Detection of damage sites on overhead power lines with a voltage of 110 kV or higher

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Abstract. The article is devoted to problems in the electric grid complex related to ageing of components of power lines, reduction of reliability and increase the number of failures. It shows the need of development of scientific and methodical bases of perfection of management and organization of the system of technical maintenance and repair of equipment in power network systems, taking into account the current state of development of the power industry. Problems of disconnections of high-voltage power lines occur periodically in many countries and the search for options for their early elimination or pre-termination is a very urgent task. Researching and developing methods and devices for early detection of fault locations will minimize the time for troubleshooting and thus reduce downtime and economic losses for all parties, both the grids organization and the electricity consumer. The paper presents the results of research and development of devices used to detect places of power line damage in the conditions of "digital transformation" of the energy complex. The implementation of the developed proposals will have a positive impact on reducing losses from under-supply of electricity and will reduce the time for identifying fault locations associated with determining the locations of short-circuit currents.

1. Introduction
Development of the energy sector of the Russian Federation is connected with the implementation of the concept and state programs for the transition to modern effective technological and economical aspects of managing the country's energy system. The implementation of the national project "Digital economy" in the concept of energy development until 2035 forms new approaches for energy companies to implement digital transformation programs. Existing models for managing power facilities need to be adapted in accordance with technical solutions to improve the reliability of operation of electric networks in the framework of digital transformation [1,2] (during operation, repairs, reconstruction, etc.) in the conditions of digitalization, which currently does not always provide high efficiency, and the introduced digital technologies often relate only to the line of newly introduced new equipment. However, the current equipment of the country's energy industry (more than 60%) operates with a service life of more than 25 years and can still be effectively used for the production and transfer of energy resources. During power supply interruptions, many production facilities stop completely, and today the urgent task is to identify and eliminate various incidents as quickly as possible with the resumption of normal operation.
In the Russian Federation, electricity transit is carried out mostly on grids of 110 kV and higher, in addition, the main consumers can be powered from substations, in this case, the disconnection of the supply over the head line by the consumer is felt more acutely. Overhead power lines run through various terrain and therefore are exposed to all possible factors: ice load, wind load, atmospheric pollution, thunderstorms, falling branches and trees, human activity, and so on. The impact of these factors leads to permanent, repeated, or single-time damage. When disconnecting, with a successful re-activation (especially once), it is often not possible to identify the place of damage during a normal walking inspection. In this case, it is necessary to disconnect the line and perform a thorough riding inspection of several supports and spans between them, which leads to the disconnection of the consumer and significant material costs for the operating organization.

A number of devices are used to determine the location of the damage. Basically, these are devices installed at substations that determine the distance from the place of installation of the device to the place of damage by various characteristics. In practice, taking into account the network modes and measurement errors, it takes quite a long time to find the location of a short circuit on the power line, even if there are special fixing devices installed at substations. Devices for determining the location of the damage, installed directly on the support, are not widely used, which is due to some shortcomings of existing modifications.

The purpose of the work is to develop a device for detecting short-circuit currents in the elements of overhead power lines with a voltage of 110 kV and higher, which are installed directly on the support and allow one to determine quickly and accurately the location of damage without disconnecting the equipment. To achieve this goal, a device was developed that meets the following requirements: it is installed onto a support without placing additional weight on it; it is possible to install and disassemble it without disconnecting the air line and in a short time; installation, disassembly and maintenance are performed by maintenance personnel, without additional involvement of specialists; there is a light indicator to facilitate search at night.

The paper analyzes the accumulated experience and scientific developments [3] in this direction: the most likely paths of short-circuit currents on overhead power lines with a voltage of 110 kV and higher are determined; the method of signaling when the device is triggered is determined; the characteristics of the device components and parts are determined.

The result of the research is the development of devices for detecting damage sites on overhead power lines with a voltage of 110 kV and higher, followed by digitalization: event recording, transmission, accumulation, and analysis of data arrays in decision-making centers

2. Analysis of the reasons for overhead line failures
The variety of causes of damage and failures of overhead power lines makes it difficult to systematize them. Failures that occur for each of the reasons listed below are not the same at different stages of operation of the overhead line. All detected manufacturing and installation defects remain inside the products and are hidden foci of future failures in the operation of high-voltage power lines. Operational failures – the ones that occur for reasons related to a violation of the established rules or operating conditions. For example, failures due to non-compliance with the actual working conditions of the project; contamination of insulators and surfaces of overhead lines, etc. However, the analysis of retrospective data on the operation of overhead lines allows us to get high-quality views on the localization of failures by overhead line elements, on their distribution by time groups.

