Influence of the measurement parameters in thermographic study of electrical equipment

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***Abstract*— The results from a study of the influence of the set measurement parameters on the temperature readings obtained during the thermographic study of a pumping station electrical equipment are presented in the paper. An analysis of the obtained results has been made taking into account the dependence of the obtained characteristics on the temperature of the tested object.**

Keywords—thermographic study, measurement parameters, error in temperature readings.

I. INTRODUCTION

In modern industrial systems, a wide variety of electrical equipment can be encountered, whose complexity is constantly increasing, following the requirements of technological processes. In this connection, the task of introducing modern methods for diagnostics of the electrical equipment, which ensures the reduction of the duration of the recovery process in the event of a failure and the possibility of control and prognosis of the technical condition, becomes more and more relevant.

The thermal imaging (thermographic) study of the equipment is one of the modern diagnostics methods that has become quite widespread. However, questions about the accuracy of the measured temperature and the measurement error still remain open due to the large number of factors that may affect the temperature measurement by means of thermal imaging cameras [1, 4].

From the point of view of temperature measurement using a thermal imaging system, the error analysis can be useful only under strictly defined reference conditions. Such an analysis can be useful for practical assessment of measurement accuracy in situations, where there is no information about these conditions. Analysis of the error can also be the starting point for the investigation of sensitivity when thermography is applied to validate numerical models for thermal fields (e.g., when the temperature measured at different points is used in finite element method (FEM) computations) [2].

II. ERRORS IN TEMPERATURE MEASUREMENTS THROUGH THERMOGRAPHIC MEANS

When conducting studies of electrical equipment by using thermographic means, it is essential to identify and eliminate systematic and random errors that affect the measurement results.

Systematic errors arise from the design of the measurement equipment and depend on its choice in accordance with the requirements for the improvement of the measurement (temperature resolution NETD, field of view FOV, etc.) [3].

Random errors occur because of the influence of factors depending on the characteristics of the tested object and the surrounding environment:

- Object emissivity ε ;
- Reflected temperature T_{refl} ;
- Distance to the observed object d ;
- Atmospheric temperature T_{atm} ;
- Relative humidity $\omega_{\%}$;
- Solar radiation;
- Airflow speed (Wind speed);
- Angle of observation;
- Load current;
- Thermal time constant of the object.

Some of these parameters are laid down in the mathematical models for radiation thermometry used by the manufacturers of thermal imaging cameras to avoid random factors influencing the measurement.

The mathematical model of the temperature measurement takes into account the following radiant fluxes:

- Radiant flux emitted by the investigated object φ_{ob} ;
- Radiant flux emitted by the ambient and reflected from the investigated object φ_{refl} ;
- Radiant flux emitted by the atmosphere φ_{atm} .

By using the equations in [2] to express the fluxes, an expression for the detector signal s_{ob} corresponding to the radiant flux of the studied object can be derived:

$$s_{ob} = s\frac{1}{\varepsilon\tau} - \left[\frac{1-\varepsilon}{\varepsilon}\frac{R}{e^{B/T_0}-F} + \frac{1-\tau}{\varepsilon\tau}\frac{R}{e^{B/T_0}-F}\right] \qquad (1)$$

where s is the output signal from the IR sensor of the camera,

τ – transmissivity of the atmosphere,

T_0 – ambient temperature,

R, B and F are constants determined in the camera calibration process.

The transmissivity model developed and used by FLIR Systems is a complex function of the three variables: relative humidity, distance between the thermal imaging camera and the object and air temperature. It includes, among others, nine coefficients adjusted empirically.

III. CHARACTERISTICS OF THE SUBJECT OF STUDY

The subject of the thermal imaging study is the electrical equipment of a pumping station. The pumping station

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consists of two pumping groups with three pumping units. Each pumping group serves one village. The control of each pumping group is carried out with a separate electrical dashboard. Each pump group can be operated locally or remotely from the control room.

IV. Survey and evaluation of error in the temperature measurement

The survey was conducted on 01.12.2017 in the time between 11:00 and 12:30.

The thermographic study of the electrical equipment was performed with a thermal imaging camera FLIR E60 using the standard 25° x 19° optical system.

