Investigation of the Temperature Sensors Accuracy in the Temperature Monitoring System for the Welded Joints of the Industrial Power Supply Main Busways

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Abstract. The article is devoted to the substantiation of the technical solution of the remote monitoring system for the temperature changes of main and branch busways of power supply to industrial enterprises of increased environmental danger. When monitoring the temperature of trunk buses of AC mains up to 1000 V, heated by an electric current, errors occur due to various factors. Studies have been carried out to evaluate the effect of temperature of surrounding objects (including neighboring busbars) on the accuracy of temperature measurements. Conclusions are made about the possibility of using alternative versions of temperature sensors as the basis of the monitoring system.

1. Introduction

In modern electrical installations of industrial enterprises, electric power networks and, in particular, AC and DC mains up to 1000V made by busways, gradually replace other types of electrical networks made by cables or uninsulated bars laid on insulators. In many cases, the transition from radial power circuits to busbar trunk systems has led to a wide application of sectional busways. The use of bus trunking allows increasing the service life of electrical networks and significantly reducing their breakdown rate [1].

Damage to the mainline leads to simultaneous disconnection of all the power collectors, feeding on it. This is particularly undesirable when many separate large consumers that are involved in a continuous technological process feed on the main line. This also applies to the enterprises classified as environmentally hazardous.

The peculiarity of the main busways installation technology is the connection of busbar sections of different lengths. So, when installing a 100 m long network, the number of connections reaches 30-40 pcs. The connection of the busbar sections is carried out by the argon-arc welding method. The technology of joints of busway sections allows isolation of the welded joint with insulation varnished cloth. The location of the welded joint is most susceptible to thermal heating, especially in case of loose connection between the busway sections. Besides, there is often need to violate the manufacturer's recommendations (for technological reasons) and welding is carried out by a single longitudinal seam. It leads to a decrease in the quality of the ohmic contact (increase in transient resistance) between the connected sections of the busway [2].

To prevent violations of technological processes and operating modes as a result of possible accidents on the electrical busbars of enterprises, it is necessary to carry out continuous (in real-time mode) or periodic monitoring of temperature changes, processing and storing (documenting) the results and predicting the changes in the busway condition. The proposed monitoring system can be constructed similarly to those presented in [3,4].

2. Results and Discussion

The remote monitoring system of temperature changes of trunk and branch busways must ensure the fulfillment of the following requirements and characteristics:

- accuracy of temperature measurement for each welded joint $\pm$ 1.0° C;

- operating range of the busbar trunking current is not more than 4000 A;
- compensation of cross impact of the neighboring buses temperature sensors;
- the maximum permissible temperature for the welded joint is 90° C.

To develop recommendations for the implementation of a system for remote monitoring of temperature changes in trunk and branch busways, it is necessary:

- to study the dependence of the temperature produced by the sensors on the current, flowing through the busbar trunking;
- to perform research to assess the influence of the temperature of surrounding objects (including neighboring busbars) on the accuracy of measurements;
- to study the effect of insulation varnished cloth on the accuracy of measuring the temperature of the busway.

To theoretically substantiate the processes of heating and cooling of a homogeneous conductor, the mathematical modeling of the dependence of the bus heating temperature on the current strength under conditions of heat transfer has been performed.

$$T = \frac{I^2 \cdot R_a}{G \cdot c} t \qquad (1)$$

where T – overheating (exceeding the temperature of the conductor in relation to the environment), C; I – the effective value of the current passing through the conductor, A; R_a – resistance of the conductor at alternating current, Ohm; G – weight of current-carrying conductor, kg; c – the specific heat capacity of the conductor material, $J \cdot s/kg \cdot \deg$ [5,6].

From the preliminary analysis of the composition and characteristics of the monitoring system, it is reasonable to use alternative versions of temperature sensors, namely the non-contact infrared sensors of the MLX90614 family and DS18S2 universal digital sensors [7, 8]. This is necessary to ensure the contact temperature control of the welded joint spot and subsequent comparative analysis of contact and non-contact monitoring results.

