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# Features of thermovision control of open substations equipment with wind load registration

A Vlasov<sup>1</sup>, K Alloyarov<sup>1</sup> and A Rubtsova<sup>2</sup>

<sup>1</sup> Murmansk State Technical University, Murmansk, Russia

<sup>2</sup> Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

k-alloyarov@ya.ru

**Abstract.** The features of the thermovision control of open substations electrical equipment when exposed to air flow (wind loads) are considered. Wind loads have a significant impact on the change (decrease) of the surface temperature of electrical equipment, which is confirmed by the experimental data presented. Disregarding wind loads impact reduces the reliability of the results of thermovision tests and subsequent expert evaluation, including hidden defects in the structure. There is no method for assessing the effect of air flow on the surface temperature of the object under study. The lack of a technique is a cause of deterring the use of thermovision diagnostic methods for evaluating electrical equipment. In order to take into account the impact of wind loads, a method developed by the authors for considering the cumulative influence of numerous factors was proposed for estimating the density of heat fluxes in the volume of electrical and dielectric materials during operation. The collection of experimental data was carried out for objects from various materials: porcelain, aluminum, nichrome. The main factors influencing the surface cooling intensity are substantiated: excess of the surface temperature blown by the wind  $\Delta t_{\text{в}}$ , external diameter  $D$  of the structure, air speed  $v$ , medium temperature  $T_0$ , thermal conductivity coefficients of materials, surface emissivity coefficients, electrical resistance of conductors, and features of the shape of the analyzed node. As a result of the analysis of experimental data, it was found that with an increase in the speed of the air flow up to 5 m / s, the temperature decreases by 25-30 ° C. The sharpest decrease in temperature of the objects under study is observed with an increase in the speed of the air flow from 0 to 1 m / s.

## 1. Introduction

Guiding documents [1,2,3] regulate the content, norms, deadlines, and expert evaluations of the thermovision (thermographic) tests results of electrical equipment at electrical substations. However, when describing the technology of thermovision tests, information on accounting and assessing the effect of wind speed on the surface temperature of equipment in an open substation is not given [4].

Tests are organized and carried out taking into account planned and unscheduled analysis at any time of the year and day. In practice, thermovision control of equipment in open substations, as a rule, is carried out in the presence of air flow.

## 2. Materials and methods

The accumulated practical experience of thermovision diagnostics shows that air flow negatively affects the final result (expert assessment); with the wind the temperature of the surface of the



surveyed object decreases, approaching the ambient temperature. Product surface temperature rise  $\Delta t_d$  defined as the temperature difference between the surface of the object (defect)  $T_d$  and the environment  $T_0$ :

$$\Delta t_d = T_d - T_0, \quad (1)$$

– decreases, and therefore the likelihood of detecting developing defects by the method of thermovision diagnostics falls.

In the early research concerning thermovision development [5], an empirical expression of the following form was used:

$$\Delta t_1 / \Delta t_2 = (v_2/v_1)^n, \quad (2)$$

$\Delta t_1, \Delta t_2$  – values of object surface temperature rise, measured at wind speeds equal to  $v_1$  and  $v_2$ :

$$\Delta t_1(v_1) = t_w(v_1) - T_0; \quad (3)$$

$$\Delta t_2(v_2) = t_w(v_2) - T_0. \quad (4)$$

When the speed of the air flow from 0.2 to 7.0 m / s, the parameter  $n$  in the calculations is assumed to be constant  $n = 0,448$  [5].

In the process of thermovision testing of the equipment of an open substation in windy weather, the value  $t_d(v, T_0)$  of the alleged defect is determined experimentally at ambient temperature  $T_0$ .

The most important task is to develop an expert decision on the degree of defectiveness of a particular node of equipment. For example, not only the maximum permissible heating temperature of metal contacts is regulated, but the permissible temperature rise of the contact (above the effective ambient air temperature  $T_{\text{eff}} = 40$  °C [6,7]).

Therefore, in order to predict the development of a defect, it is necessary to estimate the temperature  $t_d(0, T)$  of the node at zero wind speed at any ambient temperature  $T$ , including the temperature  $T_{\text{eff}}$ .

