Yaroslav Kalchenko – Mykhailo Pikalov

Determination of the electrical conductors parameters in the emergency mode of operation

Abstract

Studies have been conducted to determine the parameters of electrical conductors with different cross-sections in the event of a short circuit. Graphs of the dependence of the electric current multiplicity on the time of the short circuit occurrence at which the insulation temperature of electrical cables with different cross-sections reaches the temperature of its ignition were constructed. From the analysis of these dependencies, it follows that, depending on the multiplicity of the electric current during a short circuit, electric cables with copper conductors heat up faster than electric cables with aluminum conductors of the same cross section, which is associated with higher permissible currents for conductors with copper conductors. It is determined that even at small multiples of the short-circuit current, the insulation of electrical wiring can ignite. The minimum values of the parameters of electrical conductors at which, in the event of a short circuit in an electrical network with a faulty protection device, their insulation may ignite, which will lead to a fire, are determined.
Keywords: temperature of electric cable, short circuit, multiplicity of electric current

Introduction

A properly designed and properly installed electrical network does not guarantee the exclusion of the possibility of emergencies leading to unacceptable overheating of electrical cables in the event of a short circuit.

The duration of a short circuit is usually tenths of a second and, as an exception, can reach several seconds. During this short period of time, the heat generated is so great that the temperature of the conductors exceeds the limits set for normal operation. The heating process stops when the damaged part of the system is automatically disconnected, after which a relatively slow cooling process takes place. Even a short-term increase in the temperature of conductors during a short circuit can lead to softening and melting of the metal, burning of insulation, destruction of contacts, and other damage. To ensure reliable operation of the electrical system, it is necessary to prevent such damage, which is achieved by selecting the appropriate size of conductive parts and, if possible, by quickly automatically shutting down damaged circuits. The property of a conductor to withstand the short-term thermal effects of a short-circuit current without damage is called thermal resistance. The criterion for thermal resistance is the end temperature, which is limited by the mechanical strength of the metals and the resistance to heat of the insulation.

The permissible end temperatures of conductors have been established on the basis of experience and are given in [1]. They are higher than the permissible temperatures during normal operation, since changes in the mechanical properties of metals and insulation wear are determined not only by temperature but also by the duration of heating, which is short under the conditions under consideration. The magnitude of the electric current during a short circuit can vary in a large range. In [1], the values of electric current are not given, when passing through an electric conductor, the ignition of its insulation can occur, which will cause a

fire. In [2], studies of molten parts of copper conductors formed as a result of sparking of the wiring during a short circuit are presented. The results of the research show that the analysis of these particles allows us to make assumptions about the characteristics of electrical conductors during a short circuit, the conditions and scenario of fire.
Paper [3] presents research on determining the temperature of sparks that can be formed in electrical conductors during a short circuit. In the study, the temperature of sparks was determined for different materials of conductor cores and their height. It was determined that an electric spark formed under the ceiling at a height of 10 m can cause the ignition of paper, rubber and plastic on the floor of this room. In [4], the results of experimental studies are presented, which show that electrical sparks generated by a short circuit in a 220 V electrical network can lead to the combustion of cotton, paper and polyurethane foam. At the same time, the studies do not consider the possibility of ignition of the insulation of electrical conductors as a result of a short circuit and the parameters under which this is possible. Thus, the unresolved part of the problem under consideration is the determination of the parameters of electrical conductors when they are heated due to a short circuit.

Objective

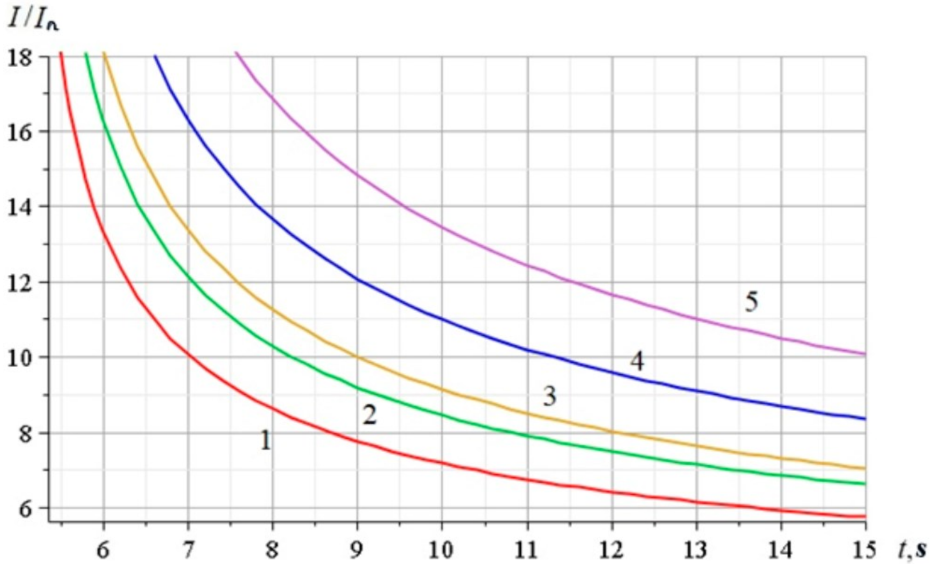
The aim of the work is to determine the time when the temperature of an electrical conductor reaches the ignition temperature of its insulation in the event of a short circuit in an electrical network with a faulty protection device.

