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Development of intelligent protection and automation control systems using fuzzy logic elements

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ABSTRACT

In this article, the causes of technological disturbances in electrical systems are considered, and several characteristic disadvantages of the protection and automation of elements of electrical systems are highlighted. The tendency to decrease the reliability of relay protection associated with the transition from analog to digital types of protection is substantiated. Based on the studied examples, the use of fuzzy logic in protections, the expediency of using fuzzy logic elements in protection devices, and the automation of electrical systems to identify types of short circuits are justified. This article analyzes the most common damages and presents the results of modeling an electrical system with transformer coupling, where all types of asymmetric short circuits were initiated. The dynamics of changes in the symmetrical components of short-circuit currents of the forward, reverse, and zero sequences are determined. Rules have been created for the identification of asymmetric types of short circuits. An algorithm of protection and automation operation using fuzzy logic elements has been developed. The proposed algorithm of protection and automation will reduce the time to determine the type of damage and trigger protections.

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1. INTRODUCTION

Identification of types of short circuits in the elements of the electrical system is an important task in the field of the electric power industry. A short circuit occurs when the electrical current in a system flows in an unintended path with low resistance. This can cause serious damage to equipment and lead to accidents and power outages. Identification of short circuit types helps to quickly respond to such events and take measures to prevent and eliminate them. To date, elements of fuzzy logic are used in various industries, which demonstrate positive qualities [1]–[3]. The existing protection and automation circuits in relay protection are interconnected by many types of protection, which reduces their speed and reliability in general. Speed and reliability, in turn, are the main requirements for relay protection and automation. According to the results of the analysis of the causes of damage in electrical systems, several characteristic disadvantages of protection and automation of elements of electrical systems can be identified, such as the complexity of implementing the interaction of protections among themselves, reduced performance in determining the types of short circuits, false alarms, a large proportion of damage without determining the cause. In this regard, the development of an algorithm for identifying types of short circuits in the elements of an electrical system using fuzzy logic elements is relevant. The advantage of this algorithm is the ability to reduce the protection response time. An analysis of publications [4], [5] in highly rated journals was carried out, which allowed us to form conclusions, such as trends in decreasing reliability of protection systems built based on increasingly complex microprocessor protection devices (MPDs), insufficient reliability of MPDs, in particular, that a significant proportion of protection failures occur on microprocessor devices (approximately 23% of all cases), which make up only about 10% of the total number of protection devices. This is, of course, one of the most important factors determining the need to take special measures to improve the reliability of the MPD. This paper considers the identification of short circuit types in the elements of an electrical system, which is an active area of research in the field of the electric power industry. Several approaches and models allow you to define different types of short circuits, including situations with and without transformer coupling. Software tools such as MATLAB/Simulink or other electrical simulation tools allow the creation of virtual models that can be used to identify different types of short circuits. In such models, it is possible to take into account the presence or absence of a transformer connection and analyze the signals received in various elements of the electrical system. The development and application of algorithms for analyzing short circuit data, including clustering, classification, and anomaly detection methods, makes it possible to identify various types of short circuits and determine their parameters.

A literature review has shown that combining multiple functions in one microprocessor terminal dramatically reduces the reliability of protection, since if this terminal fails, too many functions will be lost at once compared to the case when these functions are distributed among several terminals [6]–[9], the need to limit the number of functions implemented in one terminal was also discussed in their reports by scientists at the international conference “modern trends in the development of protection systems and automation of power systems” [10]–[12], a sharp increase in the level of complexity of the work of personnel servicing protection with the transition to the MPD, as the cause of severe accidents in power systems [13], [14], the complexity of the software interface and the need to introduce an excessive number of set points during the programming of the MPR [15]–[17], the unsatisfactory state of the electromagnetic environment at most old substations, which were designed and built for electromechanical protection [18]–[20], and not for microprocessor protection [21], and about the numerous failures in the operation of the MPD arising from this [22], the lack of universal strict requirements for the hardware of the MPD and software, and as a result [23], too many programs and algorithms embedded in the MPD used in one power system, which leads to problems during operation and to increase the probability of false operation of these devices. Most of these devices must be installed in heated switchgear, since at temperatures below -25 degrees, the liquid crystal display with which microprocessor devices are equipped becomes unreadable. This is a particular disadvantage for the Northern region of the Republic of Kazakhstan since in winter the temperature can drop to -40 degrees, which makes it impossible to use these devices in complex outdoor switchgear. The device of microprocessor complexes is more complex and this is associated with several difficulties with their repair. If the electromechanical complex can be disassembled and replaced with a damaged part, then it is possible to repair the microprocessor complex only at the manufacturer [24], [25].