As a source of current, a load measuring kit with a current regulator was used. The kit provides current intensity regulation, as well as setting the preset duration of the current flow and measuring the tripping time of the release with the display of information on the graphical LCD. The kits are used to test AC circuit breakers in mains up to 1000V with an industrial frequency of 50 Hz.

The range of regulation and measurement of the test current, A: from 20 to 2000. The resulted error of measurement of current strength, %, is no more than 5. The range of setting and measuring the duration of the current flow in short-time mode up to 99 s. To cool the source of current, a heat gun fan was used.

For the experiment, we used a two-package bus track SHMA-4 4000A (Figure 1).

The connection of the busway sections has been made through the bolt tightening method. Three infrared sensors MLX90614 have been placed above the connection points of three buses, belonging to one package. The IR sensors have been fixed on a board in one common housing. The data obtained in the course of the experiment on the current strength I and the temperature measured by the contact sensor on one bus bar of the busway, confirm the results calculated using the model (1). The average error value is 0.21ºC (Figure 2). For aluminum busways SHMA-4 4000A, the time constant is 17.5 minutes.

When location of the infrared sensors above the bus connection points, in the chart area receiving the thermal radiation sensor fall into a surrounding bus For the sensors used, the radiation reception diagram is a 90^0–opening cone. The current was supplied to only one bus. The remaining two bus bars of the package were heated only by heat transfer inside the box. The DS18B20 universal sensor was attached directly to the surface of the bus to which the test current was applied. The data have been collected using an Asus personal computer. The I²C-bus controller for the MLX90614 sensors' scanning and the 1-Ware-bus controller for the DS18B20 sensor scanning are implemented on Arduino Uno

boards. The software provides accurate temperature measurement of the sensor DS18B20 0.1° C and sensors MLX90614 1°C.
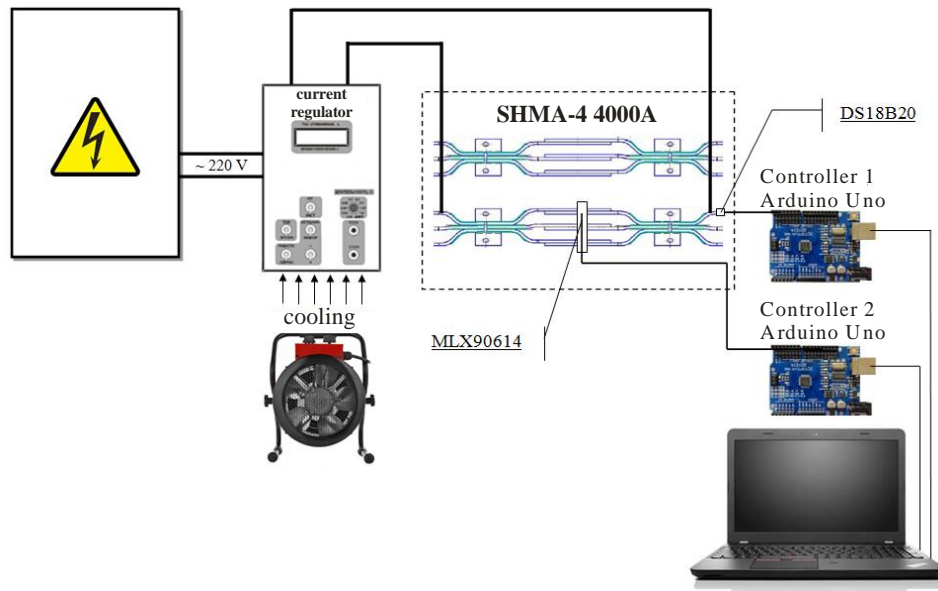

