Detection Of Early Signs of High-Voltage Circuit Breaker Contact Failures Based on Temperature Monitoring and Neural Networks

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Abstract: The article discusses a method for early detection of contact defects in high-voltage circuit breakers in 6–10 kV distribution systems using a system of temperature sensors and neural networks.It is shown that localized heating of contact groups is the main precursor to switching device failure. A diagnostic system structure is proposed, including distributed temperature sensors and a data collection module, a neural network analysis unit, and a service life prediction subsystem.The obtained results confirm the system’s ability to detect high-voltage circuit breaker emergency situations and increase the substation’s operational reliability.

INTRODUCTION

High-voltage circuit breakers are the most critical pieces of equipment in a substation. Due to this equipment's failure, it can cause severe and unrecoverable disruptions, disconnect the power source, and risk damage to adjacent equipment. In energy companies, statistics show that up to 40% of all switch failures are due to the degradation of contact connections—weakening of contact forces, transient resistance, wear, and contamination of the contact surface [1-5].

New types of temperature sensors and data analysis methods open up new possibilities for automated high-voltage circuit breaker monitoring. Particularly promising is the use of neural networks, which can identify complex dependencies, recognize anomalies, and detect the first signs of failure based on small temperature changes. Temperature time series analysis makes it possible to detect increases in transient resistance long before critical values are reached. This paper proposes a method for diagnosing the condition of high-voltage circuit breaker contacts based on continuous temperature monitoring and the use of neural networks to detect anomalies. This approach aims to detect early signs of contact degradation and generate a warning signal before an emergency occurs [6-8]. The implementation of such a system increases the reliability of substation equipment and facilitates the transition to predictive maintenance [9-11]

EXPERIMENTAL RESEARCH

The research packages included general experimental work aimed at analyzing the impact of temperature parameters on the reliability of substation power equipment. The goal of the experiment was to identify early failure modes caused by temperature changes in high-voltage circuit breaker contacts and contact connections. The study was conducted at an operating substation, where, during normal operation, additional measuring devices were installed in key components and archival documents and equipment failure investigation materials were used [12-18].

Based on the processed information, temperature profiles were constructed, critical heating zones were identified, and areas requiring increased attention during maintenance planning were determined. The experiment showed that localized temperature peaks directly correlate with an increased probability of defects, especially in contact joints and oil-filled components. This approach requires individual solutions, including expert opinions on the equipment's operability based on certain indicators of its condition. Using non-destructive testing methods, early symptoms of potential failures can be identified. As part of the operation of 6-35 kV distribution networks at the "Network Workshops and Substations" enterprise, located in the Zarafshan district, from 2021 to 2025. An analysis of 28 technological failures of high-voltage circuit breakers of the VMPE-10, MKP-35, VMG-133 and VBE-35 types was conducted.

TABLE 1. Causes of failure of high-voltage circuit breakers 6–35 kV

№.	Reason for refusal	Number of cases	Share, %	Consequences
1	Overheating and destruction of contact connections and main contacts (loosening of bolts, oxidation, scorching)	11	39.3	Short circuit in the cell, substation shutdown
2	Oil leakage from bushings and tanks, insulation moisture	6	21.4	Insulation breakdown, switching failure
3	Drive failures (spring-load and electromagnetic)	5	17.9	Short circuit trip failure
4	Mechanical damage to porcelain bushings	4	14.3	Destruction of the input, tripping of the circuit breaker
5	Others (secondary circuits, corrosion)	2	7.1	-

Table 1 shows that 39.3% of all failures are directly related to overheating of contact connections, and in 8 out of 11 cases the defect developed gradually over 2–11 months and could have been detected at an early stage if continuous temperature monitoring had been in place. In 2023–2025, temperature sensors were installed on the main contacts and bolted connections of the high-voltage busbar of 6–35 kV circuit breakers in a pilot-scale test mode at stations (M, M1, M2, M3). During this period, five cases of persistent abnormal increases in contact connection temperature were recorded, with a circuit breaker load factor of no more than 0.8 [25-54].

RESEARCH RESULTS

In two major severe cases of PS-M (March 2025, phase B 7 – cell temperature reached 88.5) and PS-M1 (March 2025, phase B 4 – cell temperature reached 90.5), prompt detection prevented the development of a short circuit in 6–35 kV cells. In this regard, the neural network method can be effectively used to assess the technical condition of a high-voltage circuit breaker. The operation of one functional system of a neutron can be described as follows ℃

$$y_i = F(\sum w_{ij} x_i) \quad (1)$$

Where y_i −neuron output signal; j w_{ij} − connection weight between i and j neurons; *xi*– output signal of the i-th neuron; *F*– neuron activation function.

