# Modeling of Characteristics of Distance Relay Protection of High-Voltage Power Lines

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***Abstract*** **– The simulation of characteristics of the directional distance protection of high-voltage power lines is realized in the PSCAD/EMTDC software complex. The comparison of the characteristics of the distance protection with the circular and polygonal tripping characteristics is conducted by means of numerical simulation. The algorithm of the fault detector is developed. Such a fault detector prevents false tripping during oscillations of the power system and asynchronous motion of generators by means of controlling the vector increase of the negative sequence currents.**

***Keywords – modeling, distance protection, distance element, fault detector, oscillation, asynchronous motion.***

## I. INTRODUCTION

The reliability of electric power systems functioning in normal mode and, especially, in emergency and post-emergency modes to a large extent is determined by the correct operation of the relay protection and automatization (RPA). In particular, distance protection (DP), which is used as the main and reserve protection of power lines and reserve protections of auto transformers [1-3]. The distance principle is also implemented in protection against the synchronism loss of synchronous generators, in automation devices for asynchronous mode liquidation, and in a few other means of relay protection [4-6].

According to statistics, 25% of emergency changes in the exploitative state or operation mode of specified elements in power systems are due to the improper functioning of the RPA [1], which may cause severe accidents. Since breakdowns, defects, personnel errors, and natural disasters are also included in this statistics, the main reason for improper functioning of the RPA is the discrepancy in its setup to a specific regime conditions [4,5].

Insofar as field experiments in power systems, especially of an emergency character, as a rule, are not permissible due to the excessive complexity of full physical simulation of power systems, the main tool for setting and analyzing the RPA functioning is mathematical modeling.

The aim of the work includes the following:

- carrying out the numerical simulation of the characteristics of distance relay protection in the software complex PSCAD/EMTDC;
- comparison of the most common types of characteristics of the DP operation;
- development of the algorithm of the DP fault detector, which prevents false tripping during oscillations of the power system and asynchronous motion of generators.

## II. MATHEMATICAL MODEL

The power line with a nominal voltage of 220 kV, performed with the aluminum-steel wire conductor AC-300/39, was selected. This system is powered by two sources. Its equivalent circuit is shown in Fig. 1. The corresponding scheme to simulate the damage to the power line, was collected in the software complex PSCAD/EMTDC. Its layout is shown in Fig. 2.

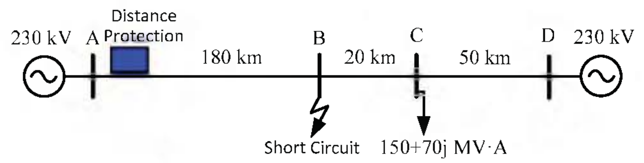


Fig. 1. Equivalent circuit electrical network

The circuit consists of the following components: B1, B2 – Three-Phase Breaker: the component simulates the function of a three-phase electrical circuit breaker; M1, M2 – Multimeter: the element measures the main electrical quantities; blocks AB, BC, CD – Line Configurations: the elements simulate the corresponding areas of the power line; S – Fixed Load: simulates the function of three-phase electric load; SC – Three-Phase Fault: it is used to simulate damages in a three-phase AC network; RS – Rotary Switch: performs the function of the short circuit switch with ten positions.

The mathematical model of the electric power line considers the position of the conductors in relation to the ground, the value of the sag, the presence of a lightning protection rope, and soil parameters.

To construct a distance relay protection we used the following components selected from the PSCAD library [7]: Fast Fourier Transform – decomposes the input signal (for the studied scheme – the currents of the phases A, B, C) into the values of the amplitudes of the harmonic components and the corresponding values of the phase shifts; Sequence Filter – carries out a linear transformation of the input values of currents' amplitudes and phases into magnitudes, which are proportional to the symmetric components of a three-phase system in the form of a module and a phase angle; Line to Ground Impedance – calculates phase and phase-to-point impedance. The tripping conditions are formed by setting the coordinates of the points of tripping characteristics, which was realized by means of the resistance element 'Trip Polygon'.

