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Condition Assessment of Low-Voltage Electrical Equipment Based on Thermal Imaging Control

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***Abstract* — The paper presents a method of monitoring the technical condition of electrical equipment on the basis of thermographic control. This method is also effective in monitoring the contacts of most switching devices. With timely detection of defects in the contact connections of electrical equipment, the probability of preventing emergencies increases. For the control assessment of defectiveness of electrical equipment, it is suggested to use thermal indicators of the state, which depend on the contact heating temperature. The values of contact heating temperatures from applied materials and type of contacts have been investigated. The optimum values of loading factors of circuit breakers and contactors are presented. Also analyses of industrial accidents have been carried out, which prove the necessity of using indicators and thermal imaging inspection. The proposed method of assessment and control of the technical condition of contacts in real time using the proposed method allows to obtain data in real time and increase the reliability of electrical equipment.**

***Keywords* — low voltage, electrical network; thermal imaging control, electrical equipment, contacts of the switching devices.**

I. INTRODUCTION

Today the most accurate method of monitoring the technical condition of electrical equipment and switchgear is thermal imaging inspection. The advantages of this type of inspection include the required degree of accuracy, the time of diagnostics, providing the most complete information about the monitored node or object, as well as the continuity of the observation itself. Following are some scientific works devoted to research in this area.

A. D. Zaripova, D. K. Zaripov, A. E. Usachev showed the methodology of thermal imaging control to detect defects in electrical equipment [1]. For the diagnosed units of the equipment the degrees of their faults are determined depending on the set values of excessive temperatures.

Lvov M.Yu., Nikitina S.D., Lesiv A.V. compared the principles of assessment of the thermal state of the contact connections of the equipment and proposed a methodology of application of thermal indicators to control their state [2].

The authors Mamontov A.N., Pushnitsa K.A. [3] have formed a list of inspected assemblies and also defined the features of thermal imaging diagnostics of reactors with voltages up to and above 1000 V, and Mamontov A.N., Rychkov A.V., Astanin S.S. have presented the results of thermal imaging inspection of current and voltage transformers and investigated their various defects [4].

Fedotov A. I., Gracheva E. I., Naumov O. V. [5] proposed a criterion for evaluating the technical condition of contact connections of low-voltage switching devices based on the results of thermal imaging inspection, which allows taking into account the dynamics of loss changes in low-voltage networks, and A. N. Shpiganovich, A. N. Mamontov, A. N. Boichevsky A. V. developed a method of thermal imaging inspection of capacitors and high-frequency barriers with the considered terms of defect elimination [6].

A. N. Shpiganovich and A. N. Mamontov investigated the peculiarities of thermal imaging inspection of disconnectors and established the number of controlled points of electrical equipment, a description of the mode of operation when a defect occurs and thermograms of disconnector defects are given [7].

Andrei P., Cazacu E., Stanculescu M., Andrei H., Caciula I., Drosu O. investigated in laboratory conditions the technical condition of contacts and low voltage contact connections taking into account heating [8]. The results of measurements were used to develop mathematical models of temperature dependence of contacts and contact connections on time and type of load. These models are used for optimal selection of types of contact connections between conductors and switching devices.

Authors Bhagat A. K., Chauhan A. propose thermal imaging inspection as one of the methods of fault diagnosis of induction motor with voltage up to 1000V [9].

Dragomir A., Adam M., Antohi S.-M., Atanasoaei M., Pantiru A. presented a methodology for monitoring and diagnostics of thermal loads of high-voltage electrical equipment using infrared technology [10].

Hadzhiev I., Malamov D., Kolev N., Balabozov I., Yatchev I. showed the results of research of temperature distribution on the surface of knife contacts and the body of a low-voltage fuse [11]. The authors investigated the influence of current and contact resistance on the fuse heating and its tripping time.

Pareek S., Sharma R., Maheshwari R. analyse the possibility of using a neural network to inspect electrical assemblies and classify their thermal state [12]. The proposed solution allows to extend the functionality of diagnostics by reducing the operation time, reducing labour costs and increasing the reliability of the system.

