Development and research of an intelligent control system and protection of electrical network equipment

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Abstract. The key element of an intelligent energy system with an active-adaptive network is relay protection, designed to ensure uninterrupted and stable operation of the energy system. The goal of the work is the development and research of intelligent control systems, protection and automation of electrical networks. Research has been carried out on an intelligent security system to determine the boundaries of restrictions in the use of artificial intelligence. The authors supplemented the existing complex with physical models of the power supply system with a digital twin, an artificial neural network, and studied the complex in order to answer some questions about the use of a neural network in relay protection. An iterative approach to software development, supervised machine learning method, and Python programming language were used. PyChram Community Edition was chosen as the integrated development environment. Intelligent system software has been developed, including a digital twin, an executive part and a neural network model, which makes it possible to recognize types of short circuits in the electrical network. The works of domestic and foreign authors on this topic are considered.

1 Introduction

Most developed countries are modernizing electrical networks using Smart Grid technology. Maintenance of modern energy systems requires specialists with a wide range of skills and abilities. Operation and maintenance of smart energy systems requires specialists to have deep technical knowledge and the ability to work with various programs and algorithms.

A literature review of domestic and foreign publications was carried out to study various aspects of the use of a neural network in relay protection.

In [1], the possibility of using a neural network in the differential protection of a power transformer is considered. An artificial neural network (ANN) distinguished inrush current from interturn short circuits. The work uses a neural network that works with input data without repeating the learning process, which reduces reaction time.

In [2], it was proposed to use an ANN to recognize interturn short circuits in transformers. Digital models have been developed to study the operation of a transformer in

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the power supply system in normal mode and during interturn short circuits. Based on the results of the study, a large amount of input data was obtained for training the ANN.

Article [3] discusses differential protection for a transformer using an accelerated ANN. Part of the input data has been combined into one value, which increases response speed and accuracy. This protection was tested on a system model under different operating modes. It has been revealed that protection based on an accelerated ANN is more reliable and also much faster. It has been established that an ANN requires a large set of input data to train an ANN.

The authors of [4] considered the differential protection of a transformer with multi-level ANN. One ANN detects damage, and the other is used as a damage classifier. Both ANNs are trained using backpropagation and genetic algorithm. The first ANN is trained using a genetic algorithm, the second - using a backpropagation algorithm. The first ANN works more accurately and faster.

As shown in [5], a neural network can be used to analyze the mechanisms of overcurrent protection (overcurrent protection) in a three-phase network without affecting the operation of the relay protection and automation system (RPA).

Work [6] discusses the use of ANN algorithms to detect unauthorized access to the operation of a digital substation.

The authors of work [7] analyzed the possibility of using recurrent ANNs to determine the protection response setpoint.

In [8], an ANN was performed - modeling of relay protection with dwell time.

In [9], based on the most successful solutions, the structure of an ANN was proposed. The resulting neural network was used to classify the operating modes of the electrical network into normal and emergency, identifying the damaged element and the type of damage. The performance of the ANN was proven by trial execution on a model of the power supply system.

The authors of [10] showed the possibility of using an ANN for the task of determining the parameters of automatic control of generator excitation. It is shown that neural networks can have calculation accuracy close to that of conventional security systems. In some cases, the ANN cannot correctly determine the coefficients. To overcome this drawback, it is necessary to include noisy data in the training set.

2 Materials and methods

The research complex for working with physical models of controls, protection and automation of electrical networks allows you to perform the following work:

- Cut-off.
- Maximum current protection.
- Protection against earth faults.
- Differential protection.
- Transformer protection.

Digital twins allow you to study the operation of relay protection without involving the electrical networks themselves in the research process. The working panel of the digital twin completely imitates the panel of the real complex, both visually and in its functionality. To put the digital twin into operation, you need to do the same operation as on the physical complex - turn on the circuit breaker to supply power.

As part of the project, digital twins of current and differential protection of power lines and transformers were implemented.

The digital twin uses specialized algorithms and data processing techniques to analyze the current and voltage coming from the transformer. In the digital twin, it is necessary to calculate the protection operation current and winding parameters.
The relay operating current is calculated by the formula:

\[ I_{op} = K_{OTC} \cdot \frac{I_1}{n_F} \]  

(1)

3 Results

Figure 1 shows the interface of the digital twin of the laboratory bench.