In the course of this work, we compared two kinds of working characteristics of the distance element (DE): circular and polygonal. Their forms are shown in Fig. 3.

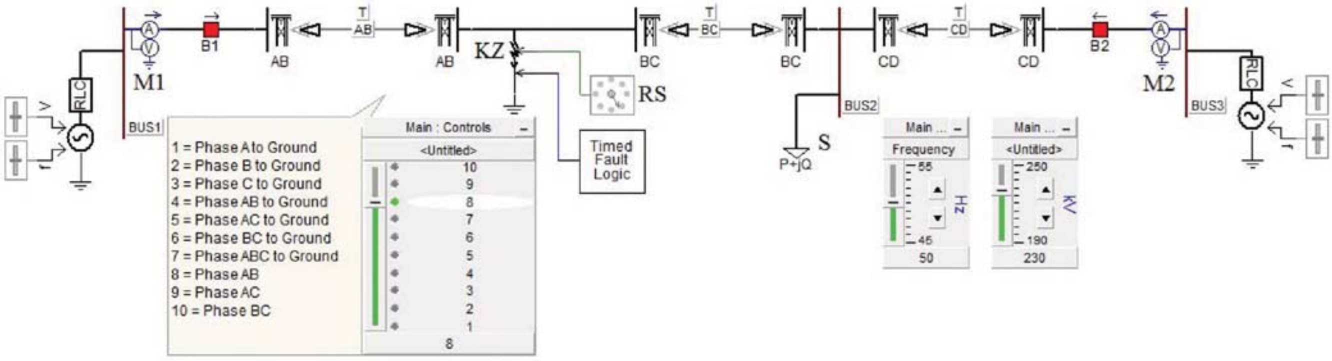


Fig. 2. Scheme to simulate damage to the power line

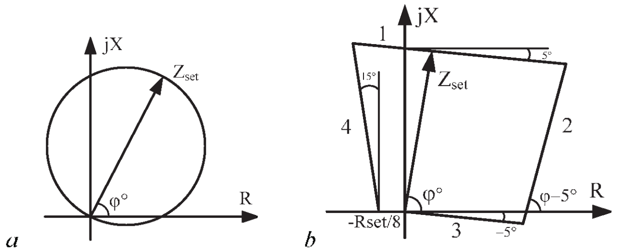


Fig. 3. The working characteristics of the distance element: *a* – circular; *b* – polygonal

The following factors influence the choice of the DE working characteristics type:

- transient resistance at the fault point;
- load conditions;
- generator swinging and asynchronous running conditions.

The presence of the named and other factors requires, on the one hand, expansion of the DE operation zone to ensure the coverage of possible fault types, and, on the other hand, the narrowing of this region to ensure non-operation in the event of a fault outside the protection zone or fault absence.

The circular characteristic is most widespread because of its simple realization and exploitation. In turn, the polygonal characteristic has the following advantages [5]:

side 1 – provides the DP increased selectivity during an arcing short circuit;

side 2 – reduces the transient resistance impact;

side 3 – ensures operation under a close short circuit regarding the DP installation point;

side 4 – considers the DE errors for static and dynamic conditions.

## III. NUMERICAL SIMULATION

To characterize the response speed of the DE, the dependence of the DE operation time from the ratio of the resistance between the DP installation point and the short circuit's location to the resistance of the protected part of the power line is used. This ratio is denoted by $\alpha_k$ and is calculated using the following formula:

$$\alpha_k = \underline{Z}_k / \underline{Z}_l ,$$

where $\underline{Z}_k$ is the resistance of the line section between the DP installation point and the short circuit point; $\underline{Z}_l$ is the protected section resistance.

As a result of the numerical analysis of the power network states (Fig. 2), the DP working characteristics depending on the type of short circuit are obtained. The most typical of them are shown in Fig. 4. The carried out analysis of these characteristics allows us to conclude that the time of DP operation with a polygonal characteristic is less than that of a circular characteristic for any short-circuit type. Therefore, the polygonal characteristic will be used in the further calculations.

