METHOD OF DETERMINING THE OVERLOAD CAPACITY OF MEDIUM VOLTAGE POWER CABLES WITH CROSS-LINKED POLYETHYLENE INSULATION

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At present, in the world practice, when modernizing old and building new medium voltage power transmission lines, they turn to modern technical solutions. So for cable lines, the main innovation is the transition from cables with impregnated paper insulation to cables with XLPE insulation. This is due to their technical advantages, such as high dielectric strength, low dielectric loss tangent, low dielectric constant, high operating temperature, which allows increasing current loads in stationary and emergency operation [1].

The use of more heat-resistant solid polymer insulation in cables has changed not only the heat dissipation in the core and the insulation temperature, but also the electrophysical and thermophysical processes in the insulation. In particular, in a macroscopically homogeneous solid polymer under the action of a strong constant electric field, bulk electric charges are formed, which in turn completely changed the methods of voltage testing of XLPE cables around the world [2, 3].

It is the peculiarities of electrophysical and thermal processes in the macroscopically homogeneous solid polymer together with a significant increase in the allowable insulation temperature that led to the fact that the XLPE-cable insulation concentrates the action of maximum energy effects, thermal, electrical and mechanical, with internal mechanical stresses in turn it is the temperature difference in the volume of the polymer.

For modern XLPE-cables the main scientific problem is the study of the processes of simultaneous influence of thermal, electrical and mechanical load on the polymer in operating conditions. Inseparable from it is the problem of determining the maximum current loads on the cable with cross-linked polyethylene insulation in the conditions of production and operation [4]. Therefore, to solve the scientific and technical problems of the introduction of cables with cross-linked polyethylene insulation, there is a study of overload capacity.

In real operating conditions, the cable almost never works in a stationary maximum allowable mode, so to check the performance of specific cables use either special laboratories [1], or the cable is accepted under the manufacturer's warranty. And this in turn means the need for appropriate research from the manufacturer. For innovative products, which differ significantly from traditional ones, it is not enough to use only standardized methods.

Therefore, a model for determining the allowable current overloads of medium voltage cable with cross-linked polyethylene insulation was developed and tested in the conditions of real cable production. The developed model was based on the analogy of heat and mass transfer processes, in particular, the processes of charge transfer and the process of heat transfer. Methods for calculating electrical circuits were used to calculate the power of the heat flux that can be transferred from the cable to the environment. Determination of thermal resistances of cable construction elements is based on the model of radial heat flux and includes heat transfer processes through thermal conductivity, convective heat transfer and radiation. To determine the heat transfer coefficient from the surface of power cables in the air, the recommendations of the relevant international standards were used in the form of empirical graphical dependences of thermophysical parameters on specific conditions of cable laying [5].

In the conditions of real cable production for a specific cable APvEgaPu 1×70 at a voltage of 35 kV, a series of experimental studies were conducted and the necessary calculations were performed. The heat transfer coefficient from the surface α was determined by the contribution of radiation and convection. The value of α nonlinearly depends on the difference between the surface temperatures of the cable and the environment $\Delta\Theta_s$, so in the thermal calculations of the cable is used as a variable.

Given the two main processes of cable cooling in air (convective heat transfer and radiation) α according to the regulations is presented as the sum [6]:

$$\alpha = \alpha_k + \alpha_r = (h_k + h_r) \cdot \Delta\Theta s^m, \tag{1}$$

where α_r – coefficient of heat transfer by radiation;
α_k – heat transfer coefficient by convection;
$\Delta\Theta_s$ – the difference between the surface temperatures of the cable Θ_s and the environment Θ_o: $\Delta\Theta_s = \Theta_s - \Theta_o$.

Since α_k and α_r are functions of the temperature difference between the surface of the heated body and the environment, denoted by $\Delta\Theta_s$ for further calculations, it is convenient to write α_r as a function $\Delta\Theta_s$:

$$\alpha_r = \varepsilon_1 \cdot C_0\, \Delta\Theta_s^{-1} \cdot [(\Theta_o + \Delta\Theta_s + 273)^4 - (\Theta_o + 273)^4], \tag{2}$$

where Θ_o – is the ambient temperature in °C.