It is obvious that the use of relation (2) to recalculate temperatures from wind speed  $v$  to zero speed in the framework of the considered problem is impossible.

Thus, the relation (2) partially reflects the effect of wind speed on the temperature of the object being blown, but it cannot adequately take into account many modes of forced and mixed convection, determined by the geometry of the objects under study (height, diameter and other characteristics), velocity value and direction of the wind speed.

### 3. Results and discussion

To solve this problem, we have proposed accounting method of numerous factors cumulative effect for estimating the density of heat fluxes in the volume of electrical and dielectric materials during operation, calculating heat transfer coefficients, emissivity of materials of test objects, their geometric dimensions, shape and other factors. Features of the software are described in [8-11].

Consider the results of experimental verification of the effect of wind speed on the objects of study from metal (aluminum, nichrome wire) and dielectric (porcelain) materials and analyze the conclusions obtained on the basis of mathematical models.

Artificial air flow was provided by local airflow with a direction perpendicular to the surface of the object of study. Wind speed in the range from 0.0 to 5.0 m / s was measured with an ATT-1002 anemometer with an accuracy of  $\pm 0, 1$  m / s.

Experimental values of surface temperature of porcelain  $t_{wF}$  in the wind ( $t_{wWF}$  without wind), with nichrome or aluminum conductors  $t_{wN}, t_{wA}$  ( $t_{wWN}, t_{wWA}$  without wind), air temperature  $t_0$  ( $T_0 = 22-24$  °C) was controlled by thermocouples with an accuracy of  $0,1$  °C, as well as by the thermovision method using FLUKE Ti-400, TESTO-875i.

The experimental values of the temperature rise  $\Delta t_{\text{exp}}$  were calculated using the relation (1); theoretical values  $\Delta t_{\text{theor}}$  were calculated using the developed programs.

Initially, the effect of wind speed on an uninsulated metal wire (nichrome; diameter  $D_N = 0,0015$  m) was estimated. In the experiment, the conductor was heated with a current to the value of  $t_{wWP}$  without air flow ( $v = 0$ ), after which the conductor was blown with air flow.

In Figure 1, the dots indicate the temperature rise of the cooled conductor. Continuous lines reflect the results of a theoretical calculation of the temperature rise of the nichrome wire at air flow speeds in the range from 0,0 to 5,0 m / s, taking into account the shape, diameter, electrical resistance, and the degree of emissivity of the material.

It is obvious that with an increase in the speed of the air flow to 5,0 m / s, the temperature rise  $\Delta t_{wWN}$  nonlinearly decreases by more than 25-30 ° C compared with the data at the “zero” wind.

Subsequently, as test objects coaxial construction: bushing insulator (material - dielectric, porcelain; external diameter  $D_P \approx 0,050$  m; height  $H = 0.2$  m) was chosen. A metal wire is installed on the central axis of the insulator (nichrome; diameter  $D_N \approx 0.0015$  m) through which an electric current of a given magnitude flows.