Figure 1. Scheme of the experiment on the influence of the current intensity on the busway temperature
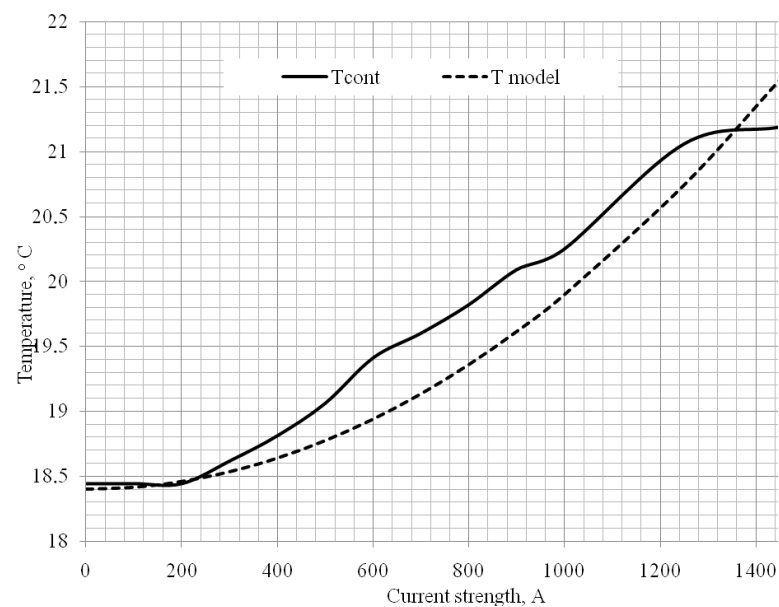

Figure 2. Heating curves of the busbar trunking system (experimental data calculated using the model (1)).

In the course of the experiment, it was found that the readings of the contact sensor and the infrared noncontact sensor are distinguished by a constant displacement value which is proportional to the area of the bus bar, getting into the infrared sensor directional pattern (Figure 3).
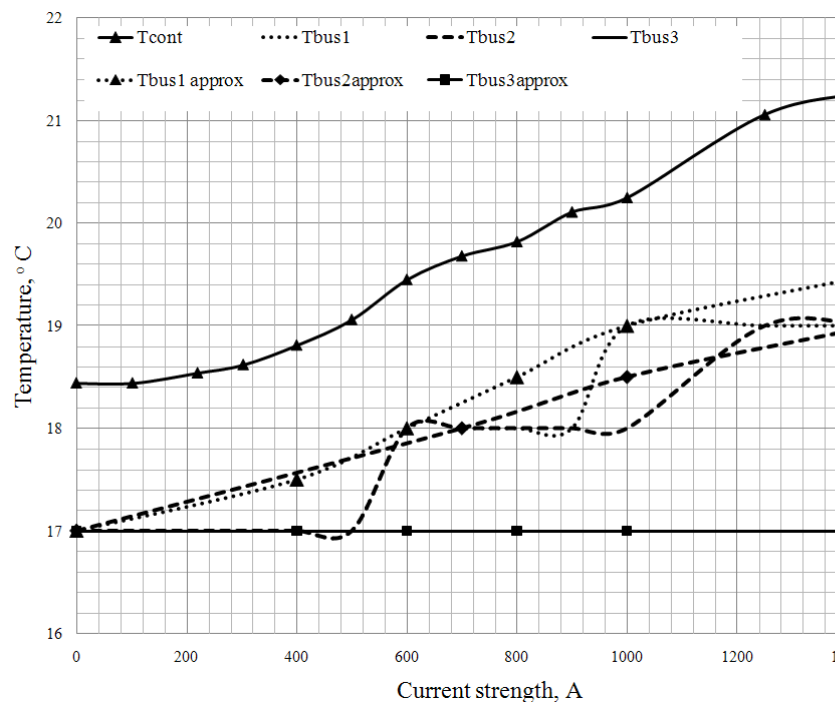

Figure 3. The graph of the dependence of the heating bus bars 1-3 (Tbus1, Tbus2, Tbus3) on the current (I) flowing through the busway 1.

