Load capacity of cables insulated materials of high thermal conductivity

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Abstract – **The influence of thermal conductivity of electrical insulation materials on the load capacity of power and installation cables is investigated.**

Keywords: cables, thermal conductivity, load capacity

I. INTRODUCTION

Polyvinyl chloride compound (PVC) is widely used in power and installation cables for insulation and sheaths. The load capacity of PVC insulated cables is determined by the heat resistance and thermal conductivity of the material. In regulatory documents for cables of this type, the load capacity is determined for the following conditions: the temperature of the conductive cores should not exceed + 65°C and the ambient temperature is +25°C. One of the main drawbacks of the PVC plastic compound is that material contains chlorine; in addition, it has a fairly low coefficient of thermal conductivity.

Halogen-free compounds are developed and used to replace PVC. One of these compounds – BIC 15, which has good electrical properties and high thermal conductivity, was developed in the SST group of companies and is used in the manufacture of installation cables.

The results of studies of insulation resistance (R ins) and thermal conductivity (λ) of two types of halogen-free compounds in comparison with similar properties of PVC are given below (table 1).

TABLE 1 PROPERTIES OF THE MATERIALS

Material	Manufacturer	R ins	λ
		Ohm·m	***W/m·K***
PVC compound IT 105 P-A-16c	Prominvest, Ukraine	$1.2{\cdot}10^{14}$	0.19
Compound BIC 15	OKB «Gamma», Russia	$2.8{\cdot}10^{15}$	0.90
Compound Fragom PR/555K1	Crosspolimeri spa, Italy	$2.5{\cdot}10^{14}$	0.72

The appearance of a three-core cable of the One Key Electro brand, manufactured by the OKB «Gamma» - the part of the SST group, for which the calculations presented below were made is shown in Fig. 1.

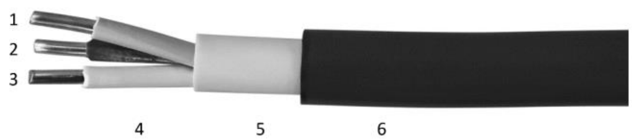

Fig. 1. Three-core One Key Electro power cable, 3 x 6 mm^2
1, 2, 3-conductive cores; 4-insulation; 5-filling; 6-sheath.

Calculation of heat flows and temperatures in cables, when current is flowing through them, for various environmental conditions, is performed using a set of programs for modeling physical fields using the finite element method ELCUT v. 6.3 [1].

II. HEAT TRANSFER FROM CABLES TO THE AIR

The results of modeling thermal fields in cables of the same design, with cores of 3 x 6 mm^2, but with different insulation materials are shown below. The current flows in two cores (the first and third), and the second core is used for grounding. The outdoor temperature in all cases is the same +25°C. The coefficients of heat transfer to still air were calculated as the sum of the convective and radiation components, based on the temperature difference between the cable surface and the surrounding air.

Table 2 shows the results of calculations for the case of the same heat release in the cores at a current of 50 A, normalized in the Rules on design of power electric installations - PUE (table 1.3.6). This calculation confirmed that at the current set in the PUE for PVC insulation, the cores do not heat above 65°C. When the insulation and cable sheaths are made of materials with high thermal conductivity, the thermal resistance of the polymer layers is significantly less. As a result, at approximately the same surface temperature, the cores are heated significantly less, not least because of the fact, that the resistance of copper increases to a lesser extent.

Less heating of cables with insulation and sheath made of halogen-free compounds, at the same currents as in PVC cables, indicates their greater thermal safety.

TABLE 2 HEAT TRANSFER TO THE AIR AT A CURRENT OF 50 AMPERES

Material	P	T cor	T she	α sum	Δ T	R sum
	W/m	***° C***	***° C***	***W/m²·K***	***° C***	***m·K/W***
PVC	8.5x2	64.7	52.1	15.4	12.6	0.741
BIC 15	8.0x2	52.5	50.1	15.2	2.35	0.147
Fragom	8.05x2	54.7	51.5	15.3	3.20	0.199

The symbols in table 2: P - the flow of heat released in the cable cores at the current of 50 A; Tcor - the heating temperature of the conductive cores; Tshe - the surface temperature of the cable sheath; α sum - the total coefficient of heat transfer from the cable surface; ΔT - the temperature difference in the cable insulation layers; R sum - the thermal resistance of the cable insulation layers.