Petrov A. R., Gracheva E. I., Sinyukova T., Valtchev S., Miceli R., Rahman A. U. investigated the parameters determining the value of power losses in low voltage switching equipment [13]. The results of the work, supplemented with the data of thermal imaging surveys, can be used to clarify the value of power losses in the workshop network.

Wei C. in [14] proposes a method for diagnosing thermal damage of power grid facilities, in particular, power transformers. The system allows to estimate their technical condition based on infrared thermal imaging data.

Researchers Zhu-Mao L., Qing L., Tao J., Yong-Xin L., Yu H., Yang B. developed a system for detecting thermal faults of high-voltage electrical equipment based on the analysis of infrared images [15].

As domestic and foreign experience shows, new improved approaches to the assessment of the technical condition of electrical equipment elements and switching devices of in-house power supply are currently required [16, 17].

The purpose of this research is timely detection of contact defects of low-voltage switching devices with the help of condition indicators.

This method of estimation and control of the technical condition of contacts of devices in real time by means of established previously, indicators and thermal imaging control allows to obtain data in real time mode and to increase the reliability of operation of the whole power supply system. This method allows to predict the failures before they appear in a more dangerous way.

II. Materials and Methods

Nowadays in the electric power industry there is a transition from the system of preventive maintenance to repairs according to the actual condition of the equipment using universal means of technical diagnostics, which include modern thermal imaging devices [18, 19]. The received thermographic images allow to reveal various defective states of contacts of devices. At the same time, it is possible to increase the technical life of electrical equipment due to the timely detection of defects at an early stage of development [20, 21].

During operation of the equipment failures may occur, such as contact system malfunctions, tripping due to overloads in the circuit, etc. These failures can be the cause of opening of the power supply circuit of contactor coils, relays, electromagnets, as a result of which the devices cannot be switched on again [22, 23]. One of the effective means of detecting faults in contact connections is thermal imaging inspection [24, 25]. Fig. 1 shows the main types of faults in contact system that can be detected by thermal imaging.

The values of contact heating temperature depend on the material and type of contact connections. On the basis of GOST 403-73 we will differentiate the contact heating temperature into indicators. The criterion for assessing the thermal state of contacts with the help of indicators is an addition to this standard, providing the formation of a clear algorithm for the automation of thermal imaging control systems.

It is also worth noting that the values presented in the table can be adjusted - for certain reasons. It is connected both with technical progress in thermal imaging inspection of equipment and with toughening of requirements to permissible temperatures of various elements of those apparats.