It was also noted that the sensitivity to electromagnetic interference of protection devices on a microprocessor element base is several orders of magnitude higher than that of their traditional electromechanical counterparts, and therefore, to ensure electromagnetic compatibility (EMC) of secondary circuits, it is necessary to dramatically increase the level of their electromagnetic protection. Without carrying out a complex of works to ensure EMC, it is impossible to achieve acceptable reliability characteristics of the MPD. All this creates a combination of several factors and criteria for the protection of electrical installations, the consideration of which is necessary, and the complexity of the organization of protection increases with the removal of protection from the consumer and approach to the power source. At the same time, the protection complex as a whole or separately must meet several requirements, and first of all, speed, quality, and reliability of operation. In this regard, a hypothesis is formulated about the application of fuzzy logic principles to protect objects of electric power systems. Identification of the types of short circuits in the elements of the electrical system is an important aspect of ensuring the safety of workers, society, and equipment. Early detection and classification of various types of short circuits allows you to quickly take measures to prevent accidents and minimize system damage. And also, knowledge about the types of short circuits and their parameters allows you to make informed decisions to improve the efficiency and reliability of the system, for example, by choosing the optimal settings for protective relays and circuit breakers, determining the causes and conditions for the occurrence of a short circuit, which in turn helps in developing a maintenance strategy and prevention of recurrence. All these factors confirm the relevance and importance of the topic of identifying the types of short circuits in the elements of the electrical system of the model with and without a transformer connection. Further research and development in this area has the potential to improve the safety, reliability, and efficiency of electric power systems.

2. METHOD

The modern electric power industry is a complex network and requires a high-speed, accurate, and emergency protection system. The quality of the protection of the overhead power lines is influenced by many designs' factors, the sensitivity of the protection, the tuning coefficient, the error of calculating the short-circuit current, and the error of the relay of the aperiodic component of the short-circuit current. It is quite understandable that the dependence on the principle of operation of current protections on the electromechanical element base causes a large number of preliminary calculations to determine the parameters of the circuit, the choice of equipment, and its configuration. At the same time, it is necessary to adjust and coordinate with other types of protections that work according to different principles. All this creates a combination of several factors and criteria for the protection of electrical installations, the consideration of which is necessary, and the complexity of the organization of protection increases with the removal of protection from the consumer and approach to the power source. At the same time, the protection complex as a whole or separately must meet several requirements, and first of all, the quality and reliability of functioning. Thus, it is possible to generalize the principle of operation of current protections, which consists in achieving the magnitude of the current strength of a given specific value. Identification of short circuit types in the elements of an electrical system based on fuzzy logic, together with the method of symmetrical components, is one of the approaches that make it possible to implement this task. During the experiment, data were collected on the current and voltage of various elements of the electrical system. These data are obtained using sensors and measuring instruments. The data has been pre-processed and removed for outliers and noise. The symmetrical component method for analyzing current and voltage signals separates signals into a positive sequence component, a positive sequence component, and a negative sequence component. An analysis of the amplitude, phase, and other parameters of each component is made. Fuzzy logic is used to determine the types of short circuits based on the parameters obtained from the method of symmetrical components. Fuzzy rules are defined as relate input variables (amplitudes and phases) to output variables (short circuit types). When performing this work, the input variables were fuzzified to bring them to fuzzy sets. Then, logical operations were performed on fuzzy sets by certain rules of fuzzy logic. Defuzzification transforms fuzzy output variables into crisp values that represent the identified fault type. And also, testing and evaluation of the effectiveness of the implementation based on various short circuit options was carried out.