Low thermal resistance of insulation layers made of polymers with high thermal conductivity allows increasing the current load on the cables. Also, taking into account the condition that the cores should not be heated above 65°C, we calculated the level of permissible current loads and thermal characteristics, which are presented in the table 3.

The permissible current load in cables insulated with halogen-free compounds increased by 22-24% in relation to cables with PVC insulation and sheaths, but at the same time, due to increased heat generation in the cores and lower thermal resistance of the insulation layers, the surface temperature of these cables increased by 17%. Symbols in the table 3 the same as in table 2.

TABLE 3 HEAT TRANSFER TO THE AIR AT MAXIMUM CURRENT

Material	I	P	T cor	T she	α sum	Δ T
	A	*W/m*	*° C*	*° C*	*$W/m^2{\cdot}K$*	*° C*
PVC	50	8.5 x 2	64.7	52.1	15.4	12.6
BIC 15	62.2	12.5 x 2	64.5	60.8	16.2	3.7
Fragom	61.0	12.0 x 2	64.4	60.0	16.0	4.4

III. HEAT TRANSFER FROM THE CABLE LAID IN THE WALL

The models, when the cable is laid horizontally within a vertical wall with thermal conductivity of the wall material 0.7 W/m·K are considered. The distance from the cable to the surface of the wall is 5 mm. Wall thickness is 100 mm. The temperature on both sides of the wall +25°C. The results of the calculations are presented in table 4. In this calculation, the same level of heat generation in the cores was set as before, when determining the maximum load capacity of the cables (table 3).

TABLE 4 HEAT TRANSFER FROM THE CABLE IN THE WALL

Material	T cor	T_1m	T_1ave	T_2ave	$α_1$	$α_2$	Δ T
	° C	*° C*	*° C*	*° C*	*$W/m^2{\cdot}K$*	*$W/m^2{\cdot}K$*	*° C*
PVC	51.7	36.5	28.7	27.0	10.34	9.6	23.0
BIC 15	48.0	41.5	30.2	27.7	10.8	9.95	17.8
Fragom	48.05	41.0	29.9	27.6	10.7	9.9	18.2

The symbols in table 4: T_1m - maximum temperature of the front wall (where the cable); T_1ave - the average temperature of the front wall; T_2ave - the average temperature of the back wall; $α_1$ - the coefficient of heat transfer from the front wall; $α_2$ - the coefficient of heat transfer from the back wall; ΔT - temperature difference between the core and the average temperature of the front wall.

Due to the fact that the heat flow in all three cases has the ability to dissipate through a larger surface than in the case of a single cable in the air, the degree of heating of the cores is reduced by 25% for cables with PVC insulation, and by 35% for cables with insulation from halogen-free compounds. At the same time, the wall itself is heated more strongly near the cable with insulation from halogen-free compounds.

The coefficient of heat transfer from the front and back walls was calculated as the sum of convective and radiation mechanisms of heat transfer from the vertical wall. The difference between the average wall temperature and the air temperature (25 °C) was taken as the temperature difference.

IV. HEAT TRANSFER FROM THE CABLE LAID ON THE WALL

In the case of horizontal cable routing in a thin-walled stainless steel tube along a vertical wall, the heat transfer conditions change. The air inside the tube prevents heat dissipation and thus the maximum permissible current levels in the cables are reduced in relation to the limit levels defined earlier (table 3). The results of calculations for this cable installation option are presented in table 5. For PVC-insulated cables, the maximum permissible current has been reduced by 10 %, and for cables with halogen-free compounds by 13%.

TABLE 5 HEAT TRANSFER FROM THE CABLE IN THE TUBE

Material	I	P	T cor	Tt	αt	Δ T
	A	*W/m*	*° C*	*° C*	*$W/m^2{\cdot}K$*	*° C*
PVC	45	6.9 x 2	64.8	34.7	12.8	30.1
BIC 15	53	9.5 x 2	65.2	37.6	13.5	27.6
Fragom	52	9.1 x 2	64.8	37.4	13.5	27.4

The symbols in table 5: Tt - temperature of the surface of the tube; αt - the coefficient of heat transfer from the surface of the tube; ΔT - temperature difference between the core and the average temperature of the surface of the tube.

V. CONCLUSION

The use of halogen-free compounds with high thermal conductivity for insulation and sheaths of power and installation cables, instead of PVC compounds, improves the conditions of heat transfer from conductive cores and allows you to increase the load capacity of cables by 15-20 %. depending on the specific operating conditions of the cables.

REFERENCES

[1] Programs for modeling physical fields ELCUT v. 6.3