Acta Technica *63* No. 5/2018, 701–708

Temperature influence of load current of overhead electrical distribution networks in difficult weather conditions

Oleksandr Kozlovskyi[1], Dmitro Trushakov[2],
Serhiy Rendzinyak[3]

Abstract. In order to increase the efficiency of overhead power lines operation in distribution electrical networks under conditions of ice formation, the effect of load currents on the wires temperature of overhead lines is estimated. As a result of the analysis of daily electric loads schedule for typical agricultural consumers, it was established that during the period of the most probable formation of glaze and rime deposits their load is in the range from 11 % to 35 % relative to the daily maximum. Theoretical study of the temperature change law for the wire showed that the load currents of overhead power lines up to 25 % of the nominal value increase the wire temperature to from 0.3 °C to 2.2 °C, depending on the wind speed. When creating technical devices for implementing information systems for monitoring overhead lines in icing conditions, it is advisable to use indirect approach to control, since the wire branching to 10/0.4 kV substations of the distribution net-work temperature is similar with the ambient temperature, due to their low loading.

Key words. Overhead power lines, graph electrical load, temperature wire.

1. Introduction

On the territory of Ukraine over the past decade, the largest number of climatic records was captured in the history of regular meteorological observations. It goes to show that irreversible climate changes have occurred, which are manifested in the growth of the frequency of extreme weather conditions, in particular, in the cold season. The wind-icing phenomena are causing significant damage to the economy

---

[1] Department of Electrical Systems and Energy Management, Central Ukrainian National Technical University, CNTU Kropivnitskiy, Ukraine; e-mail: `kozlovskiyoa@gmail.com`

[2] Department of Automation and Control in Technical Systems, Central Ukrainian National Technical University, CNTU Kropivnitskiy, Ukraine; e-mail: `dmitro.trushakov@gmail.com`

[3] Institute of Power Engineering and Control Systems, Lviv Polytechnic National University, Lviv, Ukraine; e-mail: `emd@polynet.lviv.ua`

and population. Unfortunately, forecasts of climatologists are disappointing; such trends will continue in the future [1]. Therefore, urgent adaptation to the climate changes of the basic area of the economy of Ukraine – power engineering.

An analysis of experience in the exploitation of power equipment shows that the most sensitive part of the energy system to atmospheric loads are the overhead power lines, and the maximum of technological disruptions in their work are accounted for electrical distribution networks 6/10 kV. Damages of overhead lines resulting from the action of excessive mechanical loads from the influence of ice-and-wind phenomena constitute only up to 20 % of all damages for overhead power lines, but they occur on the territory of several regions and are massive by its nature. For example, icing in 2000 led to the blackout of 3 861 settlements in 11 regions of Ukraine as a result of damage to 15 800 overhead power lines. Only in the Vinnytsia region 95 % and in Odessa region—90 % of towers of electrical distribution networks were destroyed. The total losses from these damages amounted to 512 million UAH [2].

2. Statement of the problem

Today, the increase in the efficiency of the exploitation of overhead power lines in the icing conditions is achieved by the use of automated ice melting systems. Those systems are created on the basis of complex information systems of overhead power lines monitoring in icing conditions. The structure of a typical complex system includes the following local systems: monitoring the state of the overhead power line, early confirmation of the formation of glaze and rime deposits, determining the integral parameters of glaze and rime deposits (density, sediment type), ice load control, data communication system. With the technical implementation of these systems, two approaches are possible to control of the wire parameters: the direct and indirect ones [3].

A direct approach involves placing the measuring sensors directly on the wire of an overhead power transmission line and transmitting the information that received by a high-frequency radio channel. In the case of an indirect approach, the sensors are placed on a wire analog unit, which is created on the basis of the wire section of the monitored line and has a zero potential in relation to the ground [4]. Despite its significant advantage—its accuracy, the local systems built using the direct method have significant disadvantages: high cost and complexity of maintenance. The system is built by an indirect approach with low cost and easy maintenance, but their accuracy is depends on the current load of the line. At the same time, the economic crisis and the reform of the agrarian sector were led to a decrease in the output of agricultural products, and as a result, the overhead power lines of the distribution networks of 6–10 kV were under loaded to their designed values. Therefore, in order to choose a rational approach for the construction of local control systems for overhead lines in the icing conditions, it is necessary to estimate the level of the effect of the electric load of the overhead power line on the temperature of its wire.