Method

To achieve this goal, the methods of solving the equations of mathematical physics and the use of mathematical software in the Maple environment were used.

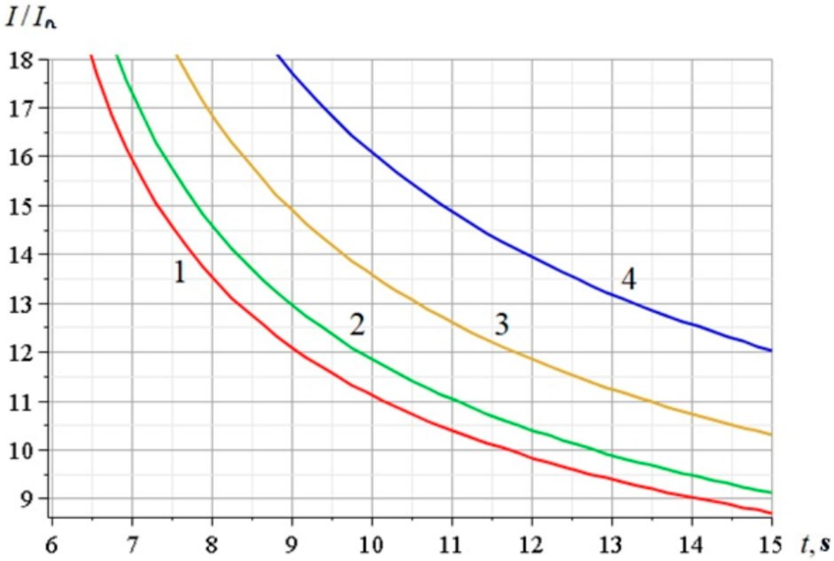
Findings/results

The calculation of the temperature of electrical conductors at a short circuit was carried out for "VVG" and "AVVG" electrical cables. The "VVG" electric cable consists of a copper conductor, polyvinyl chloride (hereinafter PVC) insulation and a PVC sheath, and the "AVVG" cable consists of an aluminum conductor, PVC insulation and a PVC sheath. The initial temperature of the cable before short circuit is 55 ℃. This temperature corresponds to the operating current carried by the cable before the occurrence of a short circuit of the order of the maximum permissible continuous current at an ambient temperature of 25-30 seconds.
The amount of electric current during a short circuit can vary in the range of (2,5 ÷ 18)In . The nominal values of the current were selected from Tables 1.3.5-1.3.6 [1]. The short-circuit time is equal to the time of operation of the protection device. The melting point of PVC insulation can vary from 150 to 250 °C, depending on the manufacturer and its manufacturing methods. In the calculations, we will assume the worst case, when the melting point of the insulation is 150 °C.
If the protective device is in a faulty state, the duration of a short circuit can be tens of seconds. The ignition temperature of PVC is 482 °C. The time for the temperature of the electric cable insulation to reach the temperature of the electric core depends on its time constant.



Picture 1 - Dependence of the electric current multiplicity of "VVG" conductors on time: 1 - conductor cross section 10 mm^2; 2 - conductor cross section 6 mm^2; 3 - conductor cross section 4 mm^2; 4 - conductor cross section 2.5 mm^2; 5 - conductor cross section 1.5 mm^2;

The value of the insulation heating time constant depends on the type of wiring, material, conductor cross-section and insulation and is determined by experiment. The temperature of the insulation can reach a temperature of 500°C if the short circuit duration is at least 5 seconds. With such a short circuit duration, the cable insulation has time to heat up to this temperature.



