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DETERMINING THE CURRENT CAPACITY OF TRANSMISSION LINES BASED ON AMBIENT CONDITIONS

DOLOČANJE TRENUTNE ZMOGLJIVOSTI DALJNOVODOV NA OSNOVI ZUNANJIH POGOJEV

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Abstract

After the incorrect prediction of generation from renewable sources, overloading of transmission lines occurred, resulting in the need for subsequent construction of new transmission lines and the maximum exploitation of existing power lines. One means of achieving this is to determine the permissible current load of power lines while respecting the surrounding climatic conditions. This article deals with determining the maximum current load of the power lines for changing various surrounding factors. The calculation is performed for conductor ACSR 350/59, which is used in the transmission system in Slovakia.

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Povzetek

Pri povezovanju energetskih sistemov in nepravilnih predvidevanjih proizvodnje iz obnovljivih virov, je prišlo do preobremenitve daljnovodov. Tako se pojavi potreba po gradnji novih daljnovodov in čim boljši izkoriščenosti obstoječih. Eden od načinov je, da se določi dovoljena trenutna obremenitev daljnovodov ob upoštevanju okoliških vremenskih razmer. Prispevek obravnava določanje največje trenutne obremenitve daljnovoda ob različnih vremenskih dejavnikih. Izračun smo opravili za vodnik ACSR 350/59, ki se uporablja v prenosnem omrežju na Slovaškem.

1 INTRODUCTION

Capacity is defined as the maximum allowable value of current that can flow through transmission lines without adversely affecting the mechanical and electrical properties of the conductor. The size of the maximum permissible current value is determined by the mechanical and electrical properties, its ability to dissipate the heat generated inside the conductor, and the ambient conditions, *[1].*

The necessity of raising the capacity of transmission lines has begun to emerge in recent years after a massive deployment of renewable energy sources (due to lack of line capacity on north-south routes within a UCTE grouping), which overloaded the lines due to the insufficient prediction of the generation of electricity from renewable sources, *[2].*

For these reasons, the construction of new transmission lines is necessary, which represents a considerable financial and time-consuming solution. One alternative is to focus on determining the maximum permissible currents depending on ambient environmental conditions, which may serve the supervisory control of power flows on uncongested lines.

2 THEORETICAL INTRODUCTION TO THE CAPACITY OF THE TRANSMISSION LINES

As mentioned previously, the concept of capacity means the maximum permissible value of current that can flow without disturbing the conductor’s electrical and mechanical properties. Capacity size depends on the electrical and mechanical properties of the conductor, its ability to spread the heat generated, and the ambient conditions, *[3].*

Ambient conditions are all climatic environment in which the line is placed. Among the climatic conditions are ambient temperature, speed and direction of wind flow, intensity of solar radiation, and precipitation, *[3].*

The most commonly used types of conductors in our transmission system include ACSR ropes, which, depending on the voltage levels, are arranged individually or in bundles. For the purposes of this article, the effects of environmental conditions on the size of the maximum permissible value of the current ACSR 350/59 rope will be discussed.

The parameters of the rope are shown in the table below (Table 1).

Table 1: *Parameters of the rope, [4]*

Rope Type	ACSR 350/59
Rope diameter (mm)	26.39
Rope cross-section (mm^2)	410.80
Nominal weight ($kg.km^{-1}$)	1453.01
Specific gravity ($MN.m^{-3}$)	0.03469
The maximum permissible stresses (MPa)	108.661
Elastic modulus (MPa)	74332
The coefficient of thermal expansion (1/°C) $.10^{-6}$	18.65
Rated DC resistance (Ω/km)	0.0835

For the construction of power lines in the currently applicable EN 50341 standard, the maximum temperature of the conductor is 70 °C.

The actual control of temperature of the conductor in the case of known current value is performed for the following conditions:

- The current load is the highest,
- Ambient temperature is 35 °C,
- Wind speed is 0.5 m/s at a 45 ° angle of impact,
- Global temperature of sunlight is 1000 W/m^2,
- Absorption coefficient is 0.5,
- Emissivity coefficient of 0.5, *[5].*

Under these conditions, it can be said that the lines are designed for the worst possible environmental conditions so as not to exceed the maximum permissible conductor temperature. It should be noted that the above climatic conditions rarely occur, resulting in a certain margin for the maximum permissible value of the current that is not in constantly changing environmental conditions can be achieved, and thus the line can be overloaded.

3 DETERMINATION OF MAXIMUM ALLOWABLE CURRENT VALUE

The dependence of the size of permissible currents for the electrical and mechanical properties of the conductor can be, provided that there is no damage to the effects of heat, considered as constant, given at the factory.

