Temperature dependence of optical fiber current sensor with external conversion

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Abstract—The paper presents the research of an optical fiber current sensor with external conversion (OFCS-EC) as a function of temperature. The sensor was developed in the Department of Optoelectronics. The sensor was tested in the temperature range from 23°C–80°C. For each of the temperatures, the sensitivity was determined on the basis of a sinusoidal waveform. Thus, the linearity of transfer characteristics was checked. The main purpose of the experiment was to check the limits of sensitivity changes in changing thermal conditions and the question of whether the sensor meets the standards used in the power industry.

Reliable and accurate measurement of electric current is an essential element in many applications in the field of power engineering. Traditional measurement methods, such as using coils, resistors (shunts), or transformers, are widely used but have their limitations. In response to these challenges, a new technology of current sensors has been developed, which is optical fiber current sensors (OFCSs).

Optical fiber current sensors represent an innovative solution that combines the advantages of fiber optics and measurement technology. Based on the principle of the magneto-optical Faraday effect, these advanced devices enable precise and safe measurements of electric current. However, one of the key factors influencing the operation and reliability of optical fiber current sensors is temperature [1–5].

Temperature is one of the most significant factors that can disturb the performance of measurement sensors. This is particularly important in the case of sensors operating in atmospheric conditions. In the case of measurement transducers used in power engineering, we also deal with high powers which are directly related to the occurrence of high-temperature values and large gradients and ranges of temperature changes. High-temperature values occur in the cases of overloads and faults. These specific cases are particularly relevant to the topic presented by the authors.

The subject of research is the fiber optic current sensor with external conversion (OFCS-EC) intended for low voltage networks, which is to be applied as a component of the protective system known as power system protection (PSP). As mentioned, this sensor is based on the Faraday effect, so its head is made of optically transparent material. As it is known, optical properties are temperature dependent. In particular, the refractive index, which is a fundamental parameter, depends on temperature. Therefore, the magneto-optical properties of materials also depend on temperature. When constructing an optical sensor for power engineering applications, its metrological properties must be verified as a function of temperature.

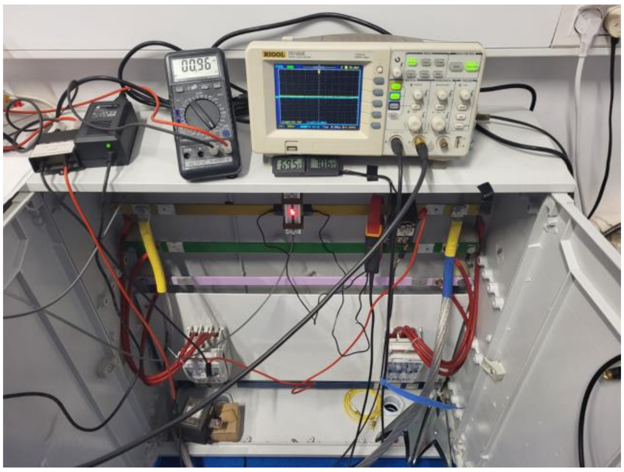

Fig. 1. Photo of the switching box.

The presented solution is intended to be used in low-voltage switchgear [6]. According to the IEC 61439 standard, temperature rise limits must not be exceeded in such switchgear. These requirements assume very high resistance to temperature rise. Therefore, it was decided to test the measurement heads of OFCS-EC at temperatures up to approximately 80°C. The selected and configured switchgear is equipped with three horizontally oriented busbars in the upper part of the switchgear (Fig. 1). The busbars are made of aluminum and coated with paint in colors corresponding to the designation of each phase (L1 – yellow; L2 – green; L3 – purple). The OFCS-EC sensor was mounted on the highest-positioned busbar. This is the most unfavourable case in terms of potential temperature rise. Measurements were carried out at progressively increasing temperature values. The

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busbars were heated by current for about 20 minutes. The heating time of the busbar was adjusted to ensure the heating of the sensor enclosure to a predetermined value. This time and the effective heating current values for each temperature value were empirically determined through a series of tests. During these tests, the upper-temperature limit, which is primarily related to the thermal resistance of the paint applied to the busbars, was also determined.

