The model of the power lines fault location method using time domain reflectometry

R I Shagiev[1], A V Karpov[1] and S A Kalabanov[1]

[1] Kazan Federal University, 18, Kremlyovskaya street, Kazan, 420008, Russia

E-mail: RIShagiev@kpfu.ru

Abstract. The article describes a simulation model of the method, locating power lines fault, using time domain reflectometry. This diagnostic method is a one-side method that can work on both enabled and disabled transmission lines and allows defining the main types of faults, including the high-impedance faults. The developed model consists of two modules: a generation unit implemented in PSCAD/EMTDC and a processing unit implemented in MATLAB. The model is successfully verified and is intended for a comprehensive study of the time domain reflectometry method for power lines diagnostics including analysis for various line topologies using different probing signals and various signal to noise ratio.

1. Introduction

Timely and accurate power grids diagnostics allows detecting electric line faults at the early stage, preventing the occurrence of major accidents and minimizing the idle time of the power lines [1].

One of the promising methods of power lines diagnostics is the time domain reflectometry method (TDR) based on the time interval measuring between the moments of probe signal sending to the line and the receiving of the reflected signal from the place of the power line fault [2-6]. The diagnostics method of time domain reflectometry is a one-side method, ie, a diagnostics device (locator) is installed on only one side of the line (generally at the beginning). Comparing with other methods of power lines fault location, the described method works on both enadbled and disabled lines, thus allowing an online monitoring and diagnosis of the state of the line.

The use of complex probing signals improves the sensitivity and resolution of the method. A rectangular video pulse can be used as the simpliest probing signal, while more complex signals such as bell-shaped pulses, Barker sequences, chirp signals provide more accuracy and reliability [5].

This article describes the developed model of the power lines diagnostic and fault location method, implemented in PSCAD/EMTDC in conjunction with MATLAB.

2. The structure of the developed model of the fault location method

The block diagram of the developed power line fault location model using time domain reflectometry is shown in Figure 1.

The simulation model consists of two main units: a reflectogram generation unit and a reflectogram processing unit. The reflectogram generation module is implemented in the PSCAD/EMTDC environment and provides the generation and sending of probing signals to the simulated power lines, as well as the subsequent recording of the resulting trace (reflectogram) and its saving to the file. The reflectogram processing unit is developed in the MATLAB. This module performs processing of the obtained traces and gives the result of the carried out power line diagnostics. If it detects the fault of the power line, the processing unit calculates and gives the distance to the found fault to the user.

A more detailed consideration of the developed model blocks is given in the following sections.

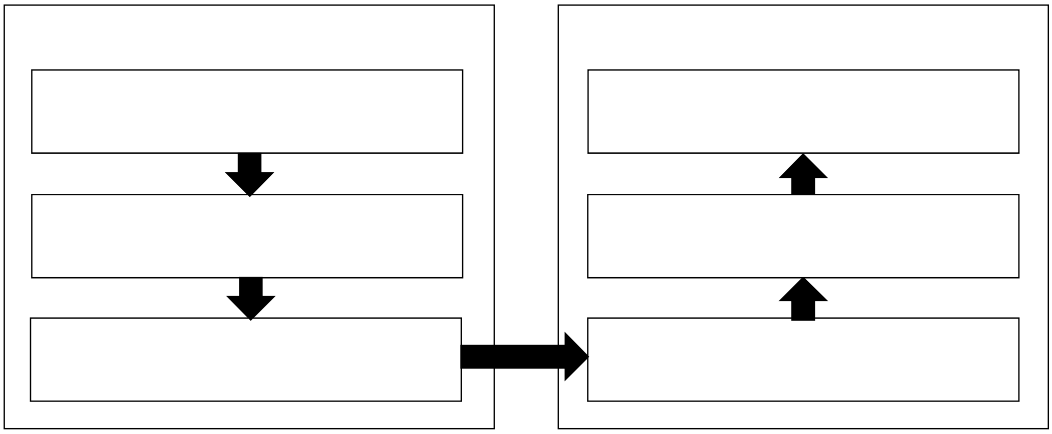

Figure 1. The block diagram of the simulation model for time domain reflectometry method.