Thanks to the latest technological advances, new and improved devices are being designed and developed to protect the power system using elements of neuro-fuzzy logic. The purpose of protection is to detect, classify and identify a fault with a minimum time delay. The most commonly used methods of fault identification are artificial neural networks and fuzzy logic. The neural network approach of fault identification is established as a successful methodology, but it requires training resources, therefore, it takes a lot of time. Error identification methods based on fuzzy logic are comparatively simpler since they require only some linguistic rules. Currently, fuzzy logic is widely used to solve real problems. Fuzzy logic is a set of mathematical principles used to represent knowledge, unlike classical binary logic. It is a powerful tool for dealing with uncertainty, which was originally introduced to provide reliable and inexpensive solutions to real-world problems. Fuzzy logic systems can be classified into three main types: i) simple fuzzy logic systems (pure fuzzy logic systems: Maimo); ii) fuzzy systems Mamdani, Takagi, and Sugeno; iii) fuzzy logic systems with fuzzifier and fuzzified [4]. Having studied the works of scientists published in highly rated journals, we can talk about the possibility of implementing the hypothesis of applying the principles of fuzzy logic to protect objects of electric power systems to identify types of short circuits in elements of electric power networks [4]–[11]. The proposed method based on fuzzy logic together with the method of symmetric components can be effective and efficient under various fault conditions. It will also increase the speed of protection.

3. RESULTS AND DISCUSSION

To experiment, models of an electromagnetic system with transformer coupling and without transformer coupling were created in the Simulink software Figure 1. On the created models, experiments were conducted on the occurrence of short circuits (single-phase, two-phase, two-phase to ground) at the beginning, in the middle and at the end of the lines. As a result of the experiments, waveforms of phase currents and symmetrical current components were obtained, and the dynamics of changes in the values of phase currents and voltages, as well as their components, were determined in Figure 2. Two models of an electromagnetic system with transformer connection and without transformer connection in MATLAB/Simulink were compiled to conduct experiments on the identification of types of short circuit on a power line. Figure 1 shows a model of an electrical system with a voltage of 110 kV without a transformer connection. The type of short circuits initiated are single–phase, two-phase short circuit, and two-phase short circuits to earth. The short circuit location was set at the beginning, in the middle, and at the end of the lines.