Climate parameters data, for the time interval considered, are given in Table 1. The data is received, from the metrological station which covers the area where the pumping station, is located.

TABLE I. Climate parameters

Climate parameter	**Value**
Minimum atmospheric temperature	8.0°C
Maximum atmospheric temperature	8.9°C
Average outdoor atmospheric temperature	8.3°C
Average indoor atmospheric temperature	12.0°C
Relative humidity	92%

The reference values of the emissivity of the objects are taken from the reference literature of the manufacturer of the thermal imaging camera [5].

A. Evaluation of the influence of the set value of reflected temperature

The change of the relative error in the temperature readings, under the influence of the set value of the reflected temperature, is shown in Fig. 1.

The analysis of the obtained results, which represent the influence of the incorrect setting of reflected temperature on the temperature measurement error, shows that:

- The error in the reflected temperature setting has a significant effect on the relative error in the temperature readings. The relative error in temperature reports changes within limits from 17% to -20%.
- Overestimation of the reflected temperature results in a negative value of the error in the temperature readings. The opposite underestimation of the reflected temperature results in a positive value of the error in the temperature readings. The resulting characteristics are asymmetrical with respect to the origin of the coordinate system.
- The error in the temperature readings due to the set value of the reflected temperature increases considerably with the reduction of the emissivity of the studied object.

B. Evaluation of the influence of the set value of the atmospheric temperature

In the processing of the thermal images, the set atmospheric temperature changes within the limits of $\pm 10°C$ with respect to the average indoor temperature indicated in Table 1.

The change of the relative error in the temperature readings, under the influence of the set value of the atmospheric temperature, is shown in Fig. 2.

The analysis of the obtained characteristics with regard to the influence of the atmospheric air temperature setting on the temperature measurement error can be summarized as follows:

- The error in the atmospheric air temperature setting doesn't significantly affect the relative error in the temperature readings. The maximum value of the relative error is slightly above 0.5 %.
- The resulting characteristics are asymmetric with respect to the origin of the coordinate system.
- A distinctive feature of the resulting characteristics is that the emissivity poorly influences the error in the temperature readings caused by the overestimation of the atmospheric air temperature. Underestimation of the atmospheric air temperature leads to an error in the temperature readings, which increases when the emissivity decreases.

C. Evaluation of the influence of the set value of the distance to the observed object

The characteristics, describing the influence of the set value of the distance to the observed object on the relative error in the temperature readings, are shown in Fig. 3.

On the basis of the obtained results, regarding the influence of the distance to the observed object on the relative error in the temperature reports, the following conclusions can be made:

- The error in the distance to object setting does not significantly affect the relative error in the temperature readings. The maximum value of the relative error in the temperature readings is 0.53%.
- The error in the temperature readings due to the set value of the distance to the observed object is poorly affected by the value of the emissivity.

D. Evaluation of the influence of the set value of the relative humidity

The change of the relative error in the temperature readings, under the influence of the set value relative humidity, is shown in Fig. 4.

The results obtained with regard to the influence of incorrect air humidity setting on the temperature measurement error can be summarized as follows:

- The error in the relative humidity setting has a minimal effect on the relative error in the temperature readings. The maximum value of the relative error in the temperature readings is 0.0075%.
- A feature inherent for the obtained characteristics is that they are asymmetric with respect to the coordinate origin. Underestimation of the relative humidity results in error in the temperature readings which is poorly influenced by the value of the emissivity and the opposite overestimation of the relative humidity results in error in the temperature readings which is strongly influenced by the value of the emissivity.