Thus, the study of thermal modes of overhead electrical distribution networks with glaze and rime deposits before the process is urgent.

3. Research goal and results

Power distribution network of 10 kV in Ukraine is mostly created by the principle of building backbone networks. In this case, the intersection guidance routes chosen taking into account the requirements of mechanical strength, providing normalized voltage drops, the possibility of reserving of nearby highways and also taken into account the prospects of 5 % annual growth of electrical loads. As a result, the network provided the necessary reliability of power supply, but the intersection of highways wire was detected 1.5–3 times higher than branching to transformer substations 10/0.4 kV.

Figure 1 represents the sample of a typical distribution network scheme section 10 kV, which consists of 6 backbone networks L121–L126 and is located in 4-th territorial region by icing characteristic parameters [5]. Overhead power lines are designed with using the wires of AC and A types [6], which are positioned on ferroconcrete supports. For realization of backbone networks, the linear disconnectors of DS-185, DS-63 and DS-202 types were installed. Customers is powered by substations consisting of power transformers with power capacity ranging from 40 to 400 kVA.

In the shown scheme, the branching load does not exceed 10 % from permitted current, and backbone networks is loaded to its 15 % nominal in the scheduled conditions, and to 25 % in accidental conditions.

The loads of agricultural electric power customers, as for industrial, is determined by production and the number of working shifts. The daily schedules of its power consuming for working winter day for typical agricultural customers: repair mechanical workshop, etc. are characterized by two strictly expressed daily maximums and single working shift (see Fig. 2).

In Ukraine rime often forms at night, and glaze in the morning, but the same number of cases recorded glaze and rime accretion in daytime, between 12 and 15 hours of day.

Thus, during the days of the formation of glaze and rime deposits the overhead power lines of distributive networks 6–10 kV are loaded within 11 to 35 % compared to daytime maximums. Also it should be noted that the years of economic crisis led to a significant reduction in the livestock number, resulting that cattle farm work in partially loaded conditions.

Thus, it is advisable to research the influence current load on wires temperature in distribution networks when they are loaded to 30 % from their scheduled current.

To determine the temperature of wire t_{wr}, we used the temperature change law founded in the work [7] for wire section in time flow

$$t_{\mathrm{wr}} = t_{\mathrm{a}} + t_{\mathrm{w}} = t_{\mathrm{a}} + \frac{P_{\mathrm{j}} - P_{\mathrm{fr}} + m_{\mathrm{w}} c_{\mathrm{w}} S_{\mathrm{p.a}} \left(t_{\mathrm{a}} + t_{\mathrm{dr}}\right)}{h_{\mathrm{c}} S + m_{\mathrm{w}} c_{\mathrm{w}} S_{\mathrm{p.a}}} \left(1 - \mathrm{e}^{-\frac{\tau}{T_0}}\right) , \tag{1}$$

where P_{j} is the power, P_{fr} denotes the internal sources of heating and cooling, $+m_{\mathrm{w}}$ denotes the mass of water falling per unit of area of the wire per unit time, c_{w} stands for the specific heat of water, S represents the surface area of the wire section, $S_{\mathrm{p.a}}$ is the projection area of the wire section, t_{w} denotes the temperature