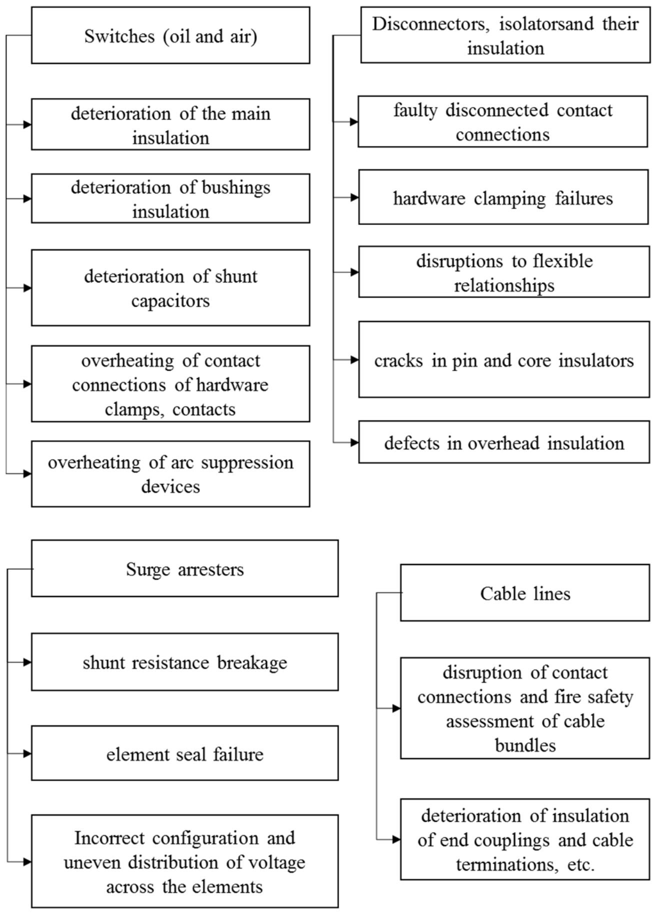

Fig.1. Types of faults in the contact systems of apparatus and cables

The «control» indicator corresponds to the permissible heating temperature of the contact connections, which should be kept under control. The «dangerous» indicator obliges you to take the necessary corrective action when the equipment is about to be repaired. Indicator «defect» - emergency condition that requires immediate elimination. Table I shows the «indicators» depending on the contact heating temperature.

The data presented in the table are relevant for continuous operation of the devices at ambient temperature of 40 °C.

To implement the system of technical condition monitoring of low-voltage apparatuses with the help of thermal imaging cameras and condition indicators it is necessary to implement automated programs that will monitor the condition of apparatuses according to the set criteria in real time and in case of deviations from the parameters signal to the technical personnel at the object about the unacceptable condition.

TABLE I. CRITERIA FOR ASSESSING THE CONDITION OF APPARATUS CONTACTS BY HEATING TEMPERATURE

Controlled area	Indicator		
	control	**dangerous**	**defect**
Main circuit contacts: - unplated copper - silver plated / with silver overlays - sliding with silver plated plates	 < 45° < 200° < 80°	 45°-85° 200°-240° 80°-120°	 > 85° > 240° > 120°
Silver plated auxiliary circuit contacts	< 80°	80°-120°	> 120°
Contacts inside the devices (except soldered and welded contacts): - made of copper, aluminium without corrosion protection coating - of copper, aluminium with corrosion protection coating - of copper with silver coating	< 55° < 65° < 95°	55°-95° 65°-105° 95°-135°	> 95° > 105° > 135°
Contacts inside the devices (soldered with soft solder - soldering provides mechanical strength)	< 60°	60°-100°	> 100°
Contacts inside the devices (soldered with soft solder - soldering partly provides mechanical strength)	individually for each device		
Contacts inside the devices (hard soldered / welded)	not regulated		
Contacts of device terminals intended for connection with external conductors: - made of copper, aluminium without protective coatings - coated with base metals - made of copper with silver coating	 < 55° < 70° < 95°	 55°-95° 70°-110° 95°-135°	 > 95° > 110° > 135°

The considered method of determining the defective state of contacts and contact connections of devices with the help of indicators will reduce the time of detection and elimination of faults to prevent emergencies. Also, it is more rational to plan actions during preventive maintenance and efficiently operate both switching devices and the power supply network as a whole.

III. RESULTS AND DISCUSSIONS

One of the main indicators affecting the duration of operation of the devices is the mode of operation, considering the load factor Kz. Let's determine the most optimal value of this parameter using the indicators discussed above. For the study selected one of the most common and used in the power supply systems of industrial enterprises of Kazan devices: circuit breaker in a molded case VA04 Kursk Electrical Apparatus Plant (KEAZ) and contactors KMI, KTI (IEK).

The expression (1) is used for determining the value of the contact heating temperature by calculation.

$$T = \frac{I^2 \cdot \rho + \upsilon_0 \cdot F \cdot k_T \cdot S}{F \cdot k_T \cdot S - I^2 \cdot \rho \cdot \alpha} \qquad (1)$$

where I – current passing through contacts, A; ρ - specific electrical resistance, Ohm·m; υ_0 – ambient temperature, °C; F – cooling surface of conductor, m^2; k_t – heat transfer coefficient, W/(m^2·K); S – cross-sectional area of contacts, m^2; α – temperature coefficient of resistance.

The results of calculations of contact temperature and contact connections for circuit breakers and contactors are given in Table II.