3. The reflectogram generation unit

The model of electric line under test is implemented using component "T-Line" in the PSCAD/EMTDC simulation tool. The frequency dependent phase model is used as the basis of the electric line model, which is a model with distributed parameters (resistance of line *R* is distributed along the entire length with inductance *L* and capacitance *C*) and takes into account the frequency dependence of internal transformation matrices (thus, the model accurately describes both balanced and unbalanced systems). A more detailed description of the model is given in [7]. The used electric line model also takes into account the parameters of power line conductors considering earth return impedance, used type of wires and power lines construction (geometric parameters). The bare steel-aluminum conductors type of AC120/19 and transmission tower PS10P-14AM for that type of conductors were used in the model. Simulation of power lines is carried out in the frequency range of 0 – 100 MHz.

The generator of the probing signal has three implementations: a generator of single pulses, a generator of chirp pulses and the generator of Barker sequences. All types of generators are implemented using blocks of DC and AC voltage generators provided in the PSCAD environment with external control components, connected to them. These additional control components allow adjusting the parameters of the probe signal such as the start time of forming of the probing signal, the duration of the probing signal, the amplitude of the probing signal, the frequency deviation in the chirp pulse, etc.

As a result, a generation unit creates two reflectograms: a reference reflectrogram in normal line conditions (without damage) and an actual reflectogram (with simulated fault). Obtained traces are saved to a file, which are then analyzed by the processing unit, the second unit of the developed model.

4. The reflectogram processing unit

The reflectogram processing unit is implemented in MATLAB. The traces processing task includes differential trace analysis, cross-correlation processing, searching the reflection of the fault and calculating the distance to it. The processing unit also allows studying the power lines diagnostic method for various signal-to-noise-ratios (SNR) by adding noise components to generated reflectogram signals. Additive white Gaussian noise of different power was used in the model.

Noise simulation is carried out by mixing additive white Gaussian noise to the resulting reference and actual reflectograms; the noise value is set by a user in decibels relative to the amplitude of the desired signal. After the addition of the noise, the difference trace is calculated by computing the difference between the reference and actual traces. When the signal to noise ratio is low, correlation analysis is perfomed comprising calculation of the cross-correlation function between the sent to the line probing signal and the received echo signal. Extremums of the cross-correlation function correspond to the front of the reflected probe pulses [8]. Thus, the first extremum of the difference reflectogram cross-correlation function corresponds to the location of the line failure. Knowing the time of the double path of the probing signal to the fault location, the desired distance is calculated.

5. Verification of the fault location method model

To test the adequacy of the developed model for powerlines diagnostics, firstly, we consider obtained impulse responses for the simplest irregularities on the line such as active resistance of the various value with a probe signal generator (locator) output resistance consistent with wave resistance of the electric line. Figure 2 shows the simulation results. It can be seen that when the load resistance is less than the wave resistance of the line, the reflected pulse changes its polarity. When the load resistance is larger than the line wave resistance, pulse polarity remains the same. In case of equality of the load resistance and wave resistance the reflected pulse is absent. These simulation results are completely consistent with the theory [9].

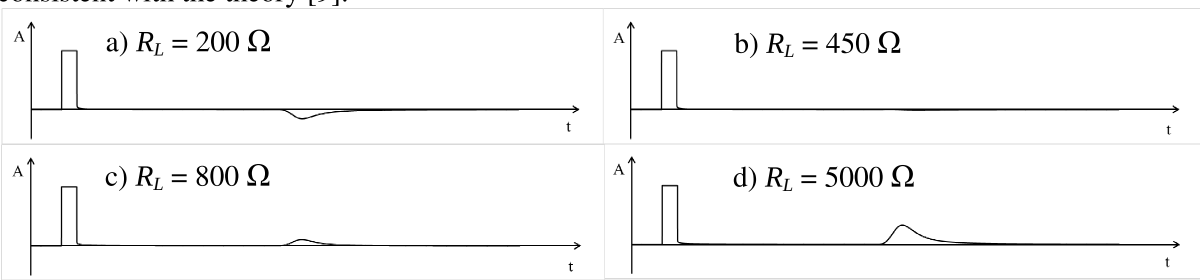

Figure 2. The simulated reflectograms for single wire AC120/19 with the length of 10 km for various resistive loads: a) R_L = 200 Ω; b) R_L = 450 Ω; c) R_L = 800 Ω; g) = R_L 5000 Ω.