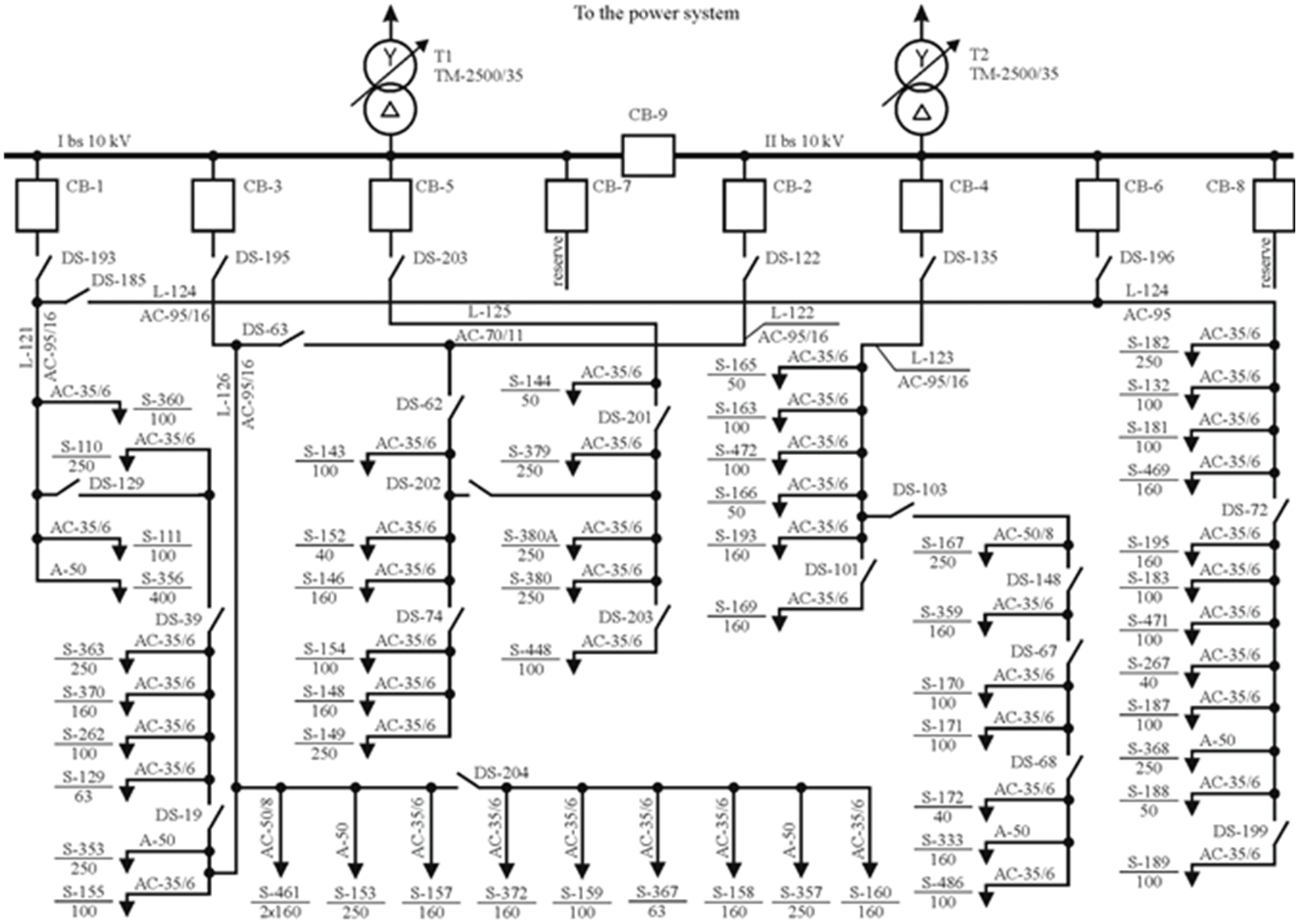

Fig. 1. Example of distribution system 10 kV (number of substation is in numerator, rated power of transformer in kVA is in denominator)

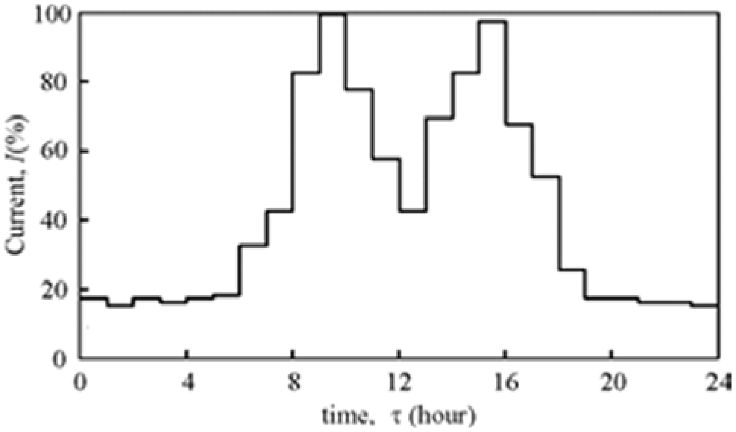

Fig. 2. Daily schedule of power consumption on winter weekdays of the common agricultural consumers

of the wire section, t_{a} stands for the temperature of ambient air, t_{dr} represents the temperatures of rain drops, τ is the current time, h_{c} is the heat transfer coefficient [8] and T_0 stands for the wire heating time constant that is given by the expression

$$T_0 = \frac{mc}{h_{\mathrm{c}}S + m_{\mathrm{w}}c_{\mathrm{w}}S_{\mathrm{p.a}}} ,$$

where m is the wire section weight and c denotes the the heat capacity of the wire.