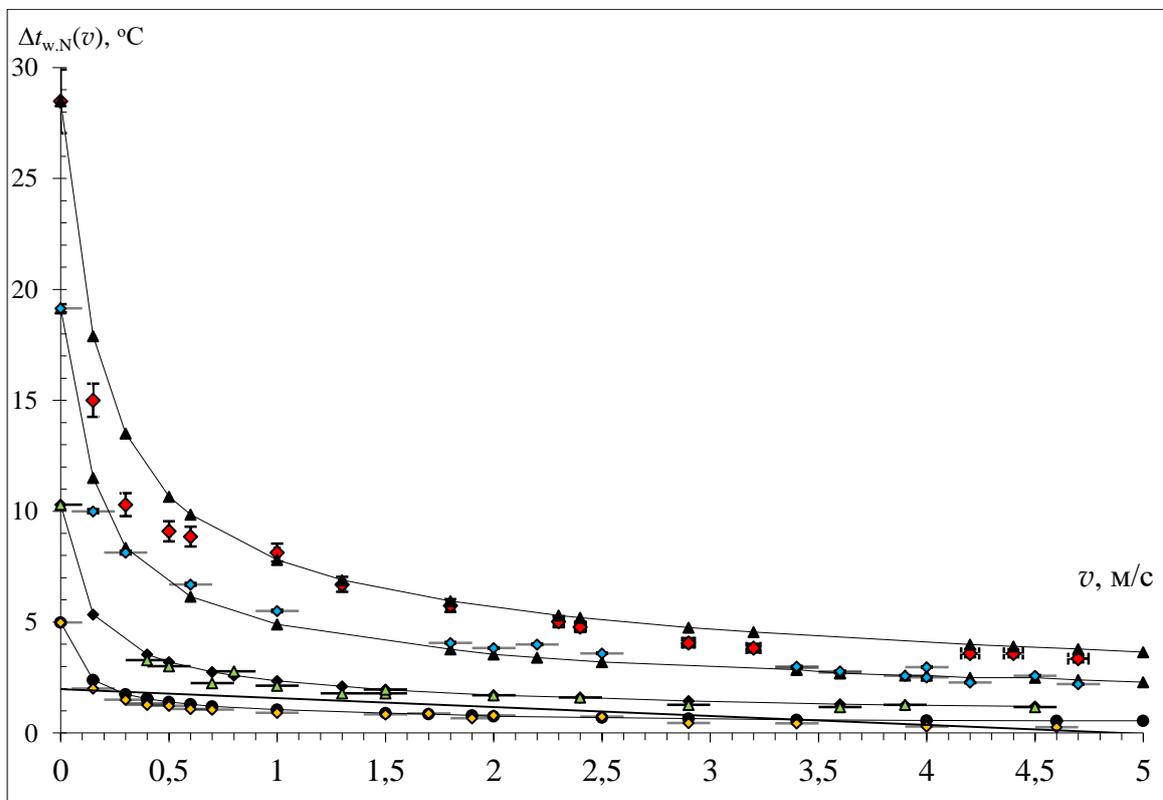


Figure 1. Wind speed effect  $v$  on the temperature rise  $\Delta t_{wN}(v)$  of wire (nichrome) at different initial values  $\Delta t_{wWN}$

As the current increases, the temperature of the wire increases, the radial heat flux increases, and, ultimately, due to the thermal conductivity of air in the cavity and the volume of the dielectric, the temperature of the outer surface of the porcelain rises to a stationary  $t_{wP}$  value in the wind or  $t_{wWP}$  without wind.

For example, at a fixed conductor current, the steady state of the temperature of the outer surface of a porcelain insulator without wind is  $\Delta t_{wWP} = (13 \pm 0.2) ^\circ \text{C}$  (Fig. 2).

The correlation between the values of the excess temperature of the porcelain insulator  $\Delta t_{wP}(v)$  and the values of the air flow velocity (Figure 2, experimental points) shows that a sharp decrease in the temperature of the dielectric surface (from 13 ° C to 5 ° C) is observed in the speed range from 0, 0 to 1,0 m / s. After that the influence of the flow velocity is less significant. In general, as the air flow rate

increases from 0.0 to 5.0 m / s, the temperature rise of the outer surface of the porcelain insulator falls by more than 6 times.

Continuous lines approximating the experimental values (Figure 2) are drawn according to the results of calculating the values  $\Delta t_{wP}(v)$  using the algorithms described above.