For further test of the model adequacy, we will consider the reflectograms obtained for different power lines topologies and the voltage class.

a) The 6-10 kV straight transmission line.

We will simulate a linear three-phase 6-10 kV power line (conductor AC120/19, tower PS10P-14AM) with the length of 40 km. For more comprehensive testing of the model, all possible types of faults are simulated (short circuit faults between lines and between lines and ground, as well as open-circuit faults) at a distance of 30 km from the beginning of the line. The probe signal – signal video pulse with an amplitude of 1 V and duration of 5 microseconds. The locator is matched to the power line characteristic impedance and connected directly to the first phase “A”.

Figure 3 shows the reference reflectogram of the power line, obtained in the absence of damage. The probing pulse is sent into the line at time t_1 = 0.1 ms. Pulse reflected from the end of the electric line comes to the beginning of the line at time t_2 = 0.366 ms and has the same polarity as the sent probe signal. There was almost a two-time decrease of the reflected pulse in the amplitude, which changed its shape because of the filtering properties of the line.

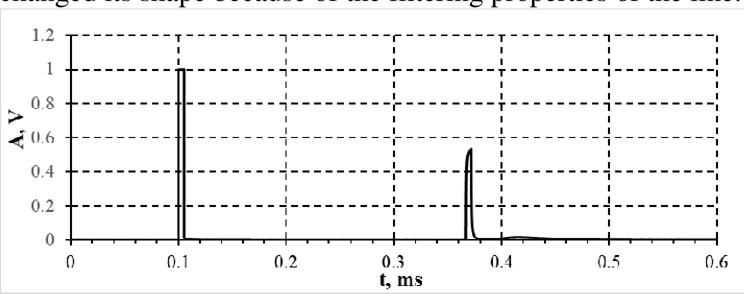

Figure 3. The simulated trace of the 6-10 kV power line with a linear structure without fault.

Knowing the pulse double travel time on the received trace, we can calculate the length of the power line. According to equation (1), the length of the line will be equal:

$$l = \frac{(t_2 - t_1)}{2} \cdot c = 0.133ms \cdot 3 \cdot 10^8 \frac{m}{s} = 39.9km \tag{1}$$

Where c – pulse propagation velocity (approximately equal to the speed of light).

Thus, the calculated length of the line coincided with the true length (simulated).

Figure 4 illustrates the reflectograms of the power line with faults. When simulating a short circuit to ground (Figure 4.a) the reflected pulse changes its polarity. The greatest amplitude of the pulse, reflected from the place of the line fault, is observed when phase "A" is damaged, i.e., the phase connected to the pulse generator. The distance to the fault, calculated by the reflectograms, is equal to 30 km and coincides with a simulated distance. A similar picture of reflected signals is obtained by modeling line-to-line short circuits (Figure 4.b). When simulating breakage of power line wires (Figure 4.c), the reflected pulse retains its polarity. Simulated reflectograms show that the time domain reflectometry method allows locating most of the transmission line faults.