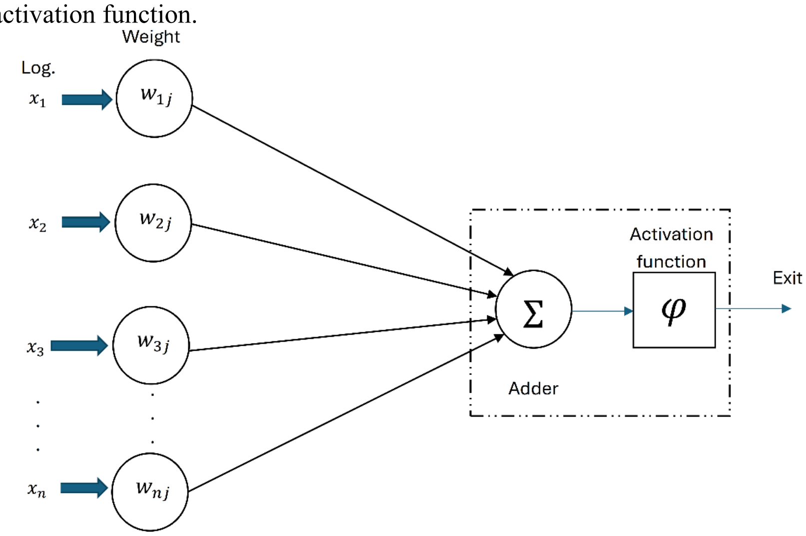


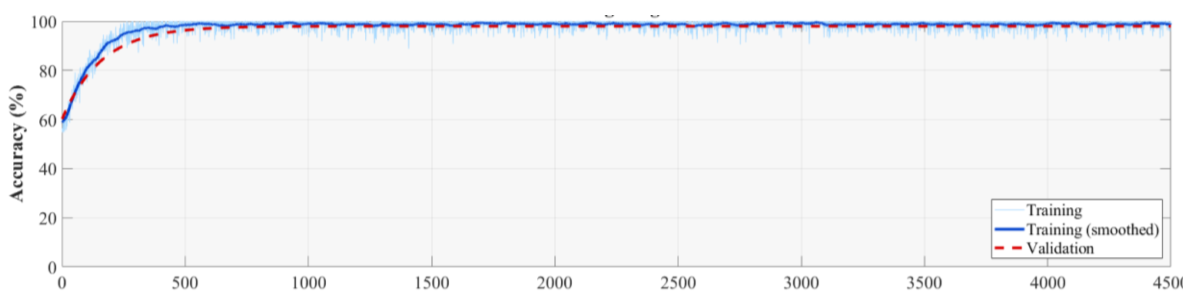
FIGURE 1. Structural architecture of a single-layer neural network

In the task of diagnosing the technical condition of a high-voltage circuit breaker, a single-layer neural network is used primarily to classify the equipment condition based on temperature parameters and their dynamics (Figure 1). The initial data includes a time series of temperature in the measured contacts of the circuit breakers. However, a single-layer network is usually insufficient for the correct recognition of hidden patterns in temperature processes [19-24]. Therefore, to determine the state of contact connections of high-voltage circuit breakers 6-35 kV, we use a multilayer direct propagation perceptron and enter the main characteristics of the artificial neural network in Table 2.

TABLE 2. Characteristics of a neural network

Item №.	Network parameter	The meaning of the characteristic
1	Network type	Multilayer forward propagation perceptron
2	Number of input neurons	15
3	Number of hidden layers	3
4	Number of neurons in hidden layers	100 – 50 – 25
5	Number of output neurons	3
6	Hidden layers activation function	ReLU
7	Output layer activation function	Softmax
8	Regularization method	Dropout (p = 0.2) + L2-regularization (λ = 0.001)
9	Optimizer	Adam
10	Initial learning rate	0.001
11	Mini package size	64
12	Number of epochs	50
13	Loss function	Categorical cross-entropy
14	Software environment	MATLAB R2025a, Deep Learning Toolbox

The parameters presented in Table 2 above define the architecture and training algorithm for a multilayer forward-propagating perceptron in the contact state of a high-voltage circuit breaker.