For normal exploitation conditions (dry wire, $m_{\mathrm{w}} = 0$, there is no internal source of cold—$P_{\mathrm{fr}} = 0$), eq. (1) takes the form

$$t_{\mathrm{wr}} = t_{\mathrm{a}} + \frac{P_{\mathrm{j}}}{h_{\mathrm{c}}S}\left(1 - \mathrm{e}^{\frac{-\tau}{T_0}}\right) , \tag{2}$$

where P_j is the power losses transferred heat that can be expressed as

$$P_{\mathrm{j}} = r_{20}\left(1 + \alpha\left(t_{\mathrm{wr}} - 20\right)\right) I_{\mathrm{l}}^2 l_{\mathrm{wr}} ,$$

r_{20} denotes electrical resistivity of the wire for direct current at 20 °C, I_{l} is the load current of the line, l_{wr} denotes the length of wire section and α stands for the temperature coefficient for material of wire.

After substituting for P_j into (2) we have

$$t_{\mathrm{wr}} = t_{\mathrm{a}} + \frac{r_{20}\left(1 + \alpha\left(t_{\mathrm{wr}} - 20\right)\right) I_{\mathrm{l}}^2 l_{\mathrm{wr}}}{h_{\mathrm{c}}S}\left(1 - \mathrm{e}^{\frac{-\tau}{T_0}}\right) . \tag{3}$$

From equation (3), it follows that the temperature of the wire is determined by the current load of line I_{l}, weather conditions h_{c}, t_{a}, and the resistivity value r_{20} which depends on the temperature of the wire. A preliminary investigation showed that the temperature of wires changes in boundaries $t_0 \pm 5\,^{\circ}\mathrm{C}$, while their resistivity varies within 2.5 %.

Therefore, in case of a small wire overheating, the replacement of t_{wr} by t_{a} does not introduce a significant error in calculations. Then the expression (3) may be

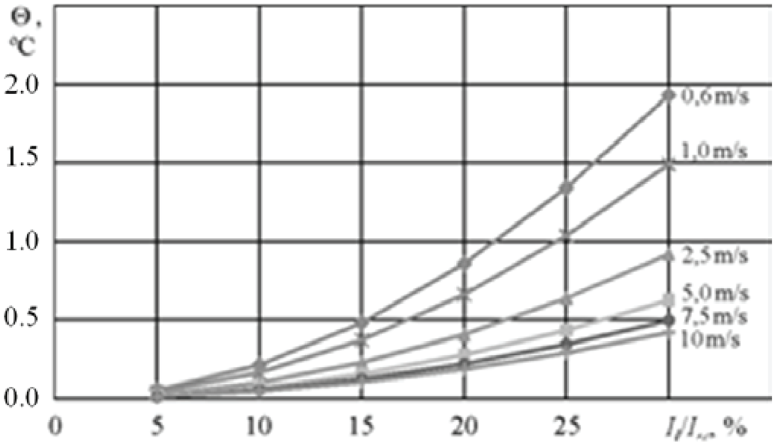

Fig. 3. Calculated curves of temperature change default values overheating wire AC-35/6

simplified to the form

$$t_{\mathrm{wr}} = t_{\mathrm{a}} + \frac{r_{20}\left(1+\alpha\left(t_{\mathrm{a}}-20\right)\right) I_{\mathrm{l}}^{2} l_{\mathrm{wr}}}{h_{\mathrm{c}} S}\left(1-\mathrm{e}^{\frac{-\tau}{T_0}}\right). \tag{4}$$