Over the past decades, there have been serious deviations in the operation of equipment, which led to its damage due to errors of personnel and production instructions. This fact indicates that special attention should be paid to the elimination of shortcomings in the work of the operating personnel, on whose work the safety and reliability ultimately depend. All failures related to operation can be divided into two groups: "eliminated" and "unavoidable". The first group includes failures that can be prevented by organizational and technical measures. The second group includes failures that can only be prevented by replacing equipment or its individual parts. Production (technological) failures often occur for reasons related to the imperfection or violation of the established process of manufacturing

2
or installation of components and parts of the overhead line. The most common failures are those associated with a violation of the connection process of overhead line elements. The share of failures due to operational shortcomings has increased sharply in recent years [4]. Modern repairs performed at a high technical and technological level and in full accordance with the normative and technical documentation and diagnostic results ensure reliable operation of the equipment. In practice, repairs are not always carried out in good quality, so it is not uncommon for equipment to fail soon after repairs. Such failures are usually referred to as repair defects if they occurred within the first two months after the end of repair work or have a pronounced repair defect and after a longer period of operation. This situation leads to the need to carry out a significant amount of work on defecation of overhead line elements during planned repairs and, as a result, to increase their duration.

It is known that the materials for manufacturing wires have a dependence of long-term strength and creep on the operating time [5, 6]. Accordingly, the overhead lines resource has specific limits, exceeding which will cause damage and failures. When determining the reasons for failures, it is not always possible to clearly determine the reason for disconnecting the power line. In the practice of overhead lines operation, it often happens that design flaws are hidden behind other circumstances that are taken as the reasons for failures or are replaced by existing violations of operating modes. The measures developed in such cases are aimed at eliminating the side causes of regime violations, while the main design flaws remain unrecorded, which leads to repeated, repeated failures. In addition, for a large percentage of overhead lines failures, it is not possible to find out the true reasons for failures.

The main causes of accidents are the following factors: damage to the wire and lightning protection wire (8%), thunderstorm activity (11%), disconnections as a result of birds’ activity (18%), overlapping of insulation and the air gap between the wire and the support (along the insulation) (56%), and other reasons. When covering the insulation (without destruction) or the air gap between the wire and the support (along the insulation), there are often very small traces in the form of thin glass flakes on the upper part of the insulator and small specks - marks of short-term thermal effects of an electric arc on the traverse and the wire, which are not always possible to see from the ground, even with binoculars. In most cases, after the overlap of the polymer insulator, insulators of glass or porcelain insulators, the performance of the suspension is preserved. The reasons for power outages over a five-year period are shown in figure 1.

Due to the development of scientific and technological progress in the past few decades, new information and communication technologies have been rapidly developing in order to improve reliability, prevent or reduce the number of failures in the Russian Federation’s power grid complex. Questions of reliability of technical objects and their reflection in modern standardization are considered in detail in [1, 7, 8].

![Figure 1. Reasons for power outages for a five-year period.](image-url)
3. Remote detection of damage sites

To determine the location of damage, power lines are equipped with various types of devices. As a rule, these devices are installed at substations and their area of operation covers several lines, including substation equipment.

The operation of such devices is aimed at determining the distance from the place of a short circuit to the place of their installation, using the following basic methods.

Pulse method, which is based on the measurement of time intervals when electromagnetic waves propagate through overhead lines. This method is divided into location-based and wave-based.

The location method is based on measuring the time interval between the moment when the probing pulse is sent and the moment when the pulse reflected from the site of damage comes to the beginning of the line. That is, the time of the double pulse run to the point of damage is measured. In this case, the distance to the short-circuit location is defined as the product of the propagation speed and the interval, divided in half.

The wave method is based on measuring the time interval between the moments when the ends of the line are reached by the fronts of electromagnetic waves that occur at the point of damage.

The induction method is based on fixing the parameters of the magnetic field of currents that flow through the wires and in the soil along the route of the overhead line.