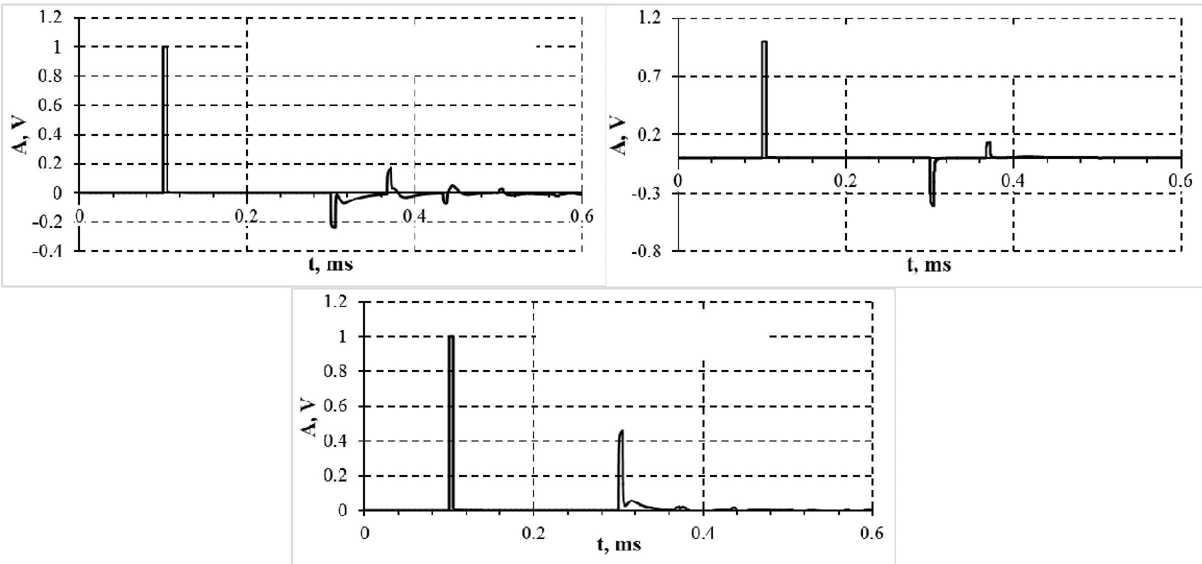

Figure 4. The simulated traces of the 6-10 kV power line with a linear structure with various faults: a) phase A shorted to the ground, b) short circuit between phases A and B (or A and C), c) phase A is open circuited.

b) The 6-10 kV transmission line with one branch

Next, we will consider a three-phase 6-10 kV power line with one branch (conductor AC120/19, tower PS10P-14AM). The topology of the simulated power line with the designation of fault places (simulated fault locations marked by red color) is shown in Figure 5.

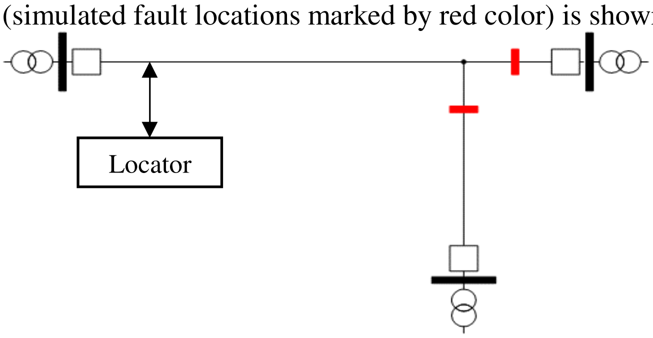

Figure 5. The topology of the simulated power line with one branch with the designation of simulated fault locations.

The length of the main (horizontal) segment of the power line is 40 km; the length of the branch line – 20 km. Faults were simulated at the points marked with red color at a distance of 5 km from the starting point of the branch. The probe signal – video pulse amplitude of 1 V and a duration of 5 microseconds. The locator, similar to previous studies, is connected directly to phase "A" of the power line and matched to the line impedance.

Figure 6 shows the reference reflectogram of the power line without any damage.