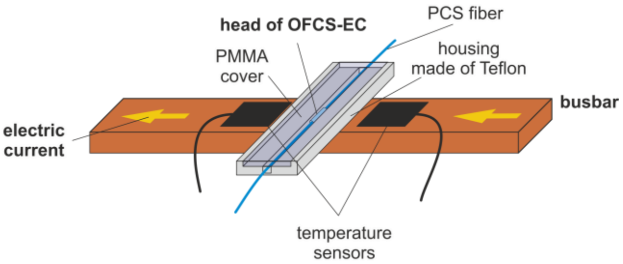

Fig. 2. Schematic view of the placement of the OFCS-EC head and temperature sensors on the busbar.

The temperature was measured at two points, as shown in Fig. 2. The values of both temperatures were averaged. The thermogram in Fig. 3 and the chart in Fig. 4 depict an example of temperature distribution along the tested busbar in the area where the OFCS-EC sensor is installed.

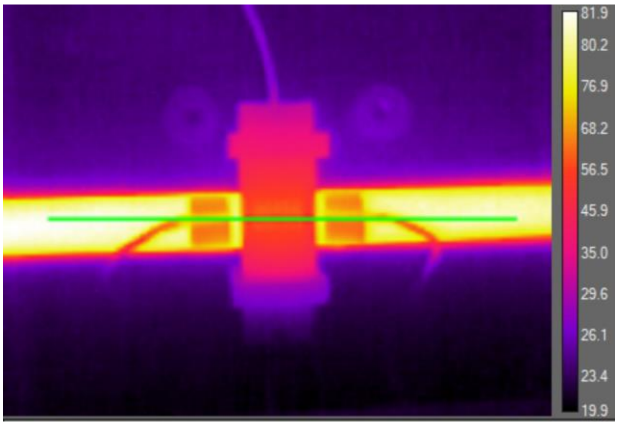

Fig. 3. Thermogram for the highest temperature of the busbar.

For each temperature value, the sensitivity of the OFCS-EC was determined using approximately the same effective current value. This measurement was performed for an effective current value of 200 A. The current was measured using a FLUKE i400s probe. Figure 5 shows an example of current waveforms recorded by the FLUKE i400s probe.

Based on the waveforms in Fig. 5, the response characteristic of the sensor as a function of current for a given temperature (in this case, 78.7°C) was plotted. This is the sensitivity characteristic, which clearly confirms the linear response of the sensor (Fig. 6). From this characteristic, the sensitivity and its uncertainty can be determined for a given temperature. The calculated sensitivities with uncertainties were used to plot the sensitivity as a function of temperature (Fig. 7).

Fig. 4. Temperature distribution along the green line from Fig. 3.

On the chart in Fig. 7, the sensitivity value obtained for room temperature is marked with a blue line, which is also the first measurement point from the left on the chart (hence it lies on the blue line). The red lines represent the range of ±5% from the value obtained for room temperature. Thus, Figure 7 shows that all measured data points, taking their uncertainties into account, fall within the range of ±5% from the value obtained for room temperature. This range corresponds to the permissible error of power engineering current transformers for 5P-class protection. All measurement results must fall within this range, especially during multiple overloads such as short circuits. Therefore, meeting this condition is necessary. The sensor was tested under multiple overload conditions, and these tests yielded positive results [7].

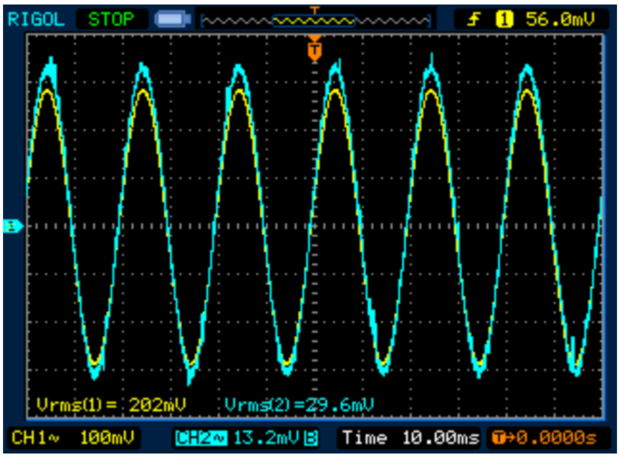

Fig. 5. Current waveform (yellow – reference; green – OFCS-EC).