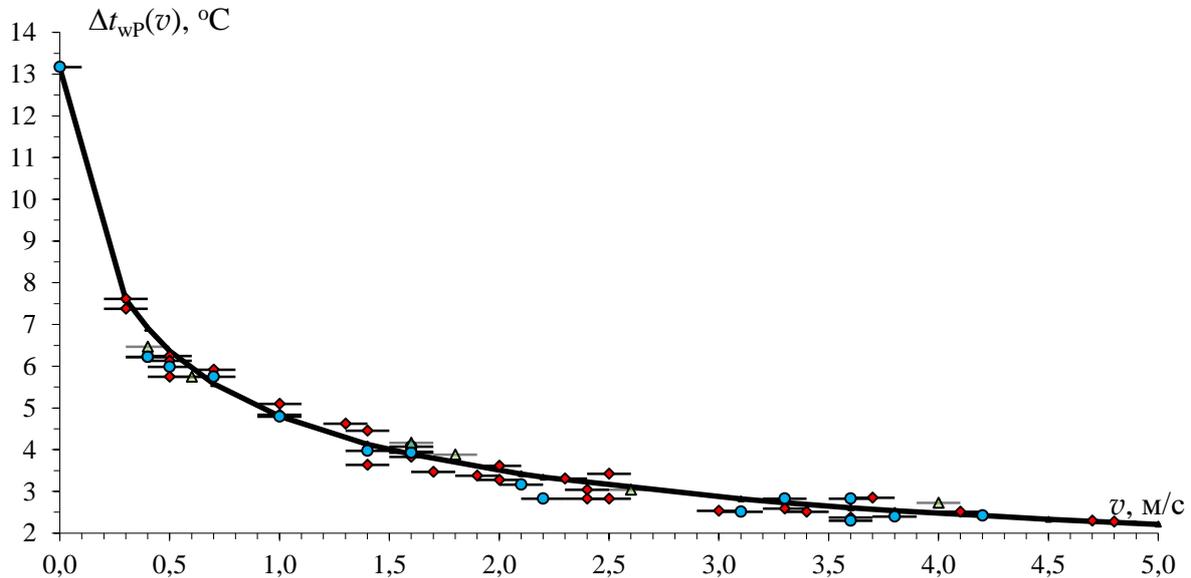


Figure 2. Wind speed effect  $v$  on the temperature rise  $\Delta t_{wP}(v)$  of the porcelain insulator surface with a fixed initial value  $\Delta t_{wvN}$

The analysis of the presented results shows that the greatest cooling of the porcelain insulator surface occurs in the area of wind speeds from 0.0 to 3.0 m / s, typical for performing thermovision diagnostics of equipment at open substations.

The diagrams obtained in the process of factor analysis allow us to estimate the temperature rise of the surface of the node without wind  $\Delta t_{wvP}$  with known initial results of thermovision tests: temperature rise of the node with a known speed of air flow.

Consider the results (Figure 3) obtained when comparing the small diameter porcelain insulator ( $D_1 = 0,05$  M) with constant ( $D$ ;  $T_0$ ) and variable ( $v$ ;  $\Delta t_{wF}$ ) factors. For the analysis, we selected range of air flow speeds,  $v$  in the range from 0 to 5 m / s and temperature rise values of the blown surface,  $\Delta t_{wP}$  in the range from 1 to 12 °C.

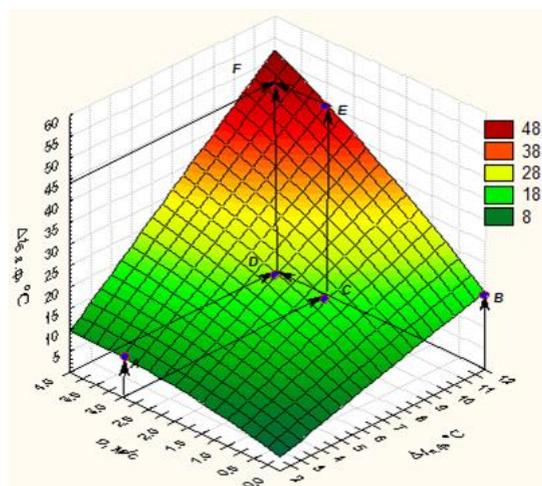


Figure 3 Various factors effect on the assessment of the porcelain insulator ( $D_1 = 0,05$  m)  $\Delta t_{wwP}$  rise

For practical assessment, the scale of temperature rise values ( $\Delta t_{wP}$ ) of the surface is divided into intervals of  $0,5$  °C. Similarly, the magnitude scale of the possible values of the air flow speed has 16 intervals.

We consider an arbitrary calculation of the temperature rise of the porcelain insulator (Figure 3). During the test, we select the following influencing parameters:  $v = 3,5$  m / s;  $\Delta t_{wP} = 12$  °C. In order to fix the conditional points A and B, we denote vertical lines to the intersection with the hypersurface. On the hyperplane ( $v$ ;  $\Delta t_{wP}$ ), using the lines of the corresponding intervals, we fix the position of points C and D. With the help of verticals from points C and D we find nodes E and D, respectively, which are located at the intersection of the corresponding lines of the intervals. From point F (segment CF, parallel to CD) we raise the perpendicular to point D.