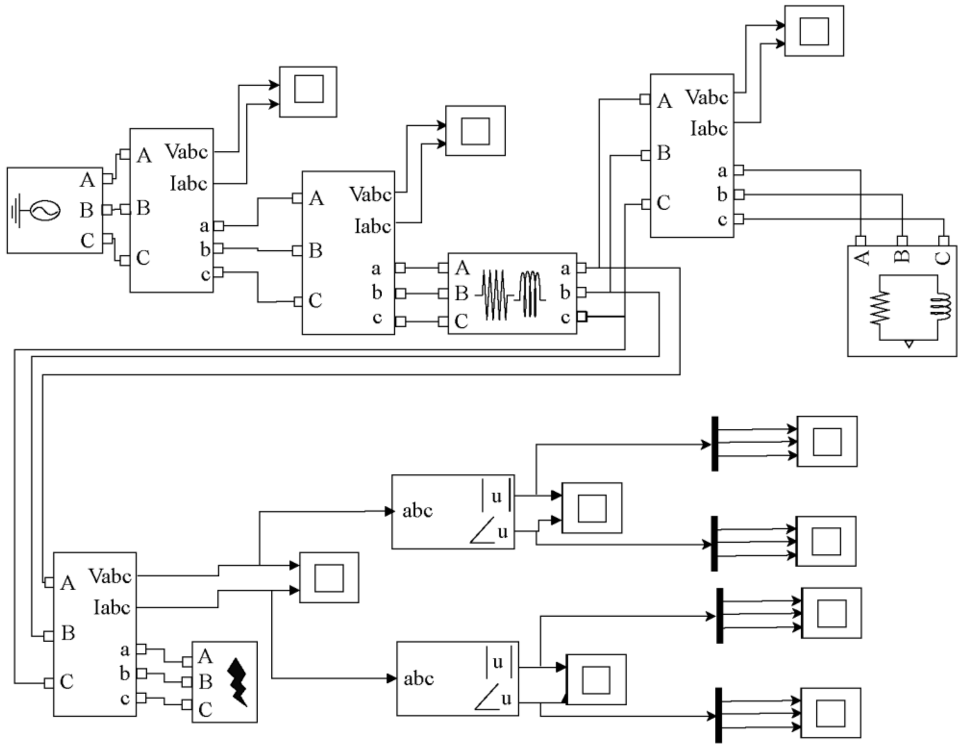


Figure 1. Model of an electromagnetic system without transformer connection

During the experiment, the variable parameter is the resistance of the lines, which can vary depending on the length of the lines, brand, and wire section. The calculation is given in relative units, respectively, the range of line resistance changes from 0 to 1. The same experiment was carried out for a 110 kV electrical network model with a transformer connection. The experiment was carried out before, during, and after a short circuit. The results of the experiment in the form of waveforms of the symmetrical components of the short-circuit current are shown in Figure 2, namely the waveform of the phase voltages and currents in Figure 2(a), the positive and negative sequence current in Figure 2(b), the zero-sequence current in Figure 2(c). The short circuit type is a two-phase short circuit, the damaged phase is the “B and C” phase, and the short circuit location is at the end of the lines. The moment before the short circuit was set to 0.050 s, the moment of the short circuit was set to 0.090 s, and the moment after the short circuit was set to 0.128 s.

The second experimental work was carried out in the Mathcad system. The calculation methods were based on the existing method of symmetrical components, which allows us to determine the values of currents and voltages of different sequences. Calculations were carried out in the system of relative units. The conditions of boundary conditions coincide with the theory. During the experiment, asymmetric types of short circuits (single-phase, two-phase, two-phase to ground) were initiated at the beginning, middle, and end of 110 kV power transmission lines. As an example, the results of calculations for a two-phase short circuit were given. Table 1 shows vector diagrams of currents and voltages constructed from the obtained values in the Mathcad system indicated in Figure 3. The results of calculations in the MatCad system for 110 kV lines with two-phase short circuits are shown in Table 1. Here are the values of currents and voltages, and their symmetrical components at the site of the short circuit.