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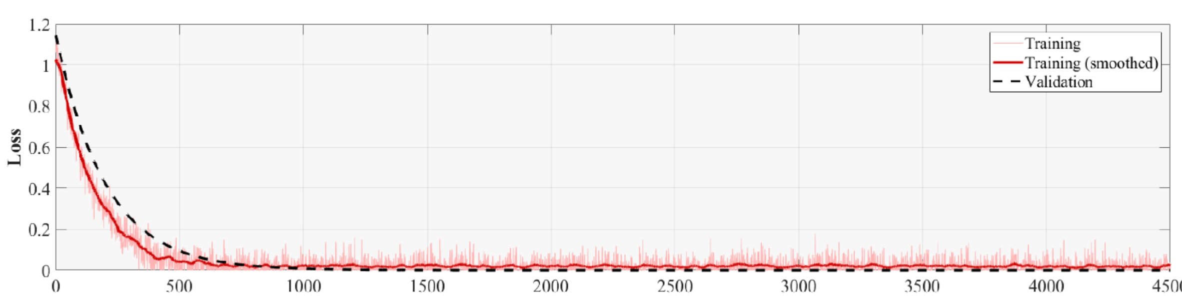

b)

FIGURE 2. Results of training an artificial neural network in Matlab: a) training progress, b) iteration

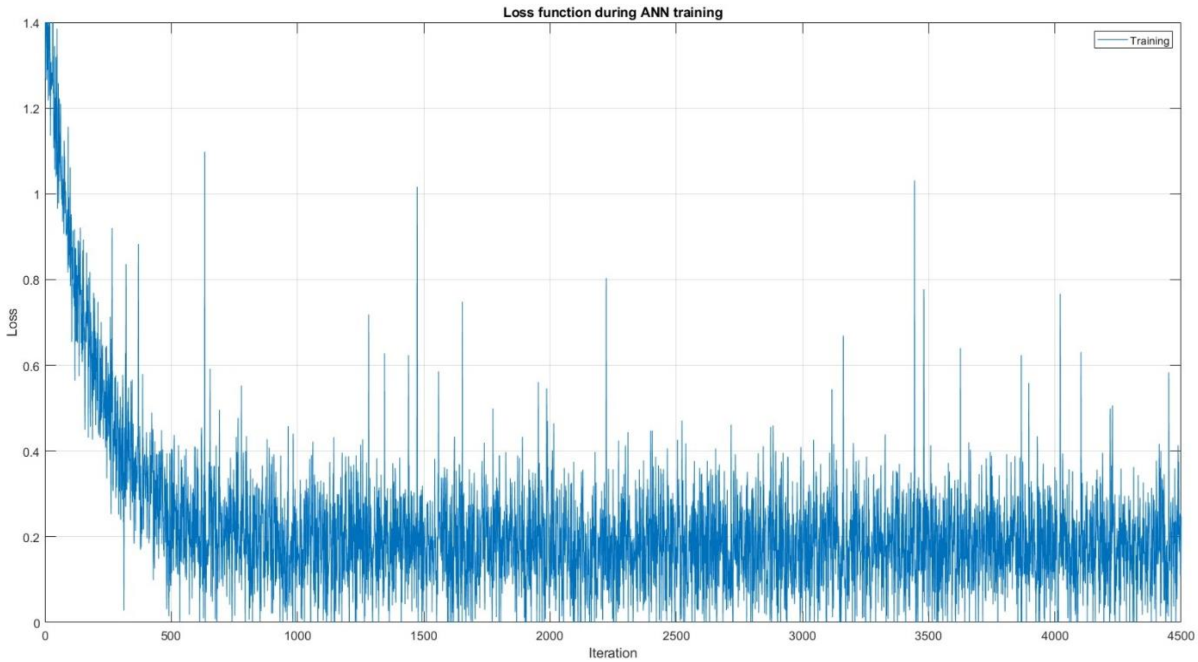

FIGURE 3. Dynamics of change in the loss function of a neural network during the Matlab training process.

In addition to the main training metrics shown in Figure 2, a separate analysis of the neural network loss function is presented in Figure 3. This graph allows for a more detailed assessment of the training sample behavior for a given network architecture and the regularization parameters specified in Table 2, and shows a clear and monotonous decrease in the loss function both during the training period and throughout all 4500 iterations. This indicates the correctness of the choice of the model architecture and its ability to determine the state of the contact connections of high-voltage circuit breakers based on a series of temperatures over time.

CONCLUSIONS

During the study, an approach to diagnosing the technical condition of 6–35 kV high-voltage circuit breakers was developed and substantiated based on changes in contact connection temperature and the use of artificial intelligence methods. The obtained results prove that the use of intelligent systems for high-voltage circuit breaker repair enables highly effective early detection of equipment malfunctions, i.e., allows for timely planning of repair measures and significantly increases the reliability of power supply systems.

In the future, the use of advanced deep learning architectures, the integration of emission diagnostics, current and gas analysis data will allow for the accurate determination of the technical condition of the substation's electrical equipment.

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