Development of a continuous thermal control device for high-voltage equipment

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Abstract. The development of devices based on IR microcameras that can operate continuously inside, for example, a distribution rack (cabinet) with high-voltage power equipment, remote transmission of information about the thermal state of electrical equipment is of interest. An autonomous device was developed for searching and monitoring an area with a malfunction in the infrared image of high-voltage electrical installations. The device is intended for continuous monitoring of the technical condition of electrical equipment in closed complete installations with no access directly in the operating condition under voltage. The construction concept and technical solutions of an experimental industrial prototype of an automated system device for continuous monitoring of electrical equipment in the infrared image and video surveillance of power facilities are presented. The device is characterized by optimal parameters for monitoring the technical condition of the equipment operating under voltage and the ability to transmit information and accumulate a data bank.

1. Introduction
The widespread introduction of thermal imaging control technology for power equipment and its automation (including the digitalization of electric networks) is currently hindered, on the one hand, due to the high cost of industrial thermal imaging complexes, on the other hand, by the closed nature of the layout of electrical installations with locating their units in complete distribution devices and switchboards inaccessible for infrared (IR) diagnostics in the working (closed) state [1].

2. Main Part
It is urgent to develop devices and systems based on IR microcams that can operate continuously both in the open space (for example, to control the outdoor switchgear of power facilities and reclosers in the network), and inside the closed structures of electrical installations, for example, in a distribution rack (cabinet) with power equipment with remote transmission of information on the thermal state of their nodes to an automated working place of the personnel of an energy facility or control area of an electric power supply network of electrical energy consumers.

The introduction of thermal imaging control technology on marine vessels has an additional difficulty, which is associated, on the one hand, with the high cost of thermal imaging systems for shipowners, and, on the other hand, with the closed nature of marine electrical equipment enclosed in complete switchboards that are not accessible for infrared diagnostics in a working (closed) condition.

The purpose and functions of an automated system device for continuous monitoring of electrical equipment in infrared images and video surveillance of power facilities are as follows:
- continuous thermal imaging control of electrical equipment of power facilities for identifying their malfunction and predictive (proactive) analysis of its risks, including their nodes, located in the closed complete distribution units with no access to them by personnel in working condition under voltage;
- video surveillance for monitoring the condition of the territory and equipment of power facilities, performing the work on them and protecting them (including in extreme weather conditions: ice, hurricane, flooding of the territory, etc.);
- creation of an archive of registered information and its systematic analysis.

Complex performance of the specified functions of the control system using thermal imaging cameras of an industrial design is currently not possible. The used industrial CCTV systems do not allow the thermal imaging control of equipment in the invisible for them spectrum of thermal radiation (usually below 600 °C).

That is why, monitoring the high-voltage equipment is currently limited to episodic thermal imaging control in accordance with regulatory documents [2] or continuously operating video cameras capable of recording the final stage of destruction in the course of an accident.

A detector device [3] allowing the continuous thermal control, including in closed complete cells with high-voltage equipment, has been developed.

The block diagram of the device is shown in Fig. 1. In the device case (1), the IR camera module (7), the video camera module (6), the information and alarm processing unit (8), including the microcontroller (9), the power supply (5), and the monitoring and control circuits (4) are localized; the detector can be connected by a data recording and storage device (2) (telephone, computer) via wired or wireless Wi-Fi connection.

![Block diagram of the detector device](image)

**Figure 1.** Block-diagram of the detector device for continuous thermal control of equipment

The device (detector), made in the form factor of modular equipment for the DIN rail, is intended for installation in electrical switchboards, cabinets or junction boxes.

The circuit uses a microcontroller - a single-board computer Raspberry Pi Model 3 B +, running the Linux Raspbian operating system, specially developed for the Raspberry Pi. The choice of the 3 B + model is determined by optimal performance and cost. Additional advantages include Wi-Fi functions and the ability to connect third-party modules.

The performance of this computer is sufficient to collect, process information and maintain video streams in real time mode.

For the device under development, a Raspberry Pi Camera Night Vision 5MP camcorder with a manual focus setting was selected, which is connected via the CSI connector; as a result, a system was implemented that can take photos with a resolution of 2592 x 1944 pixels and 1080 p @ 30 fps
video. The presence of manual focus adjustment allows to configure the device for a specific control object and place, as well as get rid of accidental loss of focus as in systems with autofocus. The presence of night shooting mode provides the device operation in closed electrical switchboards, cabinets or junction boxes.

For monitoring and recording infrared radiation, a sensor of the MLX90640 type was selected - an infrared camera module with a microcontroller manufactured by Melexis company. The thermal imaging matrix has a dimension of 32 x 24 pixels: the sensor is available in two versions, the cases of which differ in the viewing angle of the matrix: the modification of the case A has an angle of 110 ° (horizontal), 75 ° (vertical) degrees, modification B - 55 ° and 37.5 °, respectively. Communication with the control device is implemented via the I2C interface.

When power is applied, the hardware is initialized during the startup time of the operating system. After successful initialization, the basic monitoring and control functions of the device are launched. In case of failure, the device signals of a malfunction by means of a light indication. The device is configured via the web interface.

The appearance of the device is shown in Fig. 2. The dimensions of the device allow it to be placed inside cabinets of high-voltage equipment without violating safety requirements when working with installations above 1000 V.

![Figure 2. General view of the detector device](image)

Figure 3 shows a photograph and a thermogram of a heat source (oil radiator with dimensions of 620x600 mm) located at a distance of 1 m from the detector.
Based on the data obtained, it can be assumed that at a distance $L = 1$ m at an instantaneous field of view $\text{IFOV} = 3^\circ = 0.05$ rad, using the presented device, objects with linear dimensions of more than 5 cm can be distinguished. This is enough to diagnose overheating of individual elements of electrical equipment: broken contacts, bus works, cable channels, etc.

**Figure 4.** The result of shooting with three types of video stream

A detector installed in the place for the control of the equipment thermal state (for example, in a closed high-voltage cell) provides direct broadcasting of three types (Fig. 4) of the video stream (regular video stream, thermographic image and mixed frame) with the possibility of adding frames
to the database with a given periodicity, and also acts as a sensor operating on the Modbus TCP protocol and can be interfaced with various industrial equipment operating with this protocol.

3. Conclusions
An autonomous device was developed for the search and control of an area with a malfunction in the infrared image of high-voltage electrical installations. The device is intended for continuous control of the technical condition of electrical equipment in closed complete installations with no access directly to the live state under voltage.

The developed device allows you to:
- monitor the temperature of a certain area with an indication of the temperature threshold. If the temperature rises above the limit value, the corresponding signal will be transmitted to the alarm panel;
- equipment operation control. In this mode, the device automatically monitors the electrical installation, if a malfunction is detected, the corresponding signal will be transmitted to the alarm panel.

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