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Investigation of heating of 150 kV underground cable line for various conditions of laying

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Abstract. The work is devoted to study of temperature operation of a 150 kV underground cable line with XLPE insulation. The stationary thermal conditions were calculated. The influence of outer boundary radius selection on the temperature distribution was analyzed.
The limiting value of the filling mixture thermal conductivity was found, which provides an acceptable temperature of the cable.

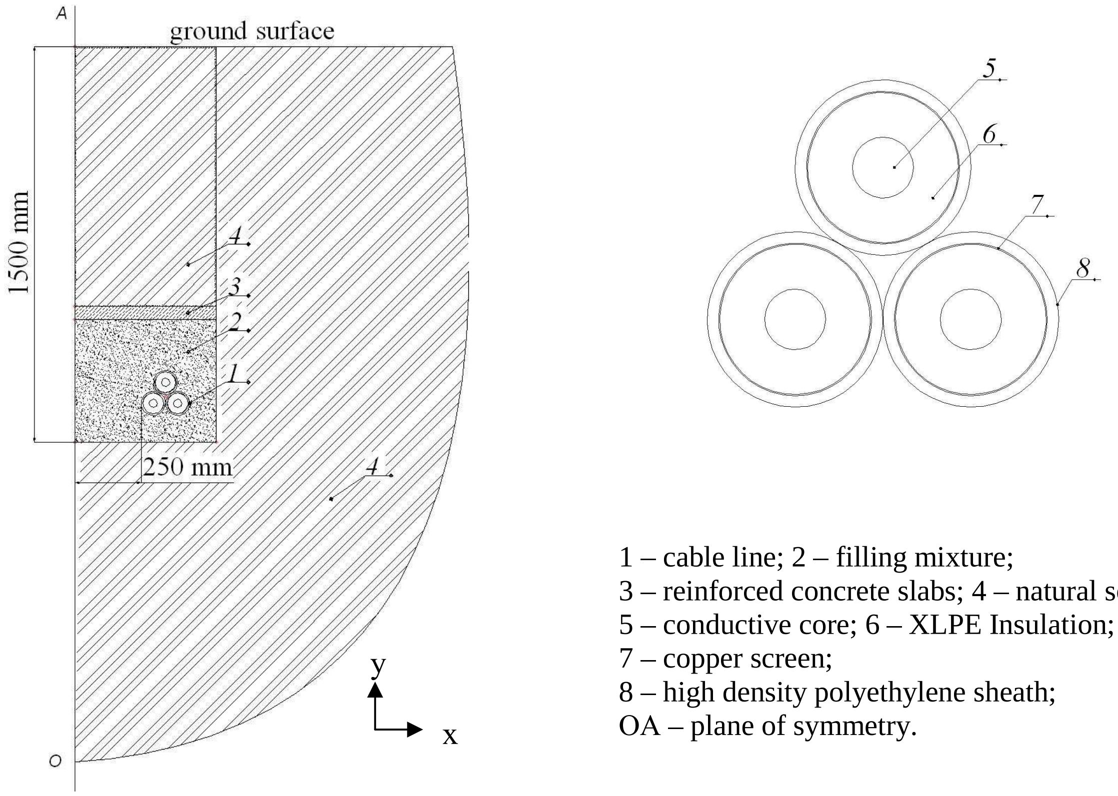
1. Introduction
At the present time, in power supply systems, cable lines paved underground are preferred. The use of cables with XLPE insulation is topical because this material has good electrophysical characteristics.

The reliability of the cable line depends on the conditions of its operation. The important parameter for monitoring is the cable core temperature limit. The maximum permissible temperature for a core of cable with XLPE insulation is 90 ° C [1]. Exceeding this value leads to an accelerated aging of the insulation, and, as a result, to a deterioration of cable characteristics.

It is convenient to use methods of mathematical modeling to determine the temperature of the cable core, which allows one to reproduce dangerous conditions of operation of a cable line without harm for real objects [2, 3].

2. Mathematical model
In this paper, a double-circuit cable line with aluminum core of 800 mm^2 is considered. The cables of each circuit are arranged in a triangle in a trench of 1.5 m deep. For the backfill, sand-cement mixture is used. Reinforced concrete slabs are stacked over as a protection against mechanical damage.

The scheme of the trench with the cable line is shown in Figure1.



1 – cable line; 2 – filling mixture;
3 – reinforced concrete slabs; 4 – natural soil;
5 – conductive core; 6 – XLPE Insulation;
7 – copper screen;
8 – high density polyethylene sheath;
OA – plane of symmetry.