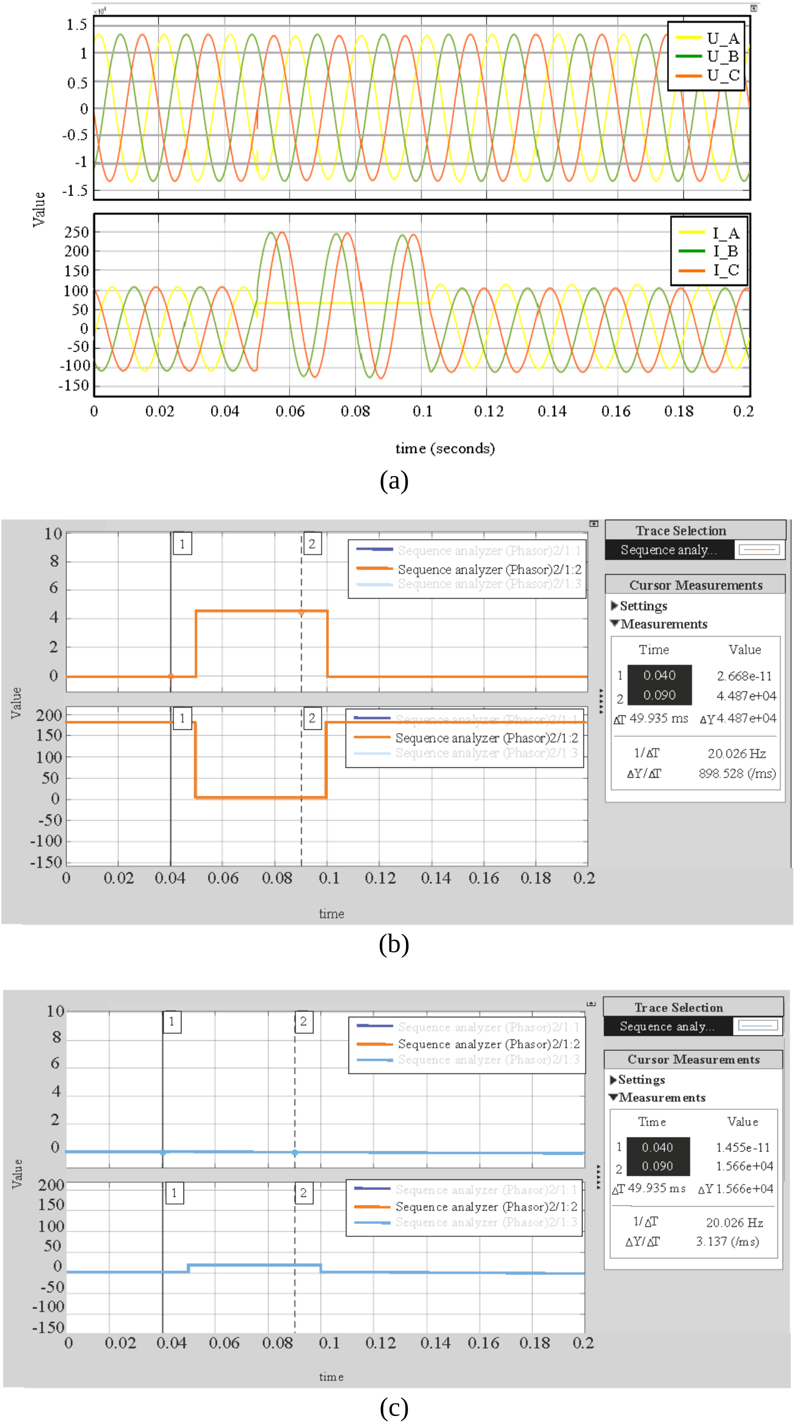


Figure 2. Waveforms of phase currents and symmetrical current components: (a) phase voltages and currents, (b) forward and reverse sequence current, (c) zero sequence current

Judging by the analysis of the data obtained, it can be concluded that a certain type of short circuit has approximately the same shape as the curve, as well as vector diagrams. Therefore, there is no need to determine specific numerical values of currents and voltages. To identify the types of short circuits, it is sufficient to determine the dynamics (trend) of changes in the above parameters. As evidence, Table 2 shows the dynamics of changes in the symmetrical components of the current for a two–phase short circuit at the end of the lines, where the damaged phase is the “B and C” phase. The data were obtained using existing microprocessor protection devices on 110 kV overhead lines of distribution networks in Almaty, Republic of Kazakhstan.

Table 1. Values of currents and voltages in two-phase short circuit

Types of damage	At the beginning of the lines	In the middle of the lines	At the end of the lines	Relative to the normal mode
K(2)	IkA1=-j17.23	IkA1=-j7.23	IkA1=-j5.11	Greatly increases
	IkA2=- IkA1=j17.23	IkA2=- IkA1=j7.23	IkA2=- IkA1=j5.11	Greatly increases
	Ik0=0	Ik0=0	Ik0=0	
	IkA=0	IkA=0	IkA=0	
	IkB=-29.84	IkB=-12.52	IkB=-8.84	Greatly increases
	IkC=- IkB=29.84	IkC=- IkB=12.52	IkC=- IkB=8.84	Greatly increases
	UkA1=0.5	UkA1=0.5	UkA1=0.5	Decreases
	UkA2=UKA1=0.5	UkA2=UKA1=0.5	UkA2=UKA1=0.5	Increases
	Uk0=0	Uk0=0	Uk0=0	
	UkA=2 UkA1=1	UkA=2 UkA1=1	UkA=2 UkA1=1	Without changes decreases
	UkB=UkC=-0.5	UkB=UkC=-0.5	UkB=UkC=-0.5	