It can be observed that the busbar has a lower temperature in the area where the temperature sensors and the OFCS-EC sensor are mounted. The sensor mounting itself acts as a radiator and reduces the temperature. In the presented research, the authors did not focus on measuring the temperature of the sensor head. From the application perspective, the focus was on measuring the temperature of the busbar on which the tested OFCS-EC sensor was mounted.

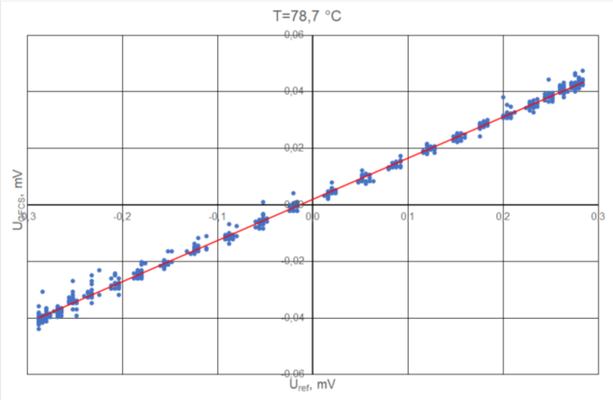

Fig. 6. Sensor output signal as a function of reference value from sinus waveform at a temperature value equal 78.7 °C.

Based on the results from the chart in Fig. 7, it can be concluded that the sensitivity within the tested temperature range (23°C–80°C) does not exceed ±5% from the value obtained for room temperature. There is no clear dependence of sensitivity on temperature in this chart. The uncertainty of sensitivity, with the main component being Type A uncertainty, also does not exhibit any dependence on temperature (Fig. 8).

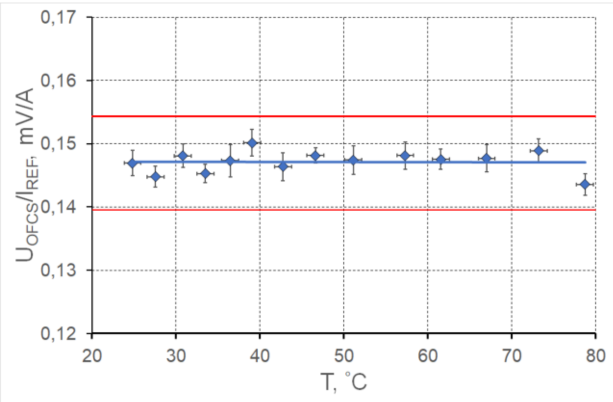

Fig. 7. Sensor sensitivity as a function of temperature. Red lines describe ±5% range around the value for room temperature.

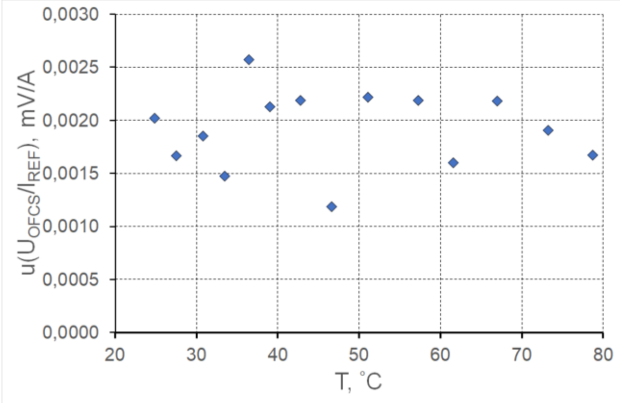

Fig. 8. Uncertainty of sensor sensitivity as a function of temperature.

In summary, the conducted tests demonstrated the insensitivity of the OFCS-EC sensor to changes in the busbar temperature on which it was mounted. The tests were carried out within a limited range of temperature values due to the temperature resistance of the paint coating the busbars. The positive test results encourage further research in a higher temperature range (up to approximately 140°C) and lower temperatures (from approximately – 40 °C).

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