Figure 1. The scheme of the trench with the cable line.

The mathematical model of the heat transfer process in the computational domain is based on the law of energy conservation. The following assumptions were made in the calculation: stationary conditions, thermophysical properties of materials are constant, temperature conditions along the cable line are unchanged. The temperature distribution in the computational domain is described by the differential equation of thermal conductivity:

- for the cable line:

$$\frac{\partial}{\partial x}\left(\lambda_k \frac{\partial t}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_k \frac{\partial t}{\partial y}\right)+q_v=0\,; \qquad (1)$$

- for the environment:

$$\frac{\partial}{\partial x}\left(\lambda_i \frac{\partial t}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_i \frac{\partial t}{\partial y}\right)=0\,, \qquad (2)$$

where x, y – cartesian coordinates; t – temperature; $\lambda_к$ – thermal conductivity of cable; λ_i – thermal conductivity of environmental materials (i – material index); q_v – power of heat loss in the core of the cable line.

The heat loss power is determined according to the Joule-Lenz law by the formula:

$$q_v=\iint\limits_S \frac{I^2}{\sigma}\,dS\,, \qquad (3)$$

where I – rated current of the cable core; σ – conductivity coefficient of core; S – core sectional area.

The following boundary conditions are supplemented to differential equations (1, 2, 3):

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1. A third-kind boundary condition with respect to temperature is given on the surface of the earth, coefficient of heat transfer α from the surface of the earth is 10 W/(м^{2}ºC), ambient temperature T_0= 20ºC;
2. Two variations of the condition are set on the outer boundary of the earth array:
   a) adiabatic heat exchange conditions;
   b) constant temperature;
3. Adiabatic heat exchange conditions are given on the plane of symmetry.

Two series of calculations are proposed to be carried out to verify the adequacy of the boundary conditions 2.

The problem is solved numerically by the finite volume method in the engineering calculations environment Fluent.

The initial data for the calculations are given in the table 1.

Table 1. Data for calculation

Geometric dimensions	
Core sectional area , mm^2	800
core sectional screen , mm^2	150
Distance between cable lines , m	0.5
Thickness of reinforced concrete slabs , mm	50
Electrical parameters	
Rated mains voltage , kV	150
Rated current under given laying conditions , A	773
Thermal parameters	
Allowable insulation temperature , ºC	90
Thermal conductivity of the core , W/(K·m)	401
Thermal conductivity of the screen , W /(K·m)	237
Thermal conductivity of the insulation , W /(K·m)	0.29
Thermal conductivity of the shell , W /(K·m)	0.29
Thermal conductivity of the filling mixture , W /(K·m)	0.5–1.5
Thermal conductivity of the soil around the trench , W/(K·m)	1
Temperature of the soil around the trench, ºC	15

3. Results and Discussion

A sufficient radius of the outer boundary for the two variants of the boundary conditions is determined at the first stage of the calculations. The number of mesh elements increases with the increase in the volume of the earth; this leads to additional costs of computing resources. At the same time, too small volume of ground leads to a distortion of the thermal field near the cable line.

In Figure 2, the thermal field directly near the cable line is represented. As seen in the figure, the inner lower core in the cable line is the most heated; therefore it is advisable to estimate the line overheating precisely on it.

The dependence of the temperature of the most heated cable core on the radius of the earth outer boundary for two variants of the boundary conditions was constructed in the course of solving the posed problem. The results are shown in Figure 3.

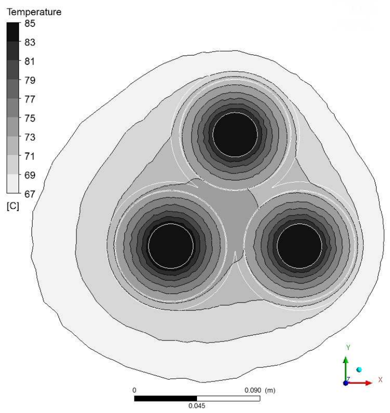

Figure 2. The thermal field of the cable.