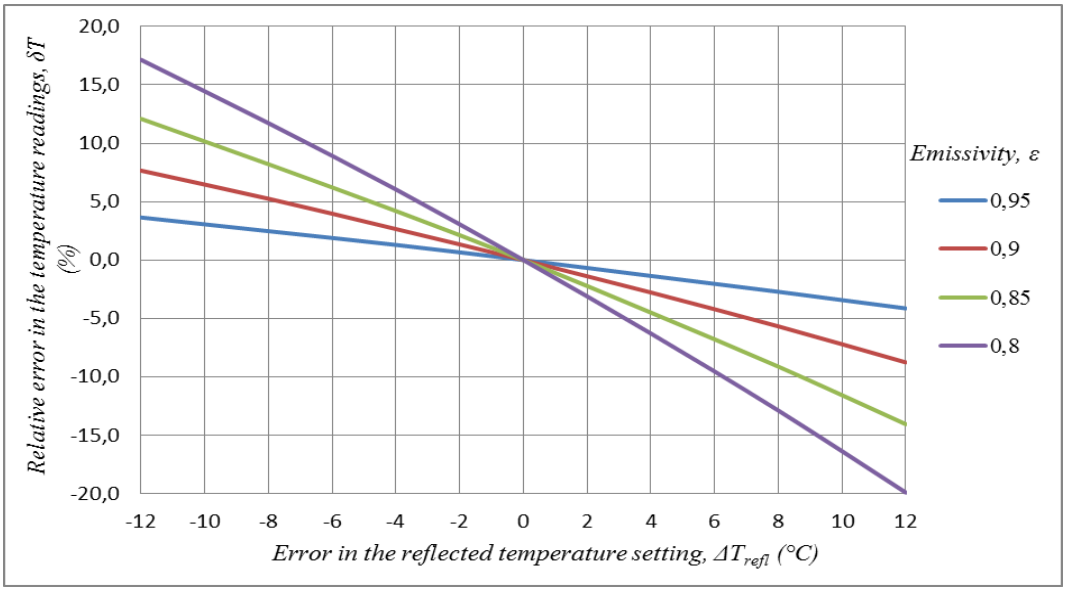

Figure 1. Influence of the set value of the reflected temperature on the relative error in the temperature readings.

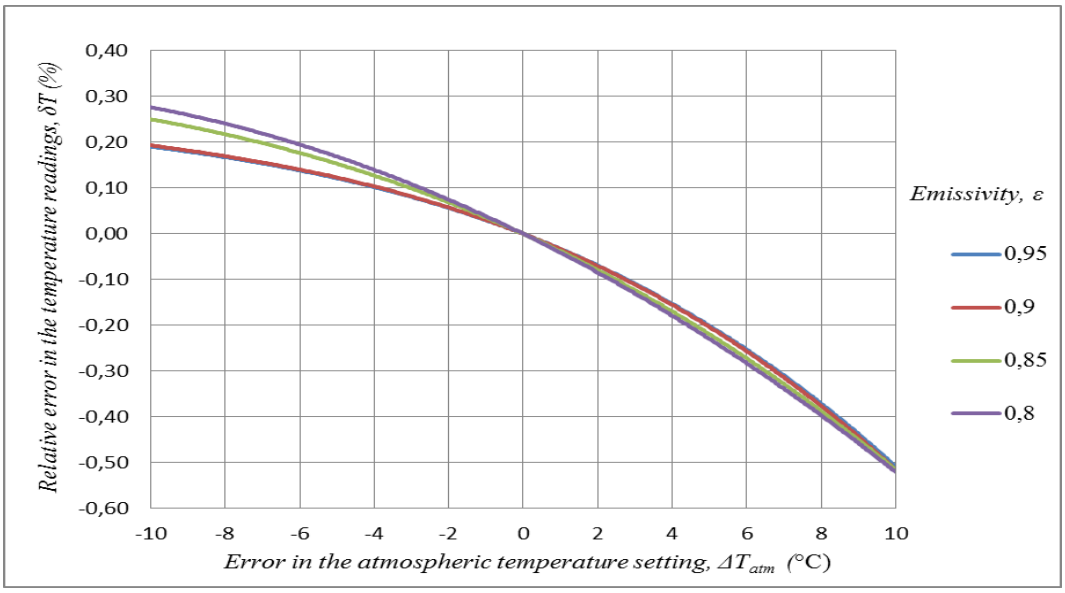

Figure 2. Influence of the set value of the atmospheric temperature on the relative error in the temperature readings.