If $\tau \to \infty$ then $T_0 \to 0$, so that (4) takes the form

$$t_{\mathrm{wr}} = t_{\mathrm{a}} + \frac{r_{20}\left(1+\alpha\left(t_{\mathrm{a}}-20\right)\right) I_{\mathrm{l}}^{2} l_{\mathrm{wr}}}{h_{\mathrm{c}} S}. \tag{5}$$

Consequently, the overheating temperature of overhead power lines wire against ambient air will be

$$\Theta = t_{\mathrm{wr}} - t_{\mathrm{a}} = \frac{r_{20}\left(1+\alpha\left(t_{\mathrm{a}}-20\right)\right) I_{\mathrm{l}}^{2} l_{\mathrm{wr}}}{h_{\mathrm{c}} S}. \tag{6}$$

According to equation (6) we calculated the temperature of overheating of the most common wires type A (AC) [6] which are used in electrical distribution networks. The calculations are produced for the most typical environmental conditions preceding process of icing: $v_0 = 0.6\mathrm{div}\ 10\,\mathrm{m/s}$, $t_0 = 1.0\,^{\circ}\mathrm{C}$.

The results showed that the load currents of up to $0.25 I_{\mathrm{r.c}}$ ($I_{\mathrm{r.c}}$ being the operating current) do not affect the temperature of the wire, even with natural convection. A similar results were obtained in [9] for calculating the active resistance of overhead wires.

The calculated curves change default values of wires overheating level depending on its load factor $k_l = I_{\mathrm{l}}/I_{\mathrm{r.c}}$ taken for environmental conditions shown in Figs. 3–6.

4. Conclusion

Given the research results, it is possible to draw the following conclusions. In modern climatic and economic conditions, to develop measures to increase the effi-

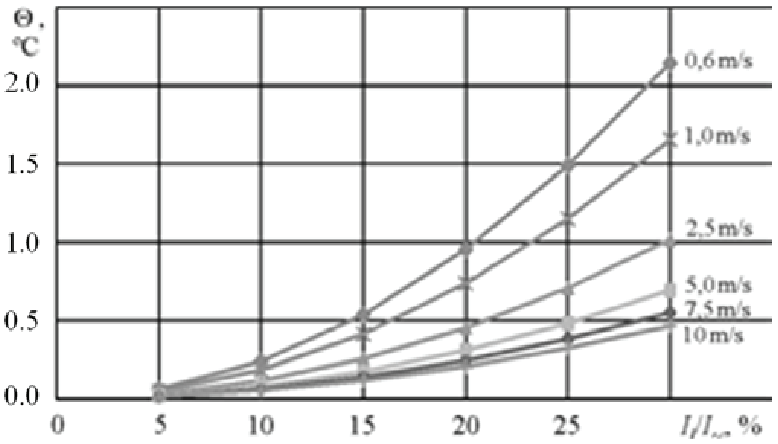

Fig. 4. Calculated curves of temperature change default values overheating wire AC-50

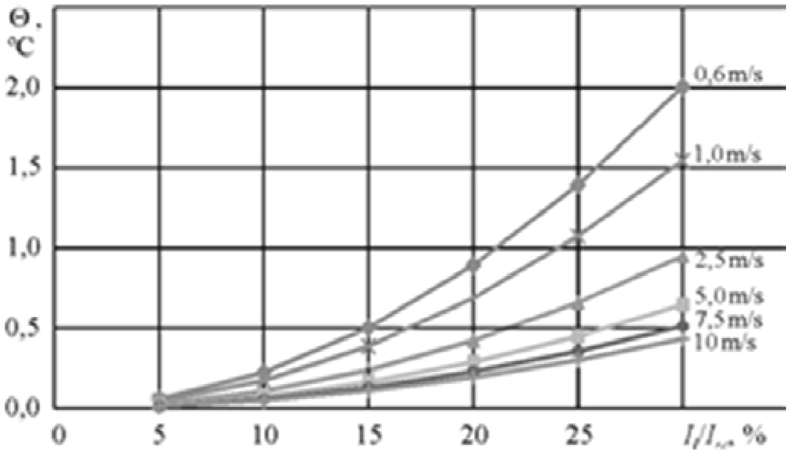

Fig. 5. Calculated curves of temperature change default values overheating wire AC-50/8