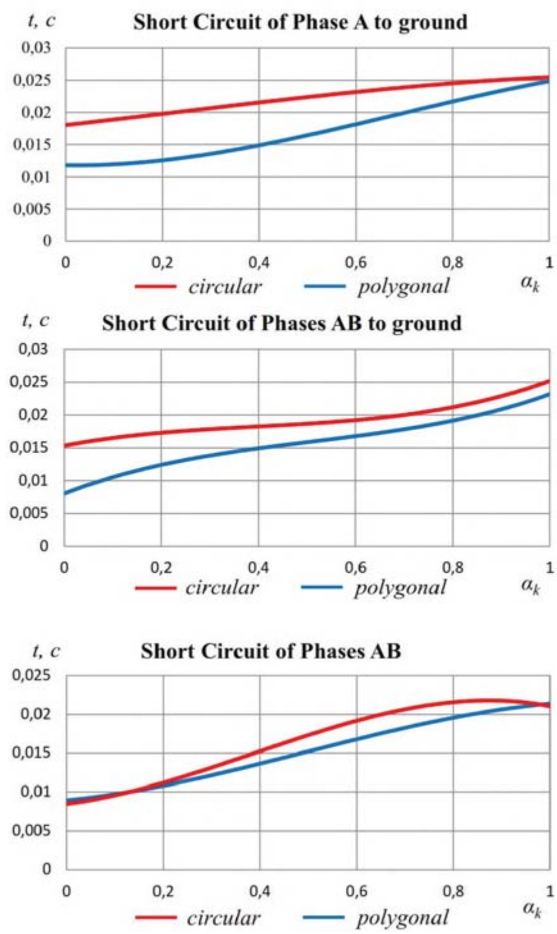


Fig. 4. The pickup characteristics of the distance element depending on the short-circuit type

The algorithm to eliminate the false tripping during the power swing and generators asynchronous running is proposed. The solution is based on the separation of the negative-sequence current vector increase.

Figure 5a depicts a vector diagram of negative-sequence currents at the moment of a short circuit in the beginning and in the end of the time interval. The difference between the vectors of these currents is the indicator of a short circuit mode. The oscillogram of the increase in the amplitude of the negative-sequence currents is depicted in Fig. 5b.

The above-mentioned algorithm realization in PSCAD software is demonstrated in Fig. 6. The block-chart of the algorithm is created in the PSCAD using the following blocks (Fig.6): 1 – the inertial element; 2 – the comparator; 3 – the signal delay; 4 – the sum/difference of signals; 5 – the constant; 6 – the sinusoidal signal generator.

During the asynchronous running of the generators, DE operates almost instantly without the occurrence of a short circuit. In turn, the software signal blocks it. At the event of asynchronous running of the generators or during the short circuit between the phases A and B, a tripping signal is sent to the DP.

Figure 7 shows the dependence of the operation time on the coefficient $\alpha_k$ . Analysis of this dependence shows that the DP operation time during the events of asynchronous running and different types of short circuits corresponds to the actual operation time of the real DP [4].

