ABSTRACT

of PhD thesis **«Dynamic monitoring and forecasting of overheating of hard-to-reach contact elements of electrical equipment of technological complexes»**

Sarsenbayev Yerlan Aliaskarovich
Specialty 6D071800 – Electric Power Engineering

Relevancy of the project. As part of the implementation of the concept of development of the fuel and energy complex of the Republic of Kazakhstan until 2030, it is expected that the average level of wear and tear of electric power equipment in the Republic of Kazakhstan will significantly decrease by 2030. At present, the high degree of deterioration in the electrical equipment of technological complexes (ETC) belongs to the weak sides of the electric power industry. This makes increased demands for a rational choice of maintenance strategy and timely maintenance. One of the weakest points of the ETC is the contact connections (CS) of switching devices of switchgears, the deteriorated technical condition of which leads to considerable overheating up to fatal welding of the contact parts. Therefore, monitoring and forecasting of overheating of contact elements are an essential component of maintenance and repair (MR) of switching equipment.

The purpose of the study -the development of a method for temperature control and prediction of the overheating of inaccessible contact elements of collapsible contact electrical equipment of technological complexes (ETC) in the dynamic monitoring mode using a microprocessor sensor for the temperature of the inaccessible surface (MS of TIS)

To achieve this goal, the following **tasks** are set:

-carry out an analysis of existing methods for monitoring the technical condition of the dismountable CS, closely related to its thermal state, characterized by the transient resistance and temperature of the contact elements - the surface of the current bus and the contact surface of the CS. Choose from an existing primary meter-transducer to measure the temperature of the contact elements in high-voltage medium voltage plants;

-to analyze the existing methods of temperature control of the contact elements of the compressor stations of the switching devices of the ETC. To justify the use of inaccessible contact elements in high-voltage medium-voltage installations for temperature control of one of the variants of a resistive temperature sensor - a microprocessor sensor for the temperature of an inaccessible surface (MS of TIS);

-to develop a design and algorithms for the operation of a sensor for the MS of TIS surface of a bus that is not available for direct measurements with a thermistor, providing an increase in the accuracy of measurements by using analytical solutions of the heat transfer equation through the insulator layer between the measured surface and the thermistor. To develop the algorithms for

the operation of the sensor of the MS of TIS when measuring the surface temperature of the bus and the temperature of the contact surface;

-to develop a method for temperature monitoring in the regime of dynamic monitoring and prediction of overheating of collapsible CS using the sensor of MS of TIS. To give recommendations on the development of the design of MS of TIS, which provides the possibility of working under conditions of electromagnetic interference from high-voltage electrical equipment.

The main idea and internal unity of work. The fundamental idea of the dissertation work is the representation of the contact part of a flat symmetrical CS in the form of a thin rod thermally insulated from one end and a side surface, the opposite end of which is heated by the thermal power allocated at the transient contact resistance. Separate analysis of the process of heating the model rod by a volumetric and flat source of heat makes it possible to obtain the conversion formula realized by the means of microprocessor technology, measured at an accessible heat-insulated end, into the temperature of the opposite end of the rod, combined with the inaccessible contact surface of the CS. Dynamic monitoring of the temperature of the contact surface with the help of a microprocessor sensor for the temperature of the inaccessible surface (MS of TIS) in the linear part of the rod heating process by a test or operational rectangular current pulse sufficient to ensure a linear law of temperature change allows predicting a further heating process and thereby eliminating the welding of contact - details. The reprogramming of the microcontroller MS of TIS makes it possible to move from determining the temperature of the contact surface to determining the surface temperature of a flat tire. In this case, the assignment in the modified transfer function of the five correction factors reduces the dynamic error in measuring the temperature of the current bus surface by using a thermistor insulated from it with a thin dielectric layer to 1 °C.

Scientific novelty. The scientific novelty of the work is that for the first time it was proposed to diagnose the defectiveness of the dismountable contact of ETC's, leading to fatal welding, by operative monitoring of the temperature of the contact surface of the CS under current influences, creating similar in shape to rectangular pulses of heat released in the dynamic monitoring mode with using the sensor of MS of TIS.

Reliability of the research. The reliability of scientific provisions, conclusions and recommendations are confirmed by publications in scientific publications recommended by the Committee for Control of Education and Science of the Republic of Kazakhstan and in the proceedings of International Scientific Conferences, as well as by the innovative patent of the Republic of Kazakhstan for invention and a positive decision to issue a patent for invention of the Russian Federation. The reliability of the experimental results is confirmed by their comparison with the theoretical calculations.

The practical value of the research. High-voltage contacts of high-voltage switching equipment of medium voltage during operation are periodically exposed to currents significantly exceeding the nominal values, the duration of which is comparable with the period of the current of the industrial frequency. This

happens, for example, when short-circuit currents flow through them, starting currents of high-power electric motors, etc. Such influences can cause considerable heating of the contacts, up to their melting and fatal welding.