Accordingly, the coefficient of thermal dissipation during radiation h_r will be written as a function $\Delta\Theta_s$ [6]:

$$h_r = \varepsilon_1 C_0 \Delta\Theta_s^{-1}[(\Theta_o + \Delta\Theta_s + 273)^4 - (\Theta_o + 273)^4]\Delta\Theta_s^{-m}. \tag{3}$$

As a result, the coefficient of thermal dissipation during convection and radiation for a horizontally located separately laid in the air cable in a polymeric outer sheath with a diameter d:

$$h = h_r + h_k = \varepsilon_1 C_0\, \Delta\Theta_s^{-1}\, [(\Theta_o + \Delta\Theta_s + 273)^4 - (\Theta_o + 273)^4]\Delta\Theta_s^{-m} +$$

$$+ C_1 (\beta\cdot d^3 g\, \nu^{-1}\cdot c\cdot\lambda^{-1})^m \cdot \lambda/d, \qquad (4)$$

where the variable $\Delta\Theta_s$ together with the outer diameter of the cable d determines the thermal resistance of the environment and can be tentatively estimated experimentally $\Delta\Theta_s^*$ for a particular XLPE-cable in specific conditions by determining the surface temperature of the cable in each mode of current load I:

$$\Delta\Theta_s = \Theta_g - \Theta_o - I^{2\cdot} R_g{\cdot}[S_1 + (1+ k_e)S_2], \qquad (5)$$

where Θ_g – set variable, limit core temperature, set under operating conditions; k_e – loss factor in the metal sheath of the cable; S_1, S_2 – accordingly, the thermal resistance of the insulation system and protective coatings [7-9].

Figure 1 compares the results of the calculation of the thermal dissipation coefficient h for (14) together with the normative equation for the stationary thermal regime for XLPE-cable with a diameter of 37 mm with a range of possible values of h according to the IEC recommendations [1,2,8].

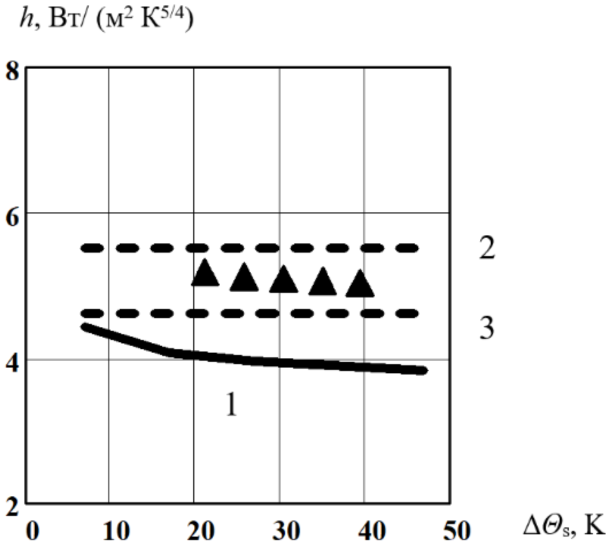

Figure 1. Dependence of thermal dissipation coefficient h on the temperature difference of XLPE-cable with a diameter of 37 mm and ambient air $\Delta\Theta_s$ by formula (4) - triangles together with the normative equation for stationary thermal regime in comparison with the range of possible values according to standard [1] (horizontal dashed) lines 2 and 3).

Curve 1 according to [9] for a cable with a diameter of 37 mm, the temperature difference between the surface of the cable with a diameter of 37 mm and the surrounding air, calculated by formula (4) in comparison with the range of possible values according to the standard [1,9].

The introduction of an analytical expression for the heat dissipation coefficient from the surface of the cable in the air in a system of proven normative equations to determine the long-term current load of the cable at a given insulation limit temperature, allows to determine the parameters of any required operating range of long-term current loads less than [7].