TABLE II. RESULTS OF CALCULATIONS OF APPARATUS CONTACT TEMPERATURE

Apparatus	Current, A	Kz	Temperature of contacts (T) °C
Circuit breaker VA04	16	1,0	38.6
	32		40.8
	40		44.3
	50		49.8
Contactor KMI	25		40.7
	40		41.6
Contactor KTI	250		41.5
	400		43

Fig. 2 shows the graphical dependence of the temperature of the contact pads T on the load factor Kz for circuit breaker VA04 with rated current 16 A, 32 A, 40 A and 50 A.

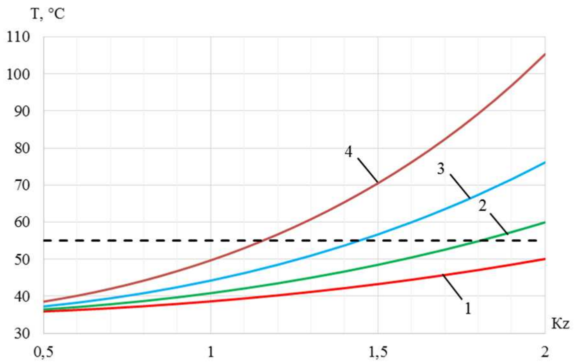

Fig.2. Dependence of heating temperature of contacts of circuit breaker VA04 on Kz:1 – I = 16 A; 2 – I = 32 A; 3 – I = 40 A; 4 – I = 50 A

Based on Table I, the indicator «dangerous» for the device under study is at a value of 55 °C. The value of loading factor for the circuit breaker at I = 50 A, at which there is no process of destruction of contacts is Kz = 1.15, and the maximum value of overload, at which the contact connections go to the state of defect, is Kz = 1.15-1.9. For I = 40 A loading of the device is allowed up to Kz = 1.45, at loading higher than this a defect may occur. The device at I = 32 A withstands loading up to Kz = 1.8 without defective state, at VA04 at I = 16 A double loading did not affect the state of contacts.

The experimental investigation was done on contactors, produced by the company IEK at nominal currents 25 A, 40 A, 250 and 400A. The results for contactors KMI are shown in Fig. 3, for contactors KTI in Fig. 4.

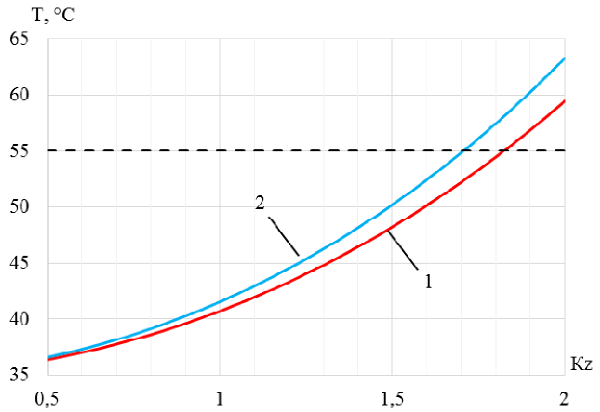

Fig.3. Dependences of contactor KMI contactor heating temperature on Kz:1 – I = 25 A; 2 – I = 40 A

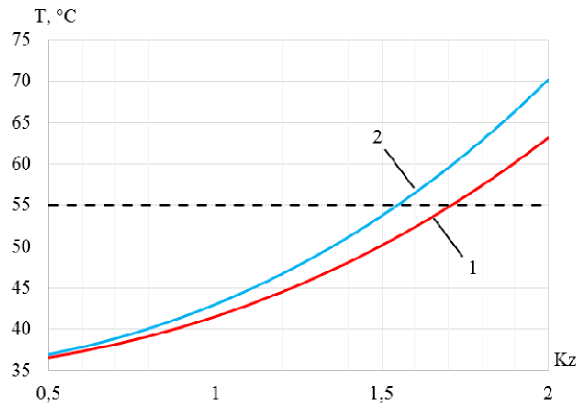

Fig.4. Dependences of contactor KTI contactor heating temperature on Kz:1 – I = 250 A; 2 – I = 400 A

The «dangerous» indicator is also placed at 55 °C. For contactors KMI for currents 25A the optimum load is up to Kz = 1.8, for the device for rated current 40 A the permissible overload Kz = 1.7.