The evaluation of environmental conditions, as factors that determine the maximum permissible load of the conductor, must be based on their variability over time.

The steady state temperature of the driver, when considering the environmental conditions can be expressed by the following equation (3.1), where left part of the equation form variables involved in increasing the temperature of the conductor, and a right part of the equation form parameters involved in the cooling section, *[6].*

$$P_Z + P_S + P_C = C_v \cdot \frac{d\Theta}{dt} + P_k + P_r + P_w \tag{3.1}$$

In calculation, conductor warming due to the corona is neglected. The most significant increase in temperature due to the corona occurs mostly during clashes when the cooling of the conductor is highest, and thus we neglect the contribution cooling of the conductor due to the water evaporation, *[6].*

For the purposes of this publication, we will base the solution from aforementioned formula of the static model, which does not change the load, the change in temperature of conductor; thus, balance equation (3.1) will have the following form (3.2), *[6].*

$$P_Z + P_S = P_k + P_r \tag{3.2}$$

Determining the impact of individual surrounding factors to the resulting current capacity of conductor will be based on the initial conditions defined by the EN 50341 standards:

1. We will examine the contribution of solar radiation by changing the intensity of it in the range of 100 W/m^2–1000 W/m^2 under constant environmental conditions given by the standard, provided the maximum recommended temperature of the ACSR rope 350/59 does not to exceed 70 °C,

2. We will examine contribution of the ambient temperature in the range -40 °C to -1 °C and in the range of + 1 °C to 40 °C under constant environmental conditions given by the standard, provided the maximum recommended temperature of the ACSR rope 350/59 does not to exceed 70 °C,

3. We will examine contribution of wind speed in the range of 1 m/s to 40 m / s under constant environmental conditions given by the standard, provided the maximum recommended temperature of the ACSR rope 350/59 does not to exceed 70 °C.

3.1 Impact of solar radiation on the maximum permissible current value

Solar radiation that irradiates the examined conductor has three components: direct radiation, diffuse radiation and reflected radiation, *[6].*

In determining thermal growth with sufficient accuracy, the diffuse and reflected light, whose effect is 2-4%, can be excluded, *[6].*

Dependence of the maximum permissible value of the current on the size of the intensity of solar radiation is shown in the figure below (Figure 1).

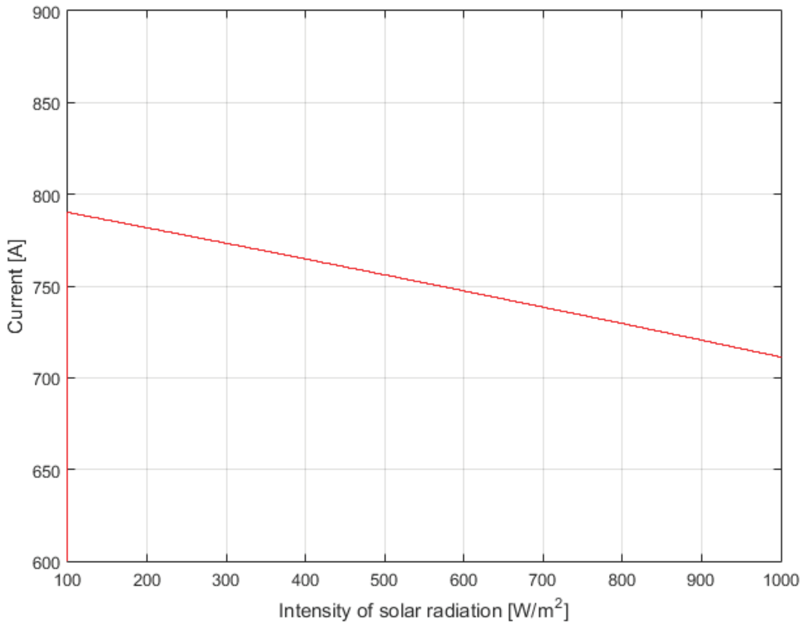

Figure 1: *Dependence of the maximum permissible value of the current on the intensity of solar radiation*

As is clear from the previous figure, change of the intensity of solar radiation leads to linear change of the maximum permissible current value. In the investigated interval of solar irradiation (100W/m² to 1000W/m²), the maximum permissible value for the current interval 790.07 A was reached at the lowest intensity of solar radiation and at a maximum intensity of solar radiation 711.22 A for a one-in-three wire bundle. The above allowed current capacity of the conductor with a minimum intensity of solar radiation is an increase in the capacity of the line to the state with the maximum intensity of solar radiation by 11%.