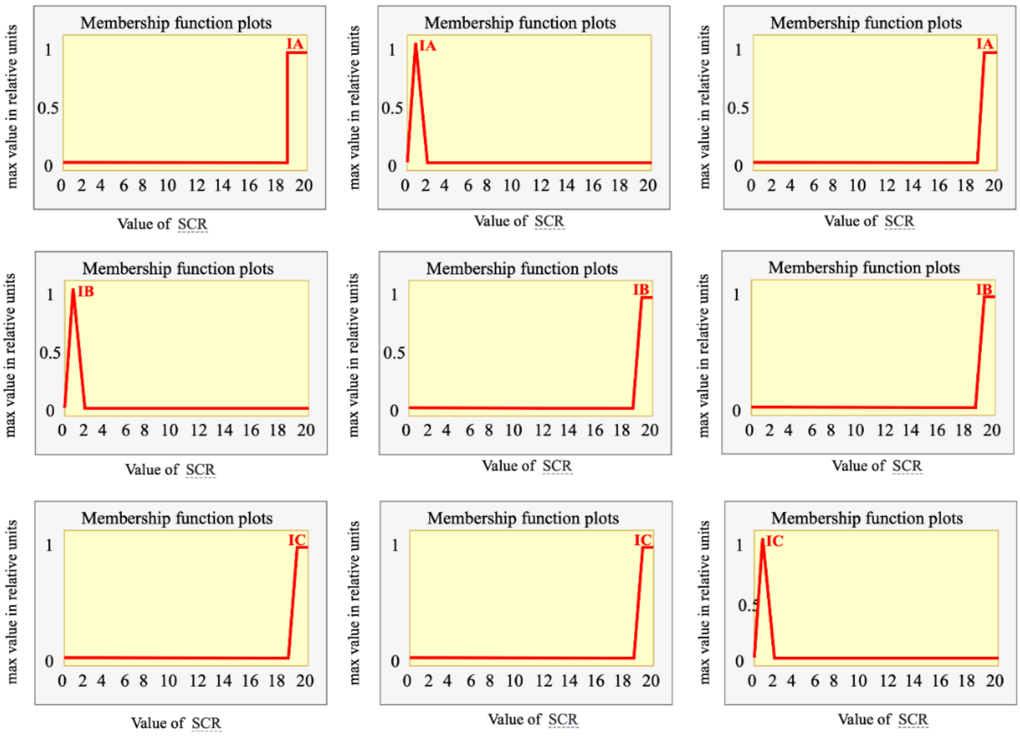


Figure 3. Vector diagrams of currents and voltages in two-phase short circuit

The dynamics of changes in the symmetrical components of current and voltage for a two-phase short circuit obtained during the experiment as shown in Figure 2 and Tables 1, 2 completely coincide with the data obtained using existing microprocessor protection devices. As a result of the experiments, rules for identifying types of short circuits have been created as shown in Table 3.

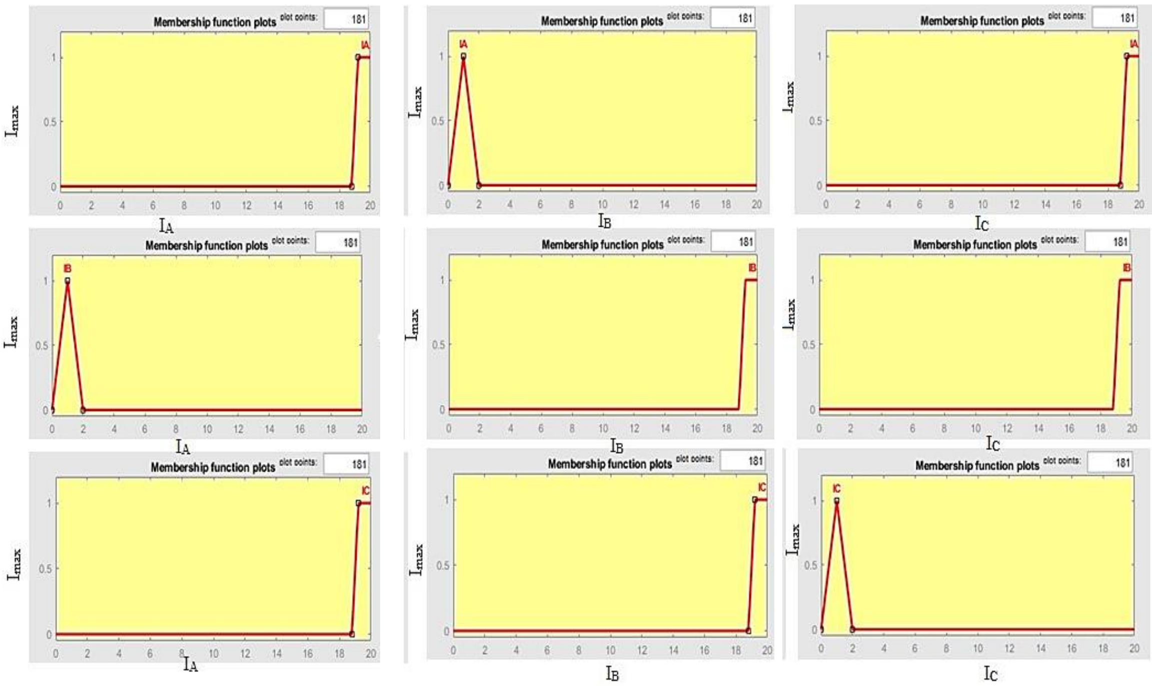
Table 2. Dynamics of changes in symmetrical components of current and voltage for two-phase short circuit