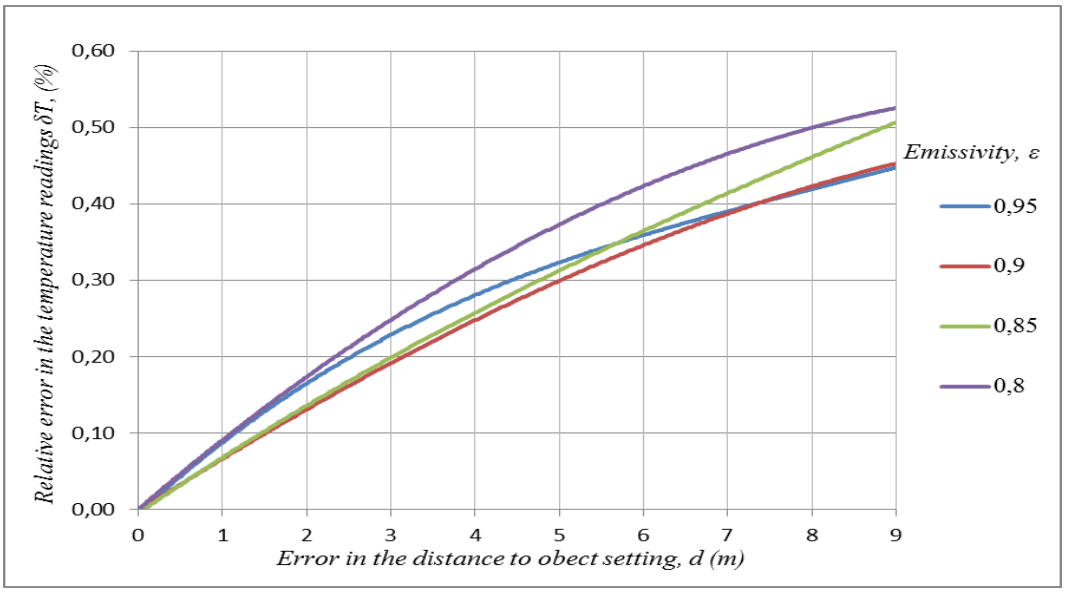

Figure 3. Influence of the set value of the distance to the studied object on the relative error in the temperature readings.

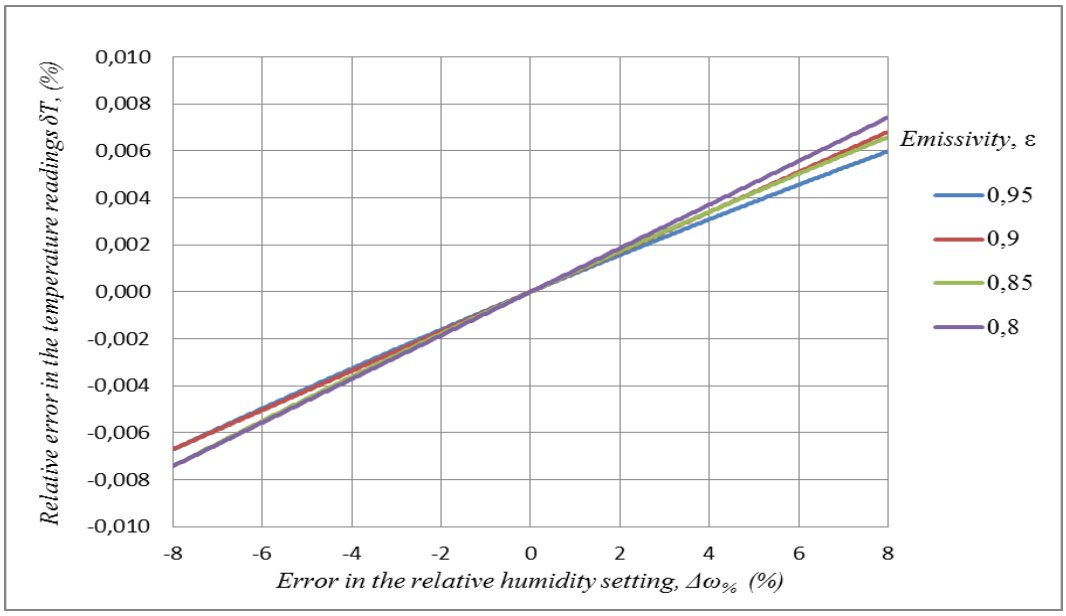

Figure 4. Influence of the set value of the relative humidity on the relative error in the temperature readings.