Using grids of lines crossing the Z axis, it is possible to find the temperature rise  $\Delta t_{wwP} \approx 45$  °C (without wind) for a porcelain insulator ( $D_1 = 0,05$  m). The relative error of calculations by various methods does not exceed a value from 2 to 4%.

Correlation analysis allows us to compare the results of calculations obtained for products with porcelain insulation with arbitrary values of external diameters. In particular, at  $D = 0,5$  m the value is  $\Delta t_{wwP} \approx 23$  °C, at  $D_3 = 0,7$  m -  $\Delta t_{wwP}$  up to 19 °C.

We suppose that analysis of the metallic conductors cooling with air flow is interesting.

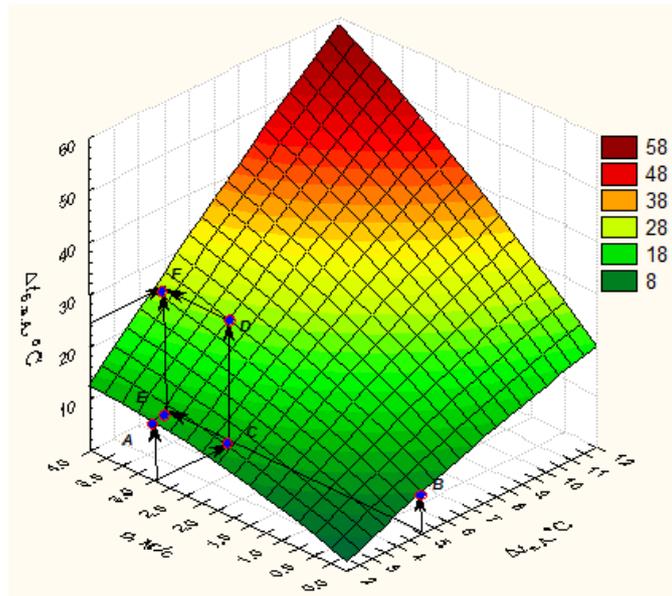


Figure 4. The various factors effect on the estimate of the  $\Delta t_{wwA}$  ( $v$ ,  $\Delta t_{wA}$ ) rise of the aluminium wire surface ( $D = 0,02$  m)

Analysis of the obtained results with accounting the cooling of the objects in the form of aluminium wires with diameters ( $D_1 = 0,02$  m,  $D_2 = 0,03$  m,  $D_1 = 0,04$  m) typical for power substations is shown in Figure 4. For example, with initial  $v = 3$  m / s and  $\Delta t_{wA} = 5$  °C for a wire with a diameter of 0,02 m, the value of the surface temperature rise without wind is  $\Delta t_{wwA} \approx 25$  °C.

We compared the influence of the wire diameter values on the temperature rise  $\Delta t_{wwA}$  (without wind) of its surface under the same initial conditions: when the air flow rate is 4 m / s, the value of the temperature rise of the wires  $\Delta t_{wwA} = 12$  °C. The calculation showed that as the wire diameter decreases from 0.04 m to 0.02 m, the temperature rise of the surface  $\Delta t_{wwA}$  increases from 54 °C to 58 °C.

#### 4. Conclusion

Cooling of electrical equipment (contact connections, dielectric insulators, tires, wires) of open substations with air currents changes the surface temperature and negatively influences the expert judgment during thermovision tests.

Evaluation of the wind impact on the surface cooling of the nodes and structures is possible considering the factors, among which the most important are: temperature rise of the surface blown by the wind  $\Delta t_w$ , external diameter  $D$  of the structure, air velocity  $v$ , medium temperature  $T_0$ . Additional factors include: thermal conductivities of materials, coefficients of surface emissivity, specific electrical resistance of conductors, shape features of the analyzed node (wire, tyre, porcelain tyre) and others.

Lack of assessment method determining the effect of wind speed on the temperature of the defect surface (especially at the initial stage of development) limits possibilities of using thermovision equipment.

The obtained results emphasize the relevance and the need to develop methods considering the effect of wind speed on the final expert assessment in the diagnosis of electrical equipment.

#### 5. Acknowledgements

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