3.2 Impact of air flow on the maximum allowed value of current

Airflow from the perspective of reducing the temperature of conductor represents a transfer of energy in macroscopic scale, between the particles of the body containing a large number of molecules. This process is dependent on the character of hydrodynamic and thermal marginal layer; the shape and size are affected by the speed and direction of air flow, *[6].*

When examining the impact of air flow, the change of the maximum permissible currents at different wind speeds at an interval of 1 m/s to 40 m/s at an angle of impact to the power line 45° will be monitored.

The dependence of the maximum permissible current value when changing the air velocity is shown in the figure below (Figure 2).

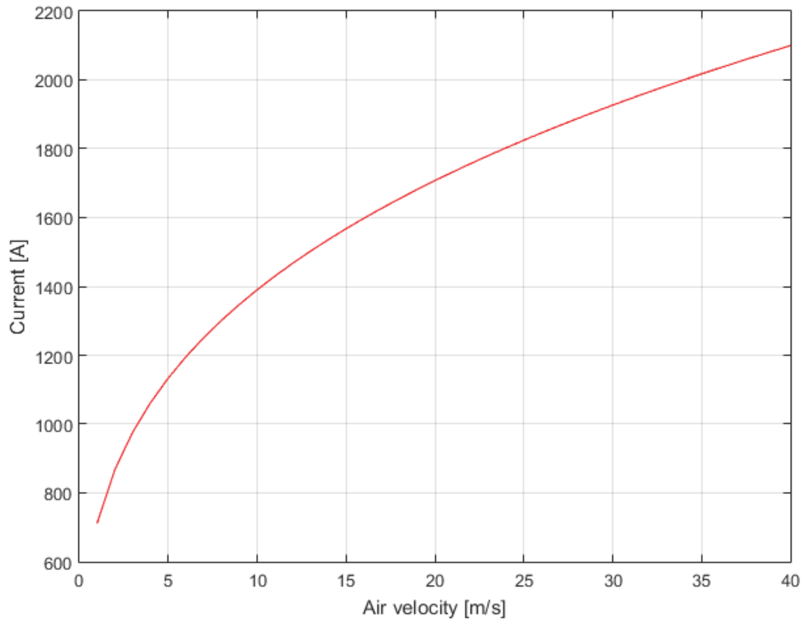

Figure 2: *Dependence of the maximum permissible value of the current on air velocity*

From the figure, we can see that with increasing air speed leads to exponential increase of the maximum permissible current value. The most significant increase in the maximum current value occurs in the interval velocity of 1 m/s to 15 m/s, with an increase in the allowable load of 711.22A to 1567.55A, representing an increase of 120% of the initial value.

In the examined range of action, the wind flow velocity to the maximum permissible current value from 15 m/s to 40 m/s occurs near a linear increase of the maximum permissible value current from 1567.55A to the 2099.70A.

3.3 Impact of radiation to the maximum permissible value of the current

The radiation represents a mechanism of heat transfer, which consists of the emission and absorption of the electromagnetic radiation. An object with a non-zero temperature emits electromagnetic radiation, according to Planck's law, *[6] [7].*

The total amount of energy emitted from the surface of the object increases with surface temperature. Depending on the temperature of the body surface, the emission spectrum changes. With the increase of the temperature, there is a change of the spectrum to shorter wavelengths. In addition to its own radiation, each object captures the photons radiated by nearby objects. The resulting energy balance of the process is given by the difference of radiated and received energy. As the amount of radiated energy increases with temperature, the resulting radiation is the transfer of energy from warmer units to cooler ones, *[6] [7].*

Studying the effect of radiation on the final current capacity will be based on the assumption that the conductor temperature is constant at 70 ° C. The examination will include the impact of ambient temperature on the maximum permissible current load at an operating temperature of 70 °C. The interval examination will consist of two parts, in the first range of -40 °C to 1 °C; in the second part, we will examine the influence of the positive ambient temperature in the scope of 1 °C to 40 °C.

Dependence of the maximum permissible current value when ambient temperature changes for the first and second studied interval are in the following figures (Figure 3, Figure 4).