In the process of using electrical machines, transformers, apparatuses, cables and other electrical equipment of technological complexes, energy losses arise in the form of heat. The allocated heat raises the temperature of the conductors and contact surfaces and is transferred to the environment. The heating of the ETC equipment at the same time limits its service life and is the cause of emergencies. This leads to the need to diagnose the ETC, in particular collapsible CS, at the stage of its operation, using the methods of temperature control.

The most critical to heating power electrical equipment. Short-time current pulses, appearing in the busses of power electrical equipment as a result of commutations during engine start-ups, short circuit trips, etc. lead to a dangerous increase in the temperature of the contact surfaces of the tires, requiring the implementation of protective measures. In this case, the instantaneous values of the temperature on the contact surface cannot be fixed by any means of measurement because of its inaccessibility.

Since the thickness of current-carrying tires reaches tens of millimeters, and the thickness of the layer with an increased level of heat generation near the contact surface is very small fractions of a millimeter, direct measurements on the tire surface do not allow fixing the true temperature directly in the contact zone.

At the same time, the analysis of the temperature field in the zone of a flat contact on the contact surface, for example, of a bolted contact connection, makes it possible to establish the functional relationship of the temperatures in the contact zone and on the open (free) surface of the contact element (bus). The connection of the temperature fixed to the tire surface with the physical characteristics of the contact quality (in particular, with the transient resistance and the specific heat flux) makes it possible to conclude the contact state.

The use of dynamic temperature estimation for impulse actions, in contrast to the methods based on the analysis of a stationary thermal field, makes it possible to observe the thermal manifestations of defects during a certain period of time under conditions of contrast temperature distribution. Based on the results of temperature control at an early stage of the pulse action, it is possible to predict the overheating of the disassembled CS and to determine the response time of the protection of the switching devices from overheating and from the fatal welding of the contact parts, including with the help of the MS of TIS.

The following provisions are made on the defense. The following provisions are made for defense:

1. As a primary measuring instrument - converter MS of TIS for temperature control of high voltage medium voltage plants with appropriate choice of material and thickness of the insulator, thermistors isolated from the busbar can be used.

2. Received as a result of theoretical studies and experimentally confirmed transfer functions connecting the temperature on a flat tire accessible to the measurement of the surface with the temperature on the contacting surfaces of the dismountable contact.

3. The calculation method, based on the representation of heat release in the contact resistance of the contact in the form of a flat source of heat flow, provides sufficient accuracy of the temperature estimation for the development of a contact defect.

4. Determination of the response time of the protection of the dismountable connection from overheating by the thermal reaction to the action of a rectangular current pulse.

The personal contribution of the author is:

- in the analysis and consolidation of literary data;
- in creation and carrying out of researches on the experimental stand for tests of the microprocessor sensor MS of TIS;
- in development of new technological solutions.

Approbation of the results. The main results of the work were presented and discussed at the scientific seminars of the department «Power engineering»and at international scientific-practical conferences and forums:

- International scientific-practical conference «Problems of increasing the efficiency of electromechanical converters in electric power systems» (Sevastopol, Russia, 2014);
- Internationalforum «Engineering Education and Science in the 21st Century: Problems and Prospects», dedicated to the 80th anniversary of KazNTU named after K.I. Satbayev (Almaty, 2014);
- International Satbayev Readings «The Role and Place of Young Scientists in Implementing the New Economic Policy of Kazakhstan» (Almaty, 2015);
- International Satbayev Readings «Competitiveness of technical science and education» (Almaty, 2016);
- «NDT days 2016»conference (Sozopol, Bulgaria,2016);
- Worldscientificandengineeringcongress «Energy of the future: innovative scenarios and methods of their implementation» WSEC-2017 (Astana, 2017).

Publications. The results of the research are presented in 17 scientific publications, including international and foreign scientific publications, and also included in the Scopus database (impact factor 0.208 Russian Electrical Engineering journal), 7 articles in the materials of international scientific and practical conferences and forums, 1 innovative patent of the Republic of Kazakhstan and 1 positive decision on granting a patent for invention of the Russian Federation.

Structure. The work consists of an introduction, four chapters and a conclusion, outlined in 149 pages of typewritten text, includes 46 figures, 12 tables, 8 appendixes, a list of used sources of 105 titles.

The introduction shows the relevance of scientific work and specifies the problem under study. The goal and tasks of scientific research have been set. The scientific novelty and the provisions brought to the defense are given. The practical significance of the results is shown. Publications, approbation, as well as communication of work with the plan of state scientific programs are covered.

The first section of the thesis is devoted to the review of existing methods of monitoring the technical state and studying the issues of overheating of ETC's dismountable contact connections.