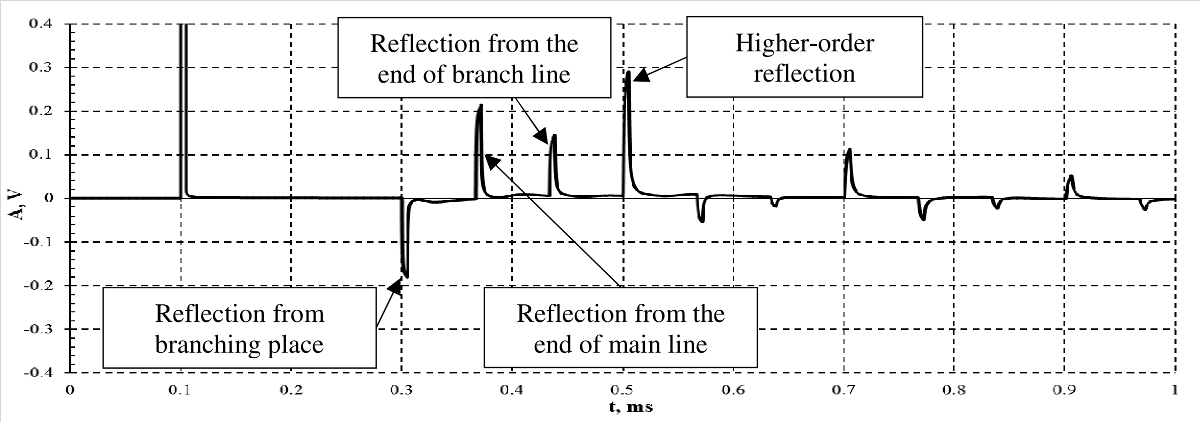

Figure 6. The reference reflectogram of the 6-10 kV power line with one branch.

The reference reflectogram consists of the sent probing pulse (at time t = 0.1 ms), reflection from the branch position (at time t = 0.3 ms), reflections from the ends of the power line and multiple higher-order reflections that attenuate in the amplitude. The amplitude of the pulse reflected from the end of the branch line is significantly smaller than the amplitude of the pulse reflected from the end of the main line segment. This is caused by the fact that at time t = 0.43 ms, two pulses simultaneously come to the signal receiving point (input of the locator) and are added together: the first pulse – reflected from the end of the branch line; the second pulse – reflected from a branch place and twice reflected from the end of the main line segment. Since the second pulse has a negative polarity, the amplitude of the resulting signal after the superposition of two pulses will be smaller. The fourth reflected pulse on the reference reflectogram has a maximum amplitude because of the superposition of two positive polarity pulses reflected from both ends of the power line. Further on the reference reflectogram, there are multiple reflections of the probing signal, a detailed examination of which is not of interest for the fault location problem.

Simulation of various faults on the power line with one branch gives results similar to those of the previous case, and agrees with theoretical calculations and experimental data [9, 10].

6. Simulation of the time domain reflectometry method for branched power line with the presence of noise

As an example, let us consider a three-phase power lines of 6-10 kV (wire AC120/19, power line tower PS10P-14AM) with the branched topology, similar to the real power lines (Figure 7).

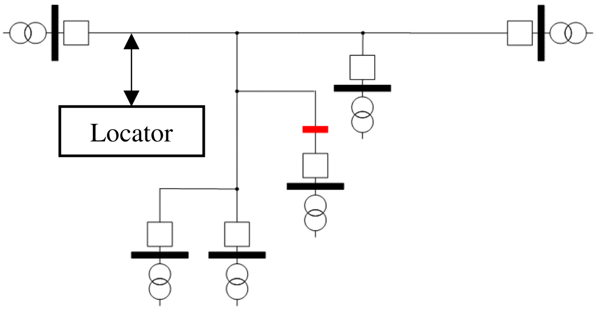

Figure 7. The topology of the simulated power line with a branched structure with the designation of the simulated fault location.

Figure 8 shows the result of simulation for the case of a three-phase short circuit to the ground with SNR=26 dB. The figure shows that the crosscorrelation processing of the difference reflectogram can reduce the amplitude of the random noise and increase the sensitivity of the location method.