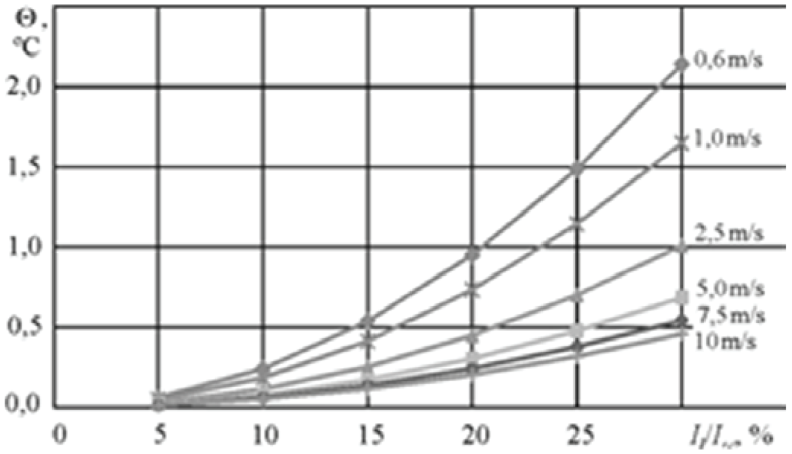

Fig. 6. Calculated curves of temperature change default values overheating wires AC-70/11 and 95/16

ciency of exploitation of 6–10 kV overhead power lines in icing formation conditions, there is a need to assess the effect of load currents on the temperature of the wire lines.

As a result of analysis of the schedules of daily electric loads for typical agricultural consumers, it was established that during the period of the most probable formation of glaze and rime deposits their load is in the range from 11 % to 35 % relative to the daily maximum.

As a result of a theoretical study of the temperature variation law of the wire in time flow for the most characteristic meteorological conditions, it is established that the load currents of lines up to $0.3\,I_{\mathrm{r.c}}$ increase the wire temperature from 0.3 °C to 2.2 °C, depending on the wind speed.

When creating technical devices for the implementation of information systems for monitoring overhead power lines in the conditions of icing, it is advisable to use an indirect approach to control. Since the actual temperatures of the branching wires to 10/0.4 kV transformer substations and the backbone networks at their loading $0.2\,I_{\mathrm{r.c}}$ that practically do not differ from the temperature of ambient air.

References

[1] *Climate change in CIS countries in the 21st century.* Byulleten' federal'noy sluzhby po gidrometeorologii i monitoringu okruzhayushchey sredy *35* (2012), 13–15 (in Russian).

[2] O. Kozlovskyi, A. Orlovich, S. Serebrennikov: *Automated system for forecasting of destructive atmospheric loads on elements of overhead power lines structures.* Technical Diagnostics and Non-Destructive Testing (2002), No. 2, 46–48 (in Russian).

[3] O. Kozlovskyi, D. Trushakov, S. Rendzinyak: *A measuring transducer in the system of technical diagnosis of overhead lines icing in electrical distribution networks.* Computational Problems of Electrical Engineering *5* (2015), No. 1, 17–22.

[4] M. Ts. Tsybikdorzhiev, A. I. Selivakhin, A. E. Orlovich, A. Z. Vinarov, R. Sh. Sagutdinov: *A section of the power transmission line with a device for determining the surface temperature of its wires.* USSR Certification of authorship 1591118, September 07, 1990 (in Russian).

[5] *Electrical installation regulations.* Kharkiv, Ukraine: Fort, 2014 (in Ukrainian).

[6] *Uninsulated wires for aerial power lines. Specification.* GOST 839, 1980 (in Russian)

[7] O. Kozlovskyi, A. Orlovich, A. Nekrasov: *Rationale selection reasoning of icing test parameter on overhead lines of electric distribution network.* Electromechanical and Energy Saving Systems (2015), No. 3, 149–157 (in Ukrainian).

[8] W. Z. Black, R. L. Rehbery: *Simplified model for steady state and real-time ampacity of overhead conductors.* IEEE Transactions on Power Application Systems *104* (1985), No. 10, 2942–2953.

[9] V. Vorotnickiy, O. Turkina: *Estimation of variable losses calculation errors of electrical power HV line caused by unaccounted meteoconditions.* Elektricheskiye stantsii (2008), No. 10, 42–49 (in Russian).

Received 26. 10, 2017