison of proposed algorithms for LG fault

Consequently, in comparison between two approaches, the second one is more precise. Simulations and calculations show that both methods can identify fault locations for all the possible fault types with high accuracy. Tables 3 and 4 show these results for the first and second proposed algorithm, respectively.

Table 3. First protection algorithm response

Actual distance (km)	Error (%) [LLG]	Error(%) [LL]	Error(%) [LLL]
10	0.617	0.617	0.469
20	0.277	0.277	0.277
30	0.307	0.307	0.233
40	0.263	0.263	0.263
50	0.219	0.145	0.071
60	0.101	0.101	0.027
70	0.057	0.057	0.057
80	0.061	0.088	0.061
90	0.044	0.192	0.104
100	0.000	0.000	0.000
Average (%)	0.195	0.059	0.156

Table 4. Second protection algorithm response

Actual distance (km)	Error (%) [LLG]	Error (%) [LL]	Error (%) [LLL]
10	0.221	0.221	0.074
20	0.074	0.074	0.074
30	0.000	0.000	0.074
40	0.000	0.000	0.000
50	0.000	0.074	0.147
60	0.074	0.074	0.147
70	0.074	0.074	0.074
80	0.147	0.000	0.147
90	0.000	0.147	0.147
100	0.000	0.000	0.000
Average (%)	0.059	0.066	0.088

As an example, for the case of LLG shown in Tables 3 and 4, the error averages are 0.195% and 0.059%, respectively which proves that both methods have good results for this type of fault, specially the second one which uses the reflected wave for calculating the traveling wave speed.

Conclusion

This paper presents two algorithms for fault location. Both approaches are based on WT for processing of transient wave traveling along the transmission line and use GPS timing for synchronization. The traveling wave speed calculated according to the two proposed algorithms and the obtained results for various quantities of fault resistance and distance to relay point are reasonably good. The error percentage is calculated and the results are tabulated in Tables 1 to 4. It is observed that the error average percentages are very low and for the first and second methods are less than 0.16% and 0.06%, respectively.

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