E. Evaluation of the dependence of the obtained characteristics from the temperature of the studied object

In order to obtain a more-complete assessment for the influence of the set measurement parameters on the values of the temperature readings considerations, about the dependence of the characteristics obtained so far from the temperature of the studied object should be given.

For this purpose, a processing of a thermographic image, of the tested asynchronous motor, has been performed, whereby the obtained maximum motor temperature is $23.85°C$. In this case, the difference in the maximum temperatures recorded in the two images is $\Delta T = 7.89°C$.

The change of the relative error in the temperature readings, under the influence of the set value of the reflected temperature, at different values of the temperature of the studied object and the emissivity is shown in Fig. 5.

The change of the relative error in the temperature readings, under the influence of the set value of the atmospheric temperature, at different values of the object's temperature and emissivity is shown in Fig. 6.

Fig. 7 shows the change of the relative error in the temperature readings under the influence of the set value of the distance to the observed object at different values of the object's temperature and emissivity.

The change of the relative error in the temperature readings, under the influence of the set relative humidity value, at different values of the object's temperature and emissivity, is shown in Fig. 8.

The analysis of the results obtained, with respect for the affect of the temperature of the studied object on the characteristics describing the influence of the set parameters on the measured temperature values, shows that:

- The change in the temperature of the studied object doesn't alter the type and shape of the resulting characteristics.
- Increase in the temperature of the studied object causes an increase in the relative error of the temperature reports caused by the set values of the distance to the observed object and the relative humidity and the decrease of the error caused by the set values of the reflected temperature and the atmospheric air temperature.
- Changes in the temperature of the studied object do not cause any change in the influence of the emissivity on the characteristics.
- The characteristics describing the dependence of the relative error in the temperature readings from the set value of the reflected temperature and the set value of the relative humidity of the air are observed to maintain a constant ratio $\delta T(T_{ob} = 23.85)/\delta T(T_{ob} = 15.96)$. The ratio $\delta T(T_{ob} = 23.85)/\delta T(T_{ob} = 15.96)$ of the characteristics describing the relative error in the temperature readings caused by the set value of the reflected temperature is equal to 0.690. The ratio $\delta T(T_{ob} = 23.85)/\delta T(T_{ob} = 15.96)$ of the characteristics describing the relative error in the temperature readings caused by the set value of relative humidity is equal to 1.925. The resulting ratios, of the relative error in the temperature readings, don't depend on the value of emissivity.

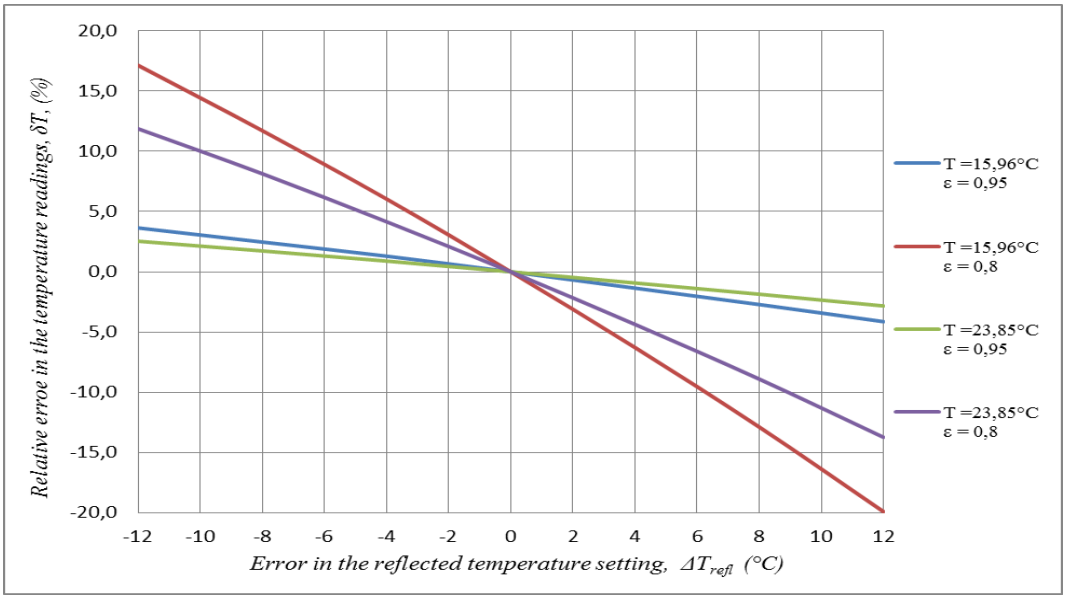

Figure 5. Influence of the temperature of the object on the error caused by the set value of the reflected temperature.