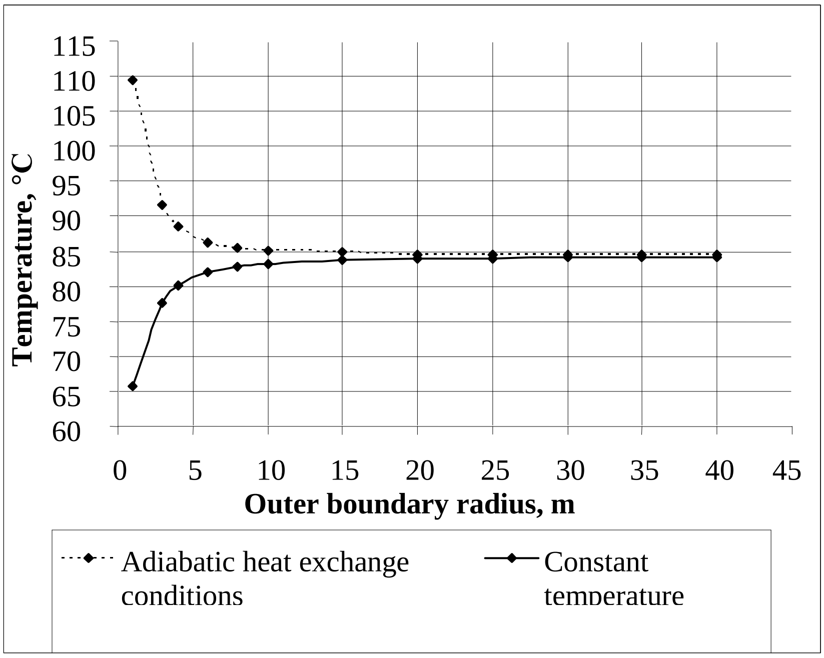

Figure 3. The dependence of the cable core temperature on the radius of the earth outer boundary for two variants of the boundary conditions.

As can be seen from the graphs, in both cases the core temperature tends to the same value of T=84º C. However, when the constant temperature at the outer boundary of the earth is given, the value was established at a radius equal to 15m. In the case of adiabatic heat exchange conditions, the value was established at a radius of 20m.

When a large enough earth array is selected (25 м and more) the influence of the type of the boundary condition on the temperature distribution near the cable line is eliminated. Thus, to reduce the error of the model in further calculations, the array of land of this radius will be taken into account.

In Figure 4, the temperature distribution near the cable line for two variants of the boundary conditions on the outer boundary of the earth array is presented for a small radius (Figure 4 a, b) and for the radius of 25m (Figure 4 c, d). As seen in the figure, with an insufficient size of earth array different boundary conditions give substantially different pictures of the thermal field. When the surface with the boundary condition moves away, the pictures become the same. In this case, the difference in temperature at the boundary of the trench does not exceed 1 %.