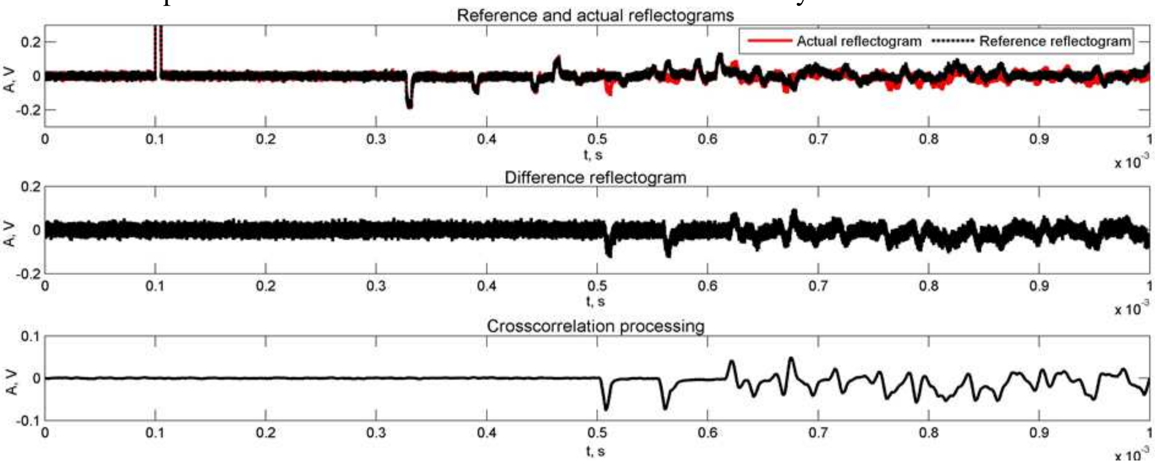

Figure 8. A simulation result for the case of a three-phase short circuit to ground fault with SNR=26 dB.

7. Conclusion

The developed model of the method of time domain reflectometry for power lines diagnostics, consisting of two main blocks – reflectogram generation unit and its processing unit, allows obtaining TDR traces of transmission lines with an arbitrary topology, operating both in normal and in fault conditions.

The developed model successfully passed verification by comparing experimental results with the theoretical data. The verification was carried out by simulating the simplest line irregularities, as well as simulating the linear and branched power lines. All possible types of power lines faults (one-, two- and three-phase open and short circuits to the ground, as well as all possible interphase short circuits) were simulated. Testing the developed model showed its adequacy and compliance with the experimental data and theoretical calculations.

The developed model can be used for a range of studies of the fault locating method, namely: comparison of the effectiveness of the method for different power lines topologies and various types of accidents, as well as the comparison of different probing signals by the sensitivity and accuracy of the fault location with different signal-to-noise ratios.

References

[1] Saha M M, Izykowski J J and Rosolowski E 2010 *Fault Location on Power Networks* (London: Springer) 425
[2] Li Q, Wang Y L 2009 *Dianli Xitong Baohu yu Kongzhi/Power System Protection and Control* **37(23)** 192–197
[3] Li Y, Wang J, Zheng Y and Zhou W 2001 *Dianli Xitong Zidonghue/Automation of Electric Power Systems* **25(14)** 36–39
[4] He J N, Chen J Y, Ai Y M, Lin P and Feng Q S 2014 *Dianli Xitong Baohu yu Kongzhi/Power System Protection and Control* **42(24)** 148–154
[5] Ghaderi A, Mohammadpour H A and Ginn H 2015 *Power and Energy Conference at Illinois (PECI 2015)*
[6] Shagiev R I, Karpov A V and Kalabanov S A 2014 *Applied Mechanics and Materials* **666** 138–143
[7] Gustavsen B, Irwin G, Mangelrød R, Brandt D and Kent K 1999 *Proc. of IPST* 61–67
[8] Horan D M, Guinee R A 2006 *J. of Computers* **1** 31–39

[9] Shi Q, Troeltzsch U and Kanoun O 2010 *7th Int. Multi-Conf. on Systems, Signals and Devices (SSD-10)*
[10] Smail M K, Hacib T, Pichon L and Loete F 2011 *IEEE Trans. on Magnetics* **47** 1502–1505