Optimum loading of contactor KTI with I = 400 A is Kz = 1.55, at loading higher than this the transition to the state of defect is possible. The device with I = 250 A withstands loading Kz = 1.7 without defect manifestation.

Further we will consider the practical application of the proposed method with the help of indicators. The application of the thermographic technique in an emergency situation, as a result of which there was a fire with subsequent smoke in the supply cable of the electric motor of the pumping station of the water supply shop. The cause of the damage was disconnection of the contactor of the pump control system. Contactor failure occurs as a result of single or two-phase earth faults.

In practice, it has been proven that when the temperature reaches over 95 °C, the contactor connection fails. Let us show the thermogram of the circuit breaker input (Fig. 5) and the thermogram of the current transformer contacts (Fig. 6).

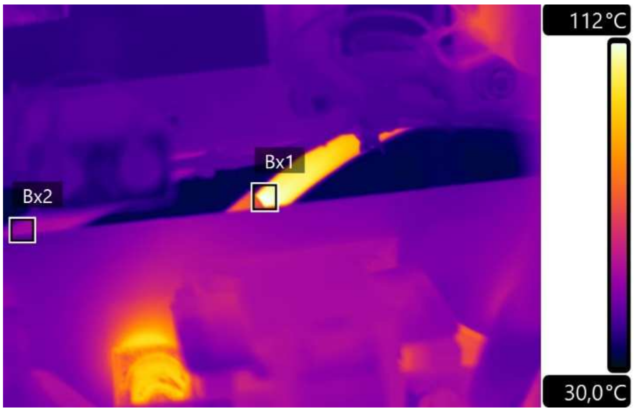

Fig.5. Thermogram of circuit breaker entry

Fig. 5 shows that the maximum temperature of the monitored node is 112 °C, this is well above the defect indicator value corresponding to 95 °C.

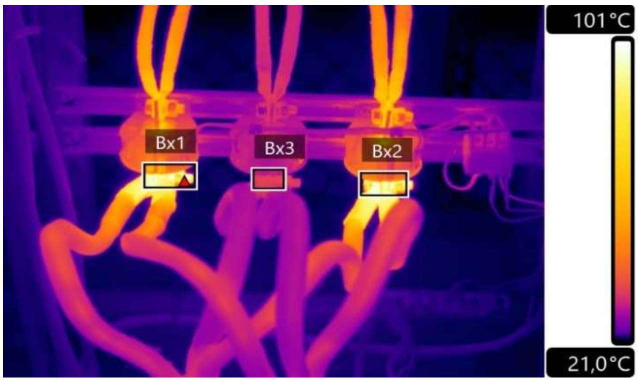

Fig.6. Thermogram of current transformer contacts

The thermogram of contacts presented in Fig. 6 shows that the maximum temperature of the controlled node was 101 °C, which is also higher than the value of the indicator «defect» corresponding to 95 °C. The considered emergency cases at the industrial facility prove the necessity of using indicators and thermal imaging control as one of the automation tools to prevent accidents in the future.

IV. Conclusion

Thermal imaging inspection has sufficient efficiency in determining the faults affecting the functioning of the entire system of power supply of low-voltage consumers. The study makes it possible to estimate the value of losses in contact connections, as well as to clarify the value of power losses in networks. The proposed method, in conjunction with other measuring means, contributes to maintain the optimal level of electrical safety at the industrial facilities.

The method of determining the defective state of electrical equipment with the help of indicators is considered as one of the ways of automated control over the technical condition of equipment in real time. The periodical observation of the working condition of the contacts quality will help to prevent failures. This will further guarantee the most reliable assessment and maintenance, avoiding economic losses and total damage of the most critical units in electrical equipment and thus maintain the reliability level of the entire power supply system.

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