To reduce the influence of radiation from foreign objects (including neighboring busbar trunking systems) falling into the radiation reception diagram, on the accuracy of temperature measurement during the research, one of the infrared sensors was placed in a metal tube. By heating the metal tube, the sensor showed the significantly higher temperature at first, since it took the total radiation of a closely located tube and a heated bus bar. Since a thin-walled tube was used, its cooling rate exceeded significantly the cooling rate of the bus, so after a certain time, the sensor readings in the tube became less than the readings of the open sensors. This is due to the fact that a narrow sector in the sensor's radiation diagram was cut out by the tube. It reduced the intensity of the received radiation and increased the error in the temperature measuring.

To reduce the influence of radiation from foreign objects was held experiment with using the polypropylene plates as limiters for infrared sensors' directional pattern. Using of plastic stoppers makes it possible to avoid the influence of spurious emission. The results are shown in Figure 4.
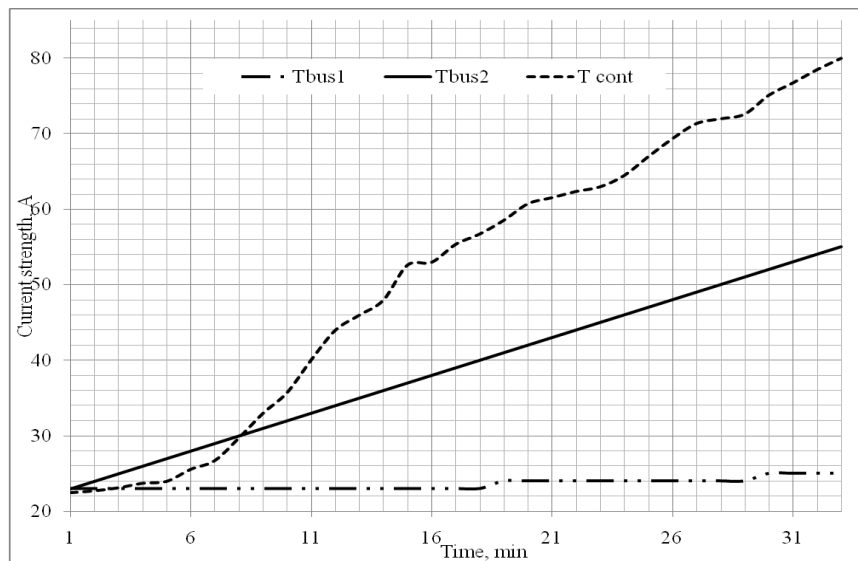
Figure 4. Influence of the heat source limiters on the MLX90614 sensor reading on the busbar 1.

In addition to the errors caused by the mutual influence of the conductors and the width of the directional pattern of the non-contact sensors MLX90614, the error results from the electrical insulation of the bus bars [9]. The electrical insulation of the welded joint of busways is made of varnished cloth. In addition to insulating properties, the varnished cloth has pronounced thermal insulation properties. While using the varnished cloth on the surface of the radiation source, a "greenhouse" effect is produced, caused by a decrease in thermal convection with the surrounding air. With the increased number of varnished cloth layers, the temperature measured by the contact sensor DS18B20 grows almost linearly. The results of the measurements are shown in Figure. 5.