Picture 2 - Dependence of the electric current multiplicity of "AVVG" conductors on time: 1 - conductor cross section 10 mm^2; 2 - conductor cross section 6 mm^2; 3 - conductor cross section 4 mm^2; 4 - conductor cross section 2.5 mm^2;

The calculation of the parameters of an electrical conductor during a short circuit is based on the assumption that heat is retained inside the current-carrying element during the short circuit, i.e., adiabatic heating occurs. However, during a short circuit, heat is transferred to adjacent materials and must be taken into

account.
The temperature of the current-carrying cores of an electrical conductor during a short circuit can be determined from the expression

$$T = (T_b + \beta)\exp\left(\frac{I_a^2 t}{K^2 S^2}\right) - \beta, \quad (1)$$

where T_b - is the initial temperature of the current-carrying core of the electrical conductor, β - is the inverse of the temperature coefficient of resistance, t - is the duration of the short circuit, K - is a constant depending on the material of the current-carrying core, S - is the cross-sectional area of the current-carrying core, and I_a is the electric current during a short circuit calculated on the basis of the adiabatic heating process.
The multiplicity of the electric current flowing in the conductor during a short circuit is described by the expression:

$$N = \frac{\sqrt{t\ln\left(\frac{T+\beta}{T_b+\beta}\right)}SK\varepsilon}{tI}, \quad (2)$$

According to formula (2) the dependences of the short-circuit current multiplicity for "VVG" and "AVVG" electric cables with different cross-sections on the time at which the insulation temperature of these cables reaches 500 °C were constructed, which are presented in pic. 1 and pic. 2, respectively.

From the analysis of the dependencies presented in pic. 1 and pic. 2, the minimum time for the insulation temperature of an electric cable to reach its ignition temperature was determined, and the results are presented in table. 1.

Table 1 - Minimum time for electric cable insulation to reach the ignition temperature.

"AVVG"				
S, mm^2	2,5	4,0	6,0	10,0
t,s	6,5	6,8	7,6	8,8

"VVG"					
S, mm^2	1,5	2,5	4,0	6,0	10,0
t,s	5,5	5,8	6,0	6,6	7,6

It should be noted that the results presented in table 1 were calculated at a short-circuit current multiplicity of N=18.

Conclusion/suggestions

The current regulatory document does not provide a methodology for determining the temperature of electrical conductors, but only the nominal values of the electric current at which the temperature of the conductor is permissible, so it is impossible to determine the critical values of the electric current at which the temperature of the insulation of electrical conductors will reach its ignition temperature, which can lead to a fire. According to the results of the study, it is possible to estimate the possibility of fire formation during emergency modes of operation of electrical networks for conductors of VVG grades with cross-sections from 1.5 to 10 mm^2 and "AVVG" with cross-sections from 2.5 to 10 mm^2.

As a result of the study, the parameters of electrical cables of the "VVG" and "AVVG" brands with different cross-sections were determined in the event of a short circuit in the electrical network.

From the analysis of the dependencies presented in pic. 1 and pic. 2, it is possible to determine the time of fire occurrence due to the ignition of electrical wiring during a short circuit. From the analysis of these dependencies, it follows that even at small multiples of the short-circuit current, the insulation of electrical wiring can ignite. From the results given in table. 1, it can be concluded that the larger the cross-section of the current-carrying core of an electric cable, the longer it will take to heat up, with the same values of the multiplicity of electric current in a short circuit. This is due to the fact that the permissible values of electric current for electric cables with copper conductors exceed the permissible current values for cables with aluminum conductors.

The values of the minimum time for reaching the temperature of electric cables of the "VVG" and "AVVG" brands with different cross-sections up to 500 °C, which is the minimum ignition temperature of PVC insulation, were determined and presented in the form of a table. The dependences of the electric current multiplicity of electric cables of "VVG" brands with cross-sections of 1.5, 2.5, 4.0, 6.0, and 10.0 mm^2 and "AVVG" brands with cross-sections of 2.5, 4.0, 6.0, and 10.0 mm^2 on time were constructed. It was determined that in the event of a short circuit in an electrical network with a faulty short-circuit protection device with an electric current multiplicity of I/In=18, the maximum time of ignition of the insulation of the studied electrical cables would be 8.8 seconds.

References

[1] Rules for the arrangement of electrical installations. [Effective as of 2017-21-08].Kyiv: Ministry of Energy and Coal Industry of Ukraine, 2017. 754p. URL:http://online.budstandart.com/ua/catalog/docpage.html?id_doc=72758.

[2] Ying Wu, Wei G., Man D., Chang Zh. (2010). Surface Analysis of Electrical Arc Residues in Fire Investigation. Applied Mechanics and Materials, 34, 172-176. doi.org/10.4028/www.scientific.net/AMM.34-35.172

[3] Kostiantyn Afanasenko. Electrical ignition sources for critical infrastructure facilities. 3rd International Conference on Central European Critical Infrastructure Protection. November 15th 2021, Budapest, Hungary. P. 13. URL:http://i-rzeczoznawca.pl/en/no-1-2021/.

[4] Bin Li, Ying Wu, Research on Ignition Characteristic of Short-Circuit Fault. Advanced Materials Research.2013. № 740. P. 496-501. https://doi:/10.4028/www.scientific.net/AMR.740.496.