The above methods, as well as other methods, are based on determining the distance from the short-circuit location to the place where they are installed, and therefore their operation is negatively affected by a number of factors, such as:

- condition of overhead line wires (the reliability of the length, the reliability of the cross-section of the wires and repair inserts; the presence of damage with a decrease in the cross-section, corrosion, especially relevant for wires made of aluminum steel alloys, etc.);
- condition of wire connections (voltage drop, reliable contact, etc.);
- equipment status of intermediate substations;
- modes of operation of electrical grids, and a number of other factors.

Taking into account the above factors, as well as the "passport-permissible" error, the readings of damage detection devices installed at the substation may differ from the actual values by several hundred meters to several kilometers. In cases where there are no obvious traces of a short circuit, it is necessary to unscheduled output to repair the overhead line and perform a riding inspection of several supports, and sometimes several dozen supports, which leads to a decrease in grids reliability, and, on end overhead lines, to disconnect end consumers while searching for short-circuit locations.

4. A new device for determining the places of passage from short-circuit currents

Analyze the existing devices for solving the problem of detecting short-circuit locations that installed directly on the overhead line support. A number of inventions (signaling devices, indicators) were considered. However, the invention is not widely used, perhaps this is due to some non-modifications, the main of which are the complexity of installation, high cost, design flaws, and the inability to reuse. During the operation of polymer insulators, it was found that when the insulator is overlapped, the screen rings located at both ends of the insulators are damaged. Such damage occurs from minor meltdowns to visible burnouts.

Based on these observations, a new design of the digital device shown in figure 2, indicating the overlap of insulators on overhead power lines, which is installed directly on the support and allows you to quickly and accurately determine the location of damage without disconnecting the equipment and meets the following requirements:

- mounted on a support without increasing the weight load;
- installation and dismantling is carried out in the shortest possible time;
- possibility of mounting and dismounting without disconnecting the power line;
- allows service personnel to accurately determine the location of a short circuit both remotely and from the ground;
- installation, disassembly and maintenance is performed by the service personnel, without additional involvement of specialists;
- light indication, for easier search at night time.

This research shows aspects of scientific and methodological bases for improving the management and organization of the system of diagnostics, maintenance and repair of equipment for power grid complexes, taking into account the current state and "digital transformation" of the energy grids complex.

A number of devices and devices have been developed to determine the path of short-circuit currents directly in place (on the support). The research on this problem is still underway, which indicates the urgency of the problem. A model of the insulator overlap indicator, which is a digital signaling device with a fuse insert, is proposed. According to the developed model, the signaling device consists of several parts connected to each other, as shown in figure 2. This indicator also allows one to determine the insulator that requires maintenance during a visual inspection from the ground, as well as sends a signal from a digital device to the dispatcher’s console. Digital module 3, short-circuit current detector is a compact protected digital device that is installed next to the visual short-circuit current detector. The device is programmed and configured for correct operation. Figure 3 shows the appearance of the microprocessor electronics on the board.

![Figure 2. Digital device for determining the location of short-circuit currents in power transmission lines. 1-visual short-circuit current detector; 2-mounting spokes; 3-digital module short-circuit current detector; 4-elements of the power line support.](image1)

![Figure 3. Implementation of microprocessor electronics on the board.](image2)

The device is mounted in a small box that is easy to install. The device is designed to detect places where short-circuit currents pass through overhead power lines and the result of the device operation is
a file with data on determining the places where short-circuit currents pass through overhead power lines. The digital device transmits a signal, i.e. informs the power system dispatcher about the current operation by sending text messages.

5. Conclusions
The following solutions are proposed for detecting damage sites on overhead power lines with a voltage of 110 kV and higher.

1. A visual and digital signaling device for the passage of short-circuit currents of power lines passing through insulators on the traverses of power transmission line supports was developed.

2. We developed a digital GSM device for transmitting information about the operation of the short-circuit current detector to the automated workplace of the power system dispatcher, in order to timely detect fault locations when disconnecting the overhead line and reduce the time of troubleshooting.

The implementation of the developed proposals, starting from the design stage of new power transmission lines and installation on all operated overhead lines, will have a positive impact on reducing losses from under-supply of electricity and will reduce the time for identifying fault locations associated with determining the locations of short-circuit currents.

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