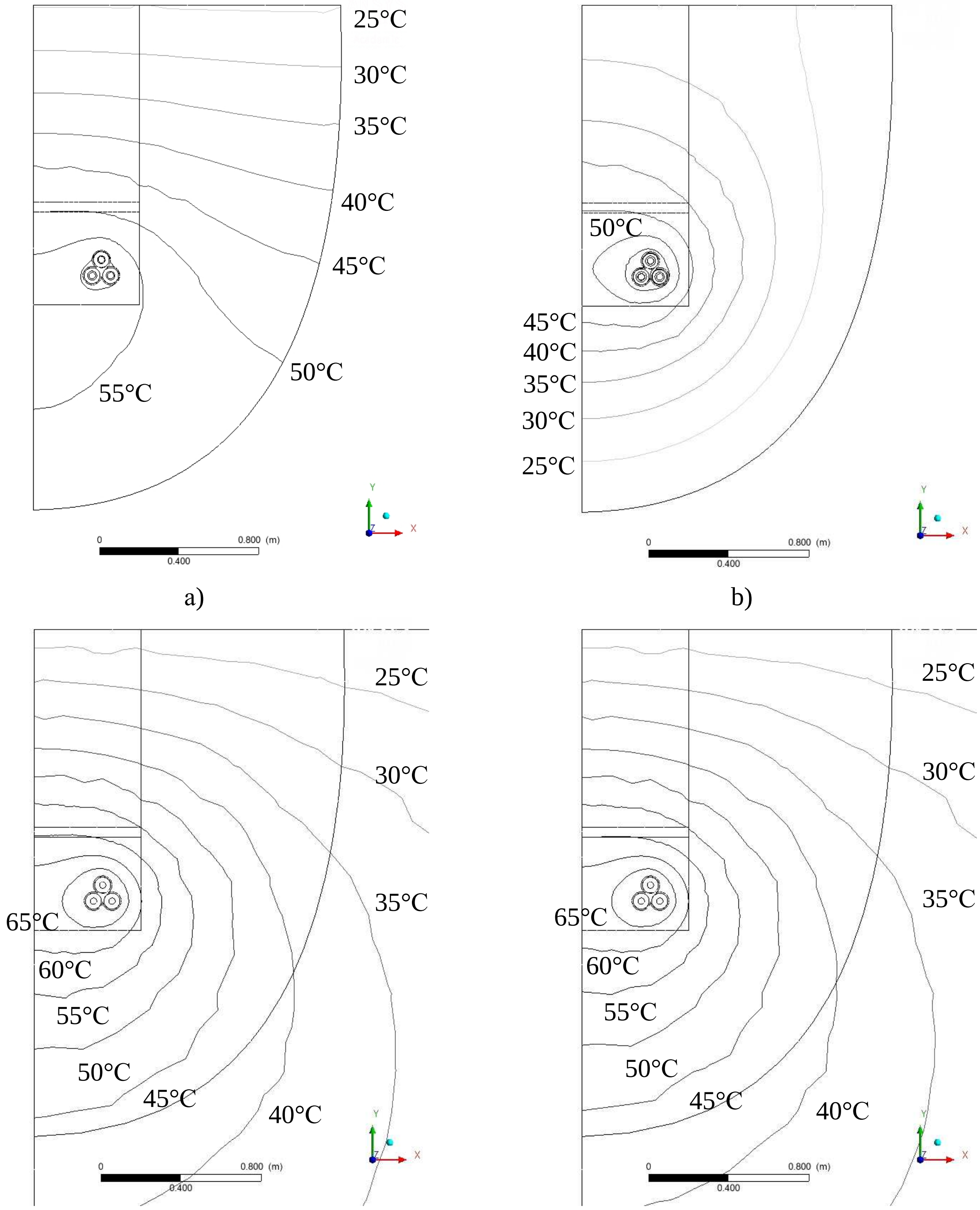

Figure 4. Isotherms: a) adiabatic boundary condition, small array of earth; b) isothermal boundary condition, small array of earth; c) adiabatic boundary condition, large array of earth; d) isothermal boundary condition, large array of earth.

In the second part of the work, the influence of the properties of the backfill mixture on the temperature distribution in the elements of the cable line construction is considered. The sand-cement mixture is used as a backfill, which may have different properties [4, 5]. The value of the thermal conductivity of the mixture will have a major effect on the temperature field. The dependence of the cable core temperature on the thermal conductivity of the backfill mixture was the result of calculation

(Figure 5). The minimum value of thermal conductivity was determined, when the core temperature does not exceed the permissible.

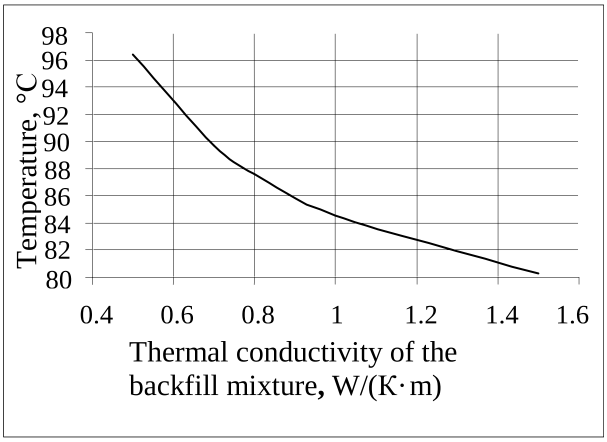

Figure 5. The dependence of the cable core temperature on the thermal conductivity of the backfill mixture.

As can be seen from the graphs, the limiting value of the thermal conductivity of the backfill mixture is 0.7 W/(K·m). The dependence is nonlinear. When the thermal conductivity of the backfill mixture is less than the limiting value, overheating of the cable structure elements is observed, which can significantly affect its resource or lead to damage to the line.

4. Conclusion

In this paper, the calculations of the temperature field of the cable line for a voltage of 150 kV located in the trench are performed. The dependence of the picture of the thermal field on the choice of the boundary condition is shown. The estimation of the specification correctness of the investigated region external boundary conditions was carried out; the conclusion about the sufficient volume of the array of earth to exclude the impact on the result of the type of boundary condition is made. The heating pattern of the cable line for a given load is obtained, which allows one to assess the possible overheating.

Also, the dependence of the cable line temperature on the conditions of its laying was obtained (thermophysical properties of the backfill mixture). The minimum value of thermal conductivity was determined, when it is smaller in the line there will be overheating at a given current. Thus, in the article, the need to take into account the thermophysical properties of structural materials when installing underground power cable lines is shown.

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