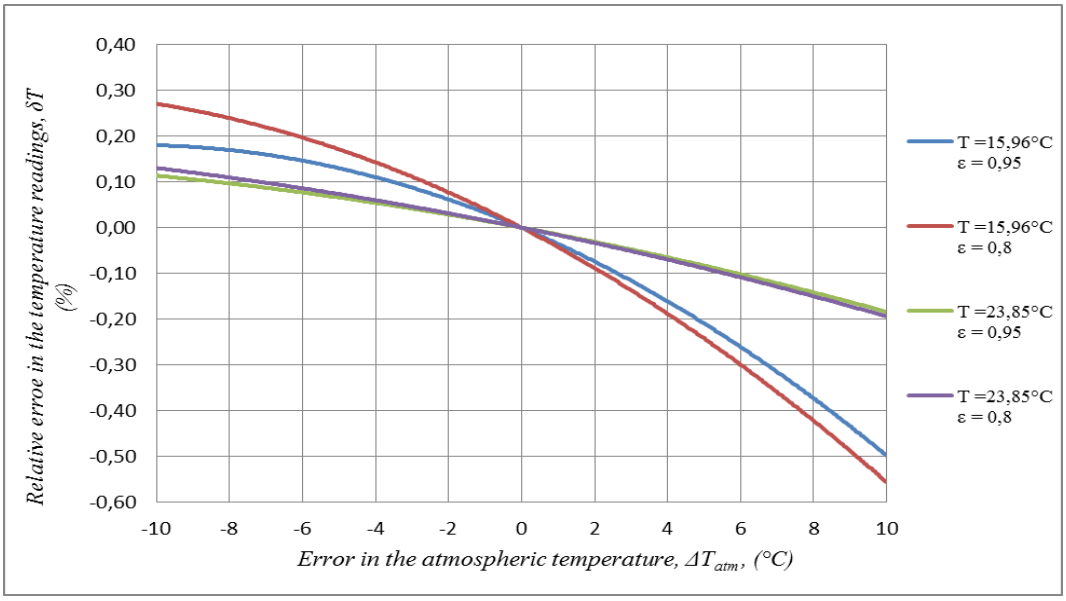

Figure 6. Influence of the temperature of the object on the error caused by the set value of the atmospheric temperature.