Currents and voltages at K(2)VS	Before the occurrence of short-term	At the time of the short circuit	After KZ
IA	100 A	90,3A	1,69A
IB	104A	2390A	1,4A
IC	100A	2450A	2,4A
I1	100A	1360A	1,7A
I2	0,9A	1440A	0,8A
I0	0,48A	3,98A	0,10A
UA	134 kV	133 kV	134 kV
UB	135 kV	110 kV	133 kV
UC	134 kV	112 kV	133 kV
U1	134 kV	118 kV	133 kV
U2	0,59 kV	15,9 kV	0,62 kV
U0	0,0556 kV	0,0743 kV	0,0609 kV

Table 3. Rules for identifying types of short circuits

	ikA1	ikA2	ik0	ikA	ikB	ikC
K(2) phases B and C	greatly increases	greatly increases ikA2=-ikA1	increases slightly	decreases	greatly increases	greatly increases ikC=- IkB

According to the rules for determining the types of short circuits, it is possible to determine the type of short circuit using elements of fuzzy logic. It is important to note that during a short circuit, the voltage tends to decrease to zero, and the current tends to increase as shown in Figure 4. Therefore, it is more efficient to determine the types of short circuits by the values of phase currents and their components, which are shown in Figure 4(a) two-phase short circuit in phases “A” and “C”, Figure 4(b) shows a two-phase short circuit in phases “B” and “C” in Figure 4(c) shows a two-phase short circuit in phases “A” and “B”.



(a) (b) (c)

Figure 4. Accessory functions for a multiplicity of short-circuit currents in two-phase short-circuit, implemented in the form of a triangle: (a) two-phase short circuit in phases “A” and “C”, (b) two-phase short circuit in phases “B” and “C”, and (c) two-phase short circuit in phases “A” and “B”

Fuzzy rule base for the identification of two-phase short circuit:

– If I_A increases greatly, I_B decreases, I_C increases greatly, and I_0 increases slightly, then this is to $K^{(2)}$ at phases A and C;
– If I_A increases greatly, I_B increases greatly, I_C decreases, and I_0 increases slightly, then this is to $K^{(2)}$ at phases A and B;
– If I_B increases greatly, I_C increases greatly, I_A decreases, and I_0 increases slightly, then this is to $K^{(2)}$ at phases B and C. The values of phase currents and zero sequence currents in real time are used as input data.

Identification of short circuit types in the elements of an electrical system based on fuzzy logic, together with the method of symmetrical components, is one of the approaches that can be used for this task. The benefits of fuzzy logic allow for uncertainty and fuzziness in the data, which is especially useful in the case of short circuits, where parameters can change depending on the conditions and characteristics of the system. As well as the method of symmetrical components, it is possible to analyze current and voltage signals based on their symmetrical and asymmetric components, which can help to highlight the specific characteristics of a short circuit. The efficiency and accuracy of short circuit identification using fuzzy logic and the method of symmetrical components may depend on the quality of the input data and the correct choice of fuzzy rules. The fuzzy logic approach and the method of symmetric components require an assessment of its performance on real data and in a real environment. Conducting experiments, testing large amounts of data, and comparing the results with other methods allows us to evaluate the effectiveness and applicability of this approach. In general, the identification of types of short circuits in the elements of an electrical system based on fuzzy logic, together with the method of symmetrical components, is an interesting approach that can be effective if implemented and configured correctly. However, further research and comparative analysis with other methods may help to better understand the advantages and limitations of this approach.

4. CONCLUSION

Based on the results of the work done, it can be concluded that it is possible and reliable to use fuzzy logic based on the method of symmetrical components of currents and voltages to identify types of short circuits. In this paper, the detection and classification of faults based on fuzzy logic in real time is proposed. For the classification of faults (type of short circuit), samples of current and voltage of the forward, reverse, and zero sequences are taken into account. It is expected that the proposed logic (method) will identify the types of short circuits on the elements of the EC with higher accuracy, also the response speed of the protection can be increased, and the detection time can be improved. Thus, it is established that it is possible to determine the types of damage by the trend of changes in the values of currents and voltages, analyzing the previous states of the system, without using numerical values dependent on the circuit parameters.

Given the complexity of implementing the interaction of protections between each other on power transformers and overhead power lines, as well as the need to configure them, the proposed method of identification on fuzzy logic makes it possible to speed up the process of determining the types of short circuits, thereby eliminating false alarms. Such an approach based on fuzzy logic can be very effective and efficient for various types of short circuits. The proposed method can determine not only the detection of malfunctions but also determined by types of short circuits with an indication of damaged phases.

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BIOGRAPHIES OF AUTHORS

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