Monitoring of technical condition of electrical equipment of technological complexes is carried out through visual and thermal imaging control. Preference is given to thermal imaging - contactless method of monitoring. This method evaluates the defectiveness of the elements of the ETC through its thermal manifestation on the external surfaces of the electrical equipment. A significant disadvantage of the thermal imaging method is that it does not allow to detect defects related to heating of the internal parts of the monitored electrical equipment-inaccessible contact elements, and in particular the external surface of the bus and the contact surface of the CS.

This disadvantage is eliminated by the transition to the use of contact methods for temperature measurement with thermistors in monitoring systems of technical condition of collapsible CS.

The second section presents the detection of ETC contact defects at an early stage of their development, monitoring of the temperature of the compressor with the use of microcontrollers, the rationale for a resistive microprocessor sensor for the temperature of an inaccessible surface (MS of TIS) and the description of the features of dynamic monitoring of the compressor station.

The dynamic evaluation of the temperature of the contact surface for pulsed current loads is based on the dynamic monitoring of the temperature inaccessible to direct measurement of the contact elements of the ETC (the surface of the busbar and the contact surface).

The use of dynamic temperature estimation for impulse actions based on the analysis of non-stationary temperature fields, in contrast to the methods based on the analysis of a stationary thermal field, allows for a short enough time to observe the thermal manifestations of defects in conditions of more contrasting temperature distribution and the results of temperature control at an early stage, predict the superheating of the COP up to the melting temperature of the contact-material material.

To implement the dynamic monitoring, it is proposed to use a microprocessor-based sensor of thetemperatureinaccessible surface (MS of TIS).

In the third section, technical solutions for the implementation of the sensor of the MS of TIS, the construction of the sensor transfer functions, and the algorithms of the sensor operation in the modes of measuring the surface temperature of the bus and the temperature of the contact surface are considered.

The design of the sensor of the MS of TIS - the surface of a bus with a resistive sensing element located on the upper surface of a disk of dielectric material, whose thickness is many times smaller than the diameter, but provides a reliable insulation of the thermistor from the surface of the tire under high electric voltage.

The possibilities of increasing the accuracy of indirect measurements of the temperature of hard-to-reach contact elements of the compressor station by means of a rational choice of the sensor design, improvement of the sensor operation

algorithms and refinement of the transfer functions realized in the microcontroller MS of TISare considered.

An algorithm has been developed and the transfer function of theMS of TIS sensor for working in the mode of measuring the temperature of the surface of the bus is constructed. Variants of the transfer function with two and five correction coefficients obtained by analyzing the analytical solution of the heat equation describing the heat transfer from the current bus to the thermistor through a thin dielectric layer are considered.

An algorithm has been developed and the transfer function of the sensor MS of TIS for the work in the mode of measuring the temperature of the contact surface during heating of the disassembled CS by a rectangular current pulse is constructed.

The fourth section is devoted to the development of a temperature control method for the collapsible CS in the dynamic monitoring mode and to predict the overheating of the collapsible CS. Considered are: construction of the transfer function of the sensor MS of TIS with the use of current pulse parameters, the realization of the sensor of the MS of TIS with the galvanic type of signal transmission and the possibility of application for the transmission of the signal of optical channels. The use of the microprocessor sensor MS of TIS in the problems of thermal diagnostics of collapsible contact connections of the ETC is shown.

The presence of temperature MS of TISsensors, having sufficient, no worse than 0.001 s time resolution, can effectively solve the problems of thermal diagnostics of contact connections in the busbars of high voltage switchgears. The ability of the sensor to measure the time dependences of the temperature of the tire surface on the segments 0.1-1 s, allows to diagnose the state of the contact connections during the disconnection of short-circuit currents or when starting the motors. Along with the requirements for a temporary resolution, the MS of TIS must satisfy the conditions of electromagnetic compatibility with the characteristic values of the short-circuit current of the order of 10 kA. It must also function safely with the electric potential of tires with respect to the ground up to 35 kV.

The sensor based on the thermistor must be provided with an autonomous power source based on an inductive coupling with the current of the power bus equipped with the necessary electronic components to protect against overvoltages at short-circuit currents and inrush currents, as well as by means of stabilizing the input voltage.

The use of a contact sensor for measuring the temperature of the surface of a high-voltage power bus (above 30 kV) is impractical due to low dynamic characteristics and unsafe consequences of electrical breakdown of the insulation component of the structure.

The use of a film thermistor in combination with an optical signal transmission channel to an amplifying and converting device provides for a low inertia of the sensor, its noise immunity, but requires an autonomous source of the supply current of the thermistor.

A promising option is the direct transmission of the thermal radiation of the bus with the help of optical fibers in the infrared wavelength range. However, fiber-optic cables capable of transmitting radiation with a wavelength of the order

of 10-20 μm currently exist only in the form of experimental samples.

In conclusion, the main results and conclusions on the thesis work are reflected.