The use in the heat balance model of formula (4) for the heat dissipation coefficient as a function of the spectrum of thermophysical parameters of convective cooling and radiation of a heated cable, on the one hand, and the function of cable current load parameters, on the other, is a necessary component of the model. stationary modes of operation at a given limit insulation temperature under operating conditions Θ_g [2,9].

To calculate the heating curves in Fig.2 used an exponential two-parameter model [9] with initial conditions $t = 0$; $\Theta = 0$:

$$\Theta - \Theta_o = (\Theta_g - \Theta_o)\,(1 - \exp(-\beta/t)), \qquad (6)$$

where β – is the constant heating [3, 9].

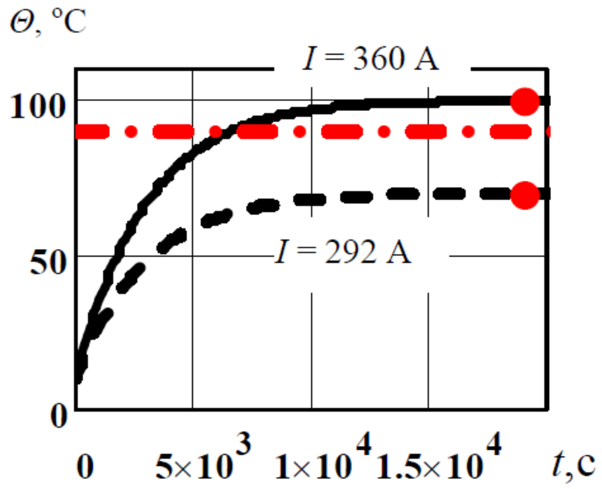

Figure 2. Curves of heating of the cable APvEgaPu 1×70-35 in the open air at different values of load current: the values of the maximum temperature are plotted as points as a solution of the proposed model of heat balance; the dashed line indicates the maximum allowable insulation temperature

The joint use of the proposed model of heat balance and calculation of heating curves according to the exponential model (6) [6] makes it possible to determine the allowable time of a given overload for real modes of long-term current load.

An example of the use of the proposed model of heat balance together with the heating curves for (6) for a particular mode of overload of a particular cable in specific operating conditions is shown in Fig.3.

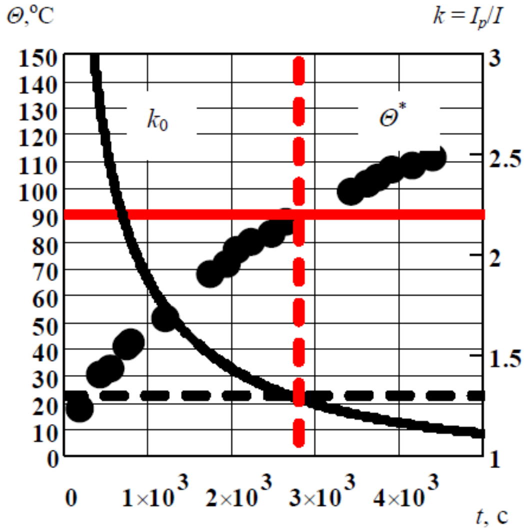

Figure 3. Nomogram for determining the parameters of the allowable overload, developed on the basis of the proposed model of heat balance together with the heating curves of the exponential model for the cable APvEVng 1×70–35 in the plant shop at $\Theta_o = 10$ °C.

Such nomograms can be constructed for a given range of possible current loads, specific designs of medium-voltage XLPE-cables based on accelerated non-destructive tests for heating in production conditions [1,3,5-9]. The initial data for such construction are:

- design and technical parameters of the medium voltage cable;
- experimentally determined heating curve of a specific cable in overload mode, which is an accelerated test to verify the calculated constant heating of the cable and at the same time an alternative to the traditional test of high DC voltage, which is not recommended for XLPE-cables [8,10].

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