The temperature monitoring of the busway during all the conducted studies was carried out with the help of the controller's Automated Workstation program (AWS program). In the program, data come from digital thermometers (contact sensor DS18B20, infrared sensors MLX90614) through the Arduino Uno platform, built on the ATmega328 microcontroller. In the AWS program, a mnemonic scheme is developed that represents the graphic scheme of a remote object and is intended to display its state at a certain point in time (Figure 6). The mnemonic diagram shows the busway where the current temperature is displayed at the junction of the sections.
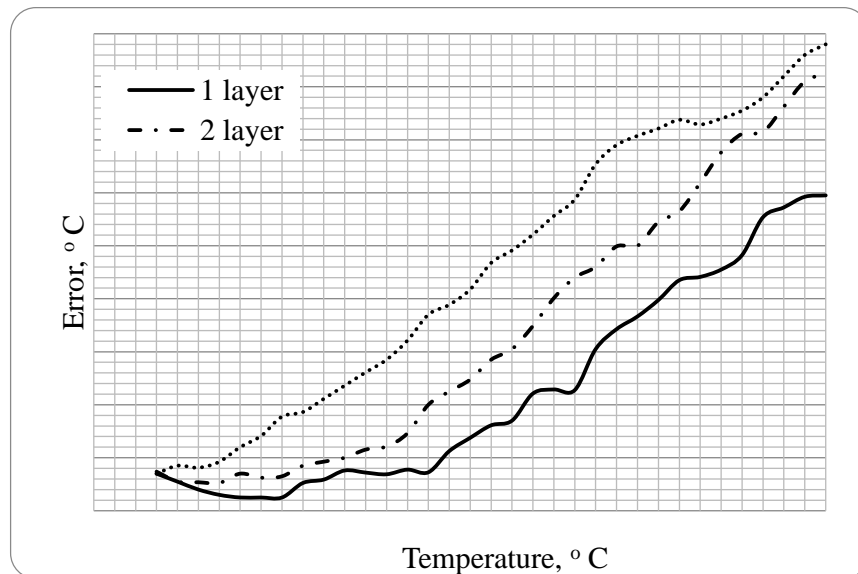
Figure 5. Error in measuring the temperature using the varnished cloth.
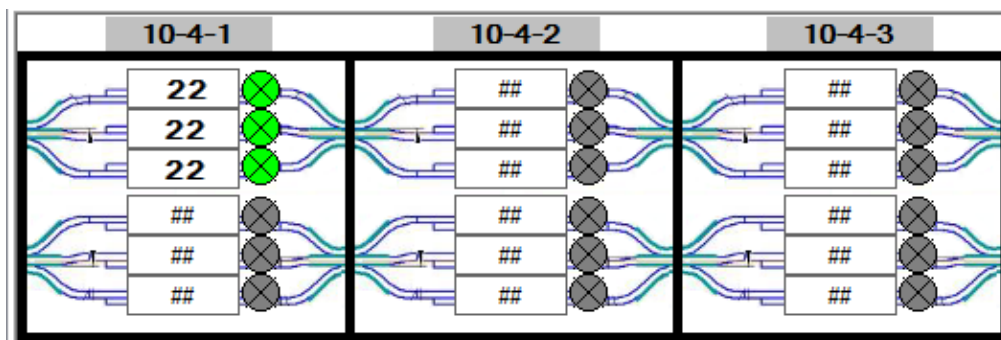

Figure 6. Fragment of the mnemonic diagram "Controller's automated workstation".

Thus, all the planned studies were carried out that allow making a conclusion about the advisability of using the MLX90614 infrared sensors and the DS18S2 universal sensors in the temperature monitoring system for the busways of SHMA-4 4000A type. All the results of the experiments were statistically processed [10].

Conclusions

Analyzing the results of the research, we can draw the following conclusions:

- non-contact infrared sensors of the MLX90614 family of the Microelectronic Integrated System (Melexis) have sufficient accuracy and operating range to control the temperature of the busways;
- to reduce the mutual influence of single buses on the measurement accuracy when using sensors, similar to the MLX90614 and with a 90-degree beamwidth, flat-plate restraints should be used (when using more expensive sensors with a 5-degree beamwidth, you do not need such limiters);
- the number of MLX90614-type sensors per one serial information bus should not exceed 127;
- when using universal DS18S20 sensors from Dallas Semiconductor, the software calibration of the results of measurements is required. The calibration must take into

account the contact density between the sensor and bus bar and the number of the varnished cloth layers. The advantage of the DS18S20 sensors is their low price (by an order less than MLX90614);

- the number of sensors used simultaneously on the same data bus of DS18S20 sensors is not limited.

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