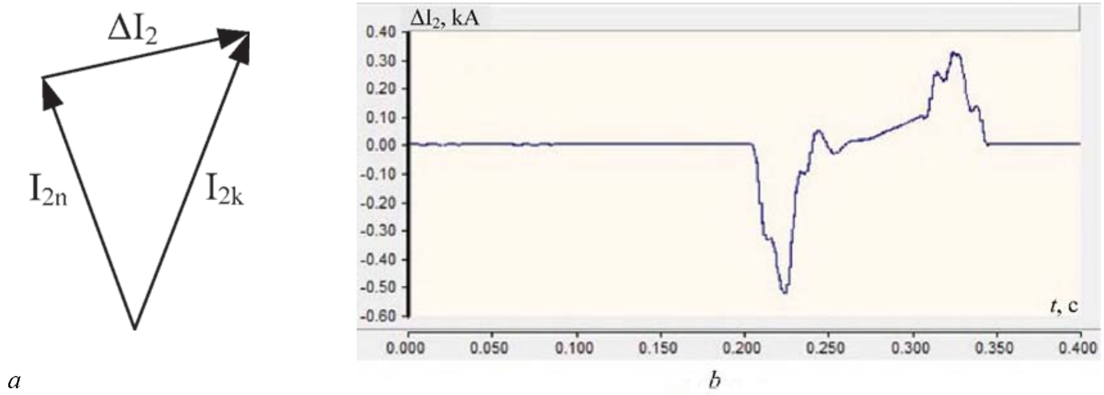


Fig. 5. The vector diagram of the negative-sequence current (*a*) and the oscillogram of the negative-sequence current in the case of a short circuit between the phases A and B (*b*)

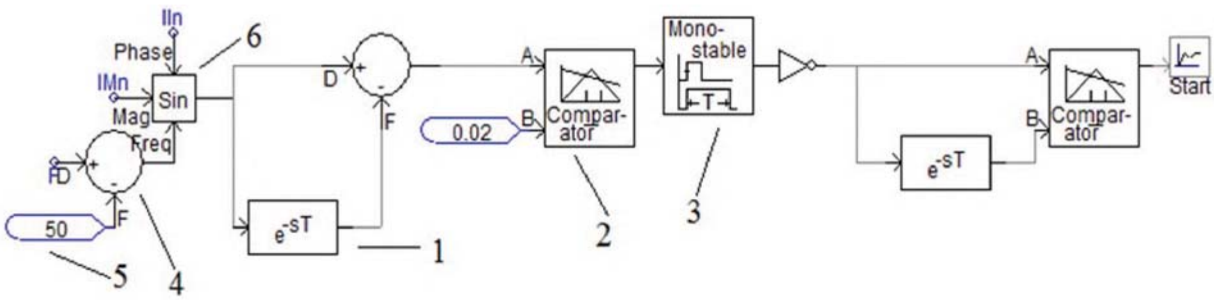


Fig. 6. The fault detector configuration chart

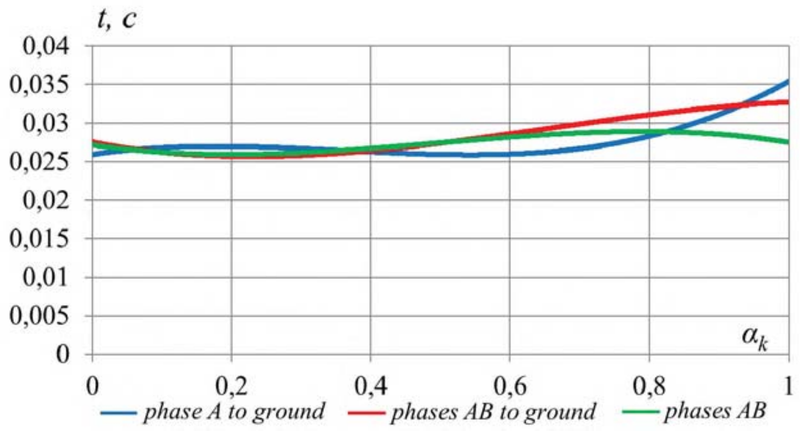


Fig. 7. Dependence of the distance protection operation time on the coefficient $\alpha_k$ in the event of generator asynchronous running and various types of short circuit

## IV. Conclusions

The proposed mathematical model allows real-time execution of various manipulations over the developed scheme and observation of all processes that occur in the system. All the processes taking place in the mathematical model correspond to those processes that take place in the real system. By numerical simulation, it has been shown that the polygonal characteristic is more accurate compared to the circular characteristic. The polygonal characteristic allows us to reduce the influence of the transients, to increase the selectivity of the DP in the event of arcing short circuits, to provide reliable operation in case of close short circuits regarding the DP installation point, and to take into account the DE errors in static and dynamic conditions. The offered DP operation algorithm allows us to prevent the false DP tripping in the event of generators asynchronous running and the power swing, thanks to control over the negative-sequence current's vector increasement.

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