The development and training of a neural network is carried out to recognize one of five protections and determine the parameters of the damaged element. Let's consider the functioning of an intelligent protection system with a digital twin using the example of differential protection of a transformer. It has been established that the neural network will solve a machine learning problem related to the class of supervised learning, namely regression.

A data sample was prepared for training, some of which was separated for testing. The data set is a vector containing the result of the digital twin calculation, namely the values of currents of individual phases and phase-to-phase faults. By running the digital twin in a cyclic mode for all possible values, the minimum required database was generated to solve the problem.

![Fig. 1. Interface of a digital twin of a laboratory bench.](image)

After entering the appropriate data and clicking the “Calculate” button, the program accesses the trained intelligent model and performs a calculation, as a result of which it shows which protection settings have been exceeded at a given time and generates a control signal for shutdown.
Figure 2 shows the functional diagram of the intelligent system.

![Functional diagram of an intelligent system](image)

**Fig. 2.** Functional diagram of an intelligent system.

The neural network processes the input data and generates the values of the output parameters. Based on these values, a signal is generated to the protection system. The structure of the neural network is shown in Figure 3.

A data sample is generated in MS Excel format for further loading into an artificial neural network for its training. One line corresponds to one measurement.

![Neural network structure](image)

**Fig. 3.** Neural network structure.

To develop a software product and train a neural network within the educational and research complex, the Python programming language was chosen. The TensorFlow library was chosen as the main tool for developing a neural network. When training neural networks, validation was carried out to achieve sufficient model efficiency.

At the final stage, the neural network algorithm was built into a single software solution that provides a convenient interface for the user. Through a window application made using the PyQt5 library, all five structural components of the software part of the complex are implemented into the project. Thus, the visual representation acts as a connecting element.
between the neural network and the digital twin, as well as the executive parts of the program.

The results of the ANN study on current protection using 450 sets of training sample values are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Numerical values of the ANN parameter</th>
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<tbody>
<tr>
<td>Error rate for training set</td>
<td>0.059</td>
</tr>
<tr>
<td>Test sample error rate</td>
<td>0.128</td>
</tr>
<tr>
<td>Number of false positives in the training set</td>
<td>5.45%</td>
</tr>
<tr>
<td>Number of false positives in the test set</td>
<td>6.02%</td>
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</tbody>
</table>

4 Discussion

The research complex is designed to study aspects of the use of ANN in relay protection, acquire the fundamentals of the development and application of neural networks to implement the functions of protecting electrical networks and electrical equipment, adapt specialists to work in conditions of active-adaptive electrical networks with intelligent control, protection and diagnostic systems.

The effectiveness of relay protection of power supply systems remains quite low; for example, relay protection of a power transformer only operates correctly in 70–80% of damage cases and promptly prevents the development of an accident. One of the main problems is the recognition of internal short circuits (turn-to-turn short circuits in the winding). Using the educational and research complex, the operation of current line protection and transformer differential protection was studied. The ANN is sufficient to recognize current protection modes of exceeding the threshold for three phases. The developed ANN can be trained using a sample consisting of at least 450 current values of each phase. At the same time, the accuracy of determining the response threshold does not exceed 1.5 A; a training sample from 10% of the total sample was used for training. All errors occur within 1.5% of the trip setting. The training time for current protection was 45 seconds, and the operating time of the trained ANN was 0.04 s. The number of false positives from all test sets was 6%. The number of false positives of an ANN as part of a real electrical network will be even greater due to the noisy input data.

5 Conclusion

The use of ANN is becoming a promising direction in the development of relay protection and automation, making it possible to reduce the number of false alarms compared to conventional protection. The use of ANN in relay protection has the potential to improve the efficiency and reliability of the protection system, but requires strict risk assessment, safety assurance and careful management to ensure the effective operation of the system.

When operating as part of current protection, ANNs have high accuracy. Errors in the operation of overcurrent protection occur when the current values differ little from the setting. If the current in at least one of the phases differs significantly from the setting, the ANN provides 100% recognition.

Classifiers can work even with low values of short-circuit currents, this opens up the possibility of their use in relay protection.

ANNs can be used in two ways, directly for decision making and for calculating relay protection coefficients. The first option is preferable for simple current protections, the second protection option is preferable for implementing more complex protections, such as
differential protection, since the ANN is used as a fault classifier and for calculating weighting coefficients, monitoring modes and accuracy of relay protections. In complex protections, it is possible to use an ANN as a backup protection.

References

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