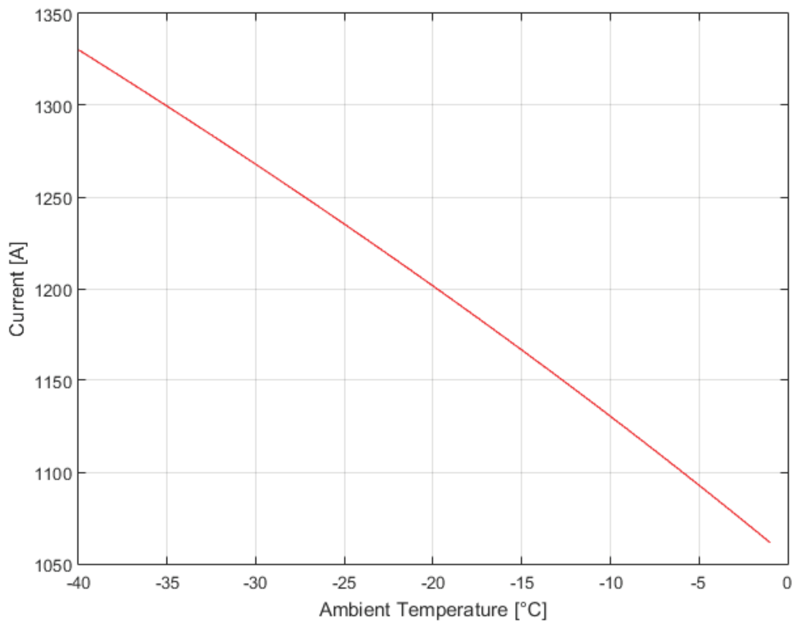

Figure 3: *Dependence of the maximum permissible value of current on ambient temperature of the first examined interval*

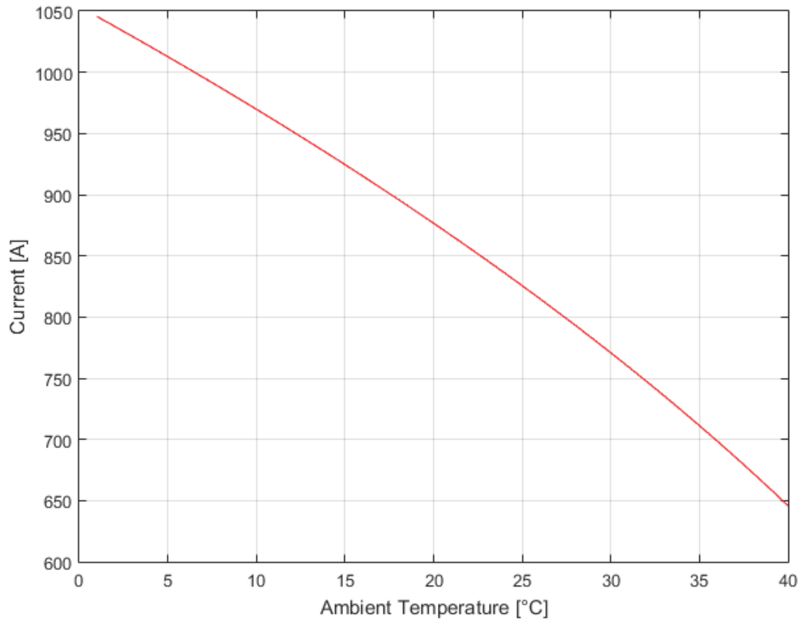

Figure 4: *Dependence of the maximum permissible value of current on ambient temperature of the second examined interval*

From the figures above, we can see that with increasing ambient temperature leads to decrease of the maximum permissible current value. This change ampacity occurs as a direct result of changes in the coefficient of heat loss by radiation (P_r), wherein in increasing the ambient temperature leads to inversely proportional heat rejection to the environment.

In terms of size ampacity in the first interval, there is a decrease in the permissible current value from 1330.23 A to 1061.63 A. For the second period, there was a decrease in the permitted current value from 1045.63 A to 645.74 A. For the first interval, the decrease was nearly 20.19%, but in the second interval at positive ambient temperature, this change is more pronounced. For the second interval, there was a decrease the maximum permissible current value for the conductor ACSR 350/59 by 38.24%.

4 CONCLUSION

Determining permissible current load in real time is an important and highly relevant issue in professional circles. In recent years, what is needed is to increase the capacity of transmission systems. The first option is the construction of new lines; however, this is a time-consuming and costly solution. The second option is to maximize the use of existing transmission lines in knowledge of environmental conditions and taking into account their impact on the maximum permissible current load in terms of the standard recommended temperature.

This article describes the different environmental factors affecting the maximum permissible current load at a maximum conductor temperature of 70 °C and examines their impact on the final ampacity of lines. The resulting current load has been studied for an electrical conductor in the three-volume configuration of one phase for the voltage level 400 kV.

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Nomenclature

P_Z	conductor warming influence current flow
P_S	conductor warming influence of sunlight
P_C	conductor warming influence the corona
C_V	heat capacity of conductor
P_K	conductor cooling influence air flow
P_R	conductor cooling influence radiation
P_W	conductor cooling influence water evaporation