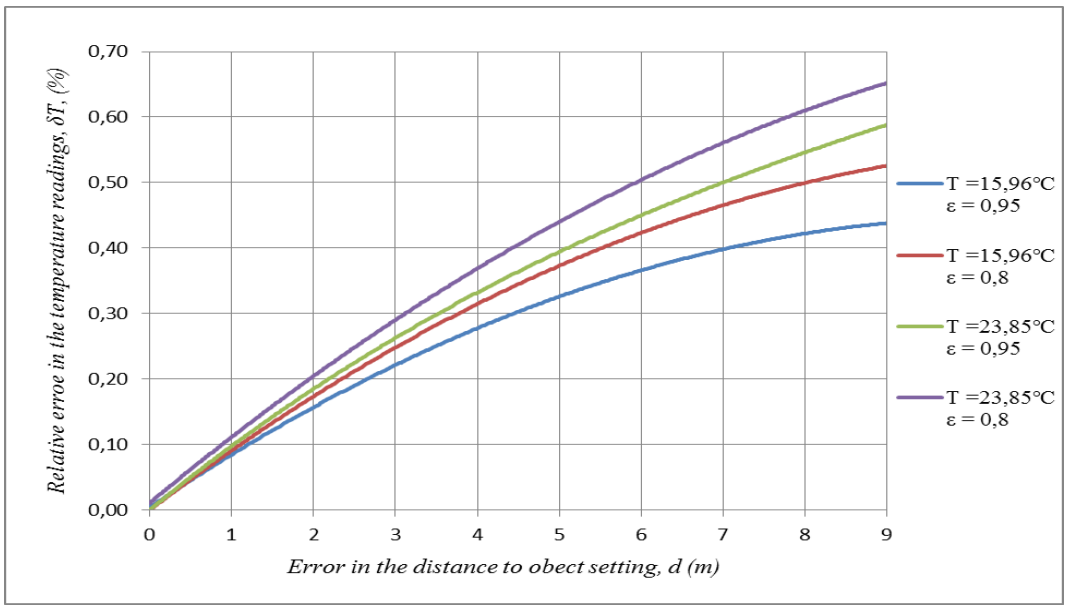

Figure 7. Influence of the temperature of the object on the error caused by the set value of distance to the studied object.

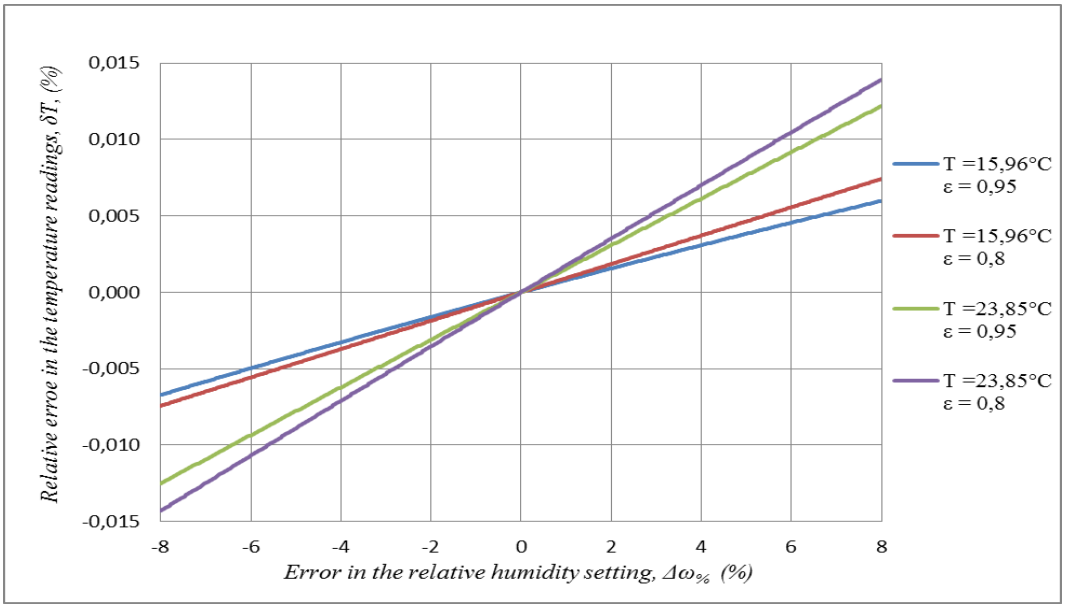

Figure 8. Influence of the temperature of the object on the error caused by the set value of relative humidity.

V. CONCLUSION

The obtained results with respect for the influence of the set measurement parameters on the temperature readings show the strong effect of some of the parameters examined on the accuracy of the temperature measurement. Therefore, a very important aspect in thermal imaging testing of electrical equipment, especially at low emissivity and low object temperature, is the determination of the exact values of the measurement parameters.

In order to increase the accuracy of temperature measurement, it is advisable to follow the test methodologies, which are prescribed, in the normative documents.

REFERENCES

[1] Vollmer M., K. Möllmann, Infrared Thermal Imaging: Fundamentals, Research and Applications, Wiley, Weinheim - Germany, 2011

[2] Minkina W., S. Dudzik, Infrared thermography: Errors and uncertainties, Wiley, Czestochowa University of Technology - Poland, 2009

[3] Бажанов С. А. Инфракрасная диагностика электрооборудования распределительных устройств, НТФ "Энергопрогресс", 2000

[4] Mohanty A. R., Machinery condition monitoring principles and practices, CRC Press Boca Raton, 2015

[5] http://www.flir.com/instruments/exx-series/e60/.