THE INFLUENCE OF CLIMATIC CONDITIONS ON THE DYNAMIC AMPACITY OF OVERHEAD POWER LINES

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ABSTRACT

The constantly growing demand for electricity demands both on the installed power of energy sources and on the transmission capabilities of electrical networks. Considering the fact that increasing the transmission capabilities of electrical networks by building new lines is a time and financially demanding process, network operators strive to use the transmission capacities of existing lines as much as possible. One of the possibilities of this maximum use of existing capacities is the application of the calculation of the dynamic ampacity of the lines, when the operators of electric networks know how to determine the maximum load capacity of the lines depending on the current climatic conditions. The presented publication presents a methodology for determining the dynamic ampacity of overhead power lines under different climatic conditions with the subsequent application of this methodology to a specific conductor used in the implementation of overhead transmission lines.

Keywords: *ampacity, overhead power line, climatic conditions*

1. INTRODUCTION

The ampacity of overhead power lines is defined as the maximum permissible value of the current that can flow through the line without disturbing its mechanical and electrical properties. The most used conductors of overhead power lines are ropes with an iron core ensuring the necessary mechanical strength of the line, the outer layer of the rope with good conductivity is made of aluminium. The manufacturers of these ropes indicate their maximum operating temperature in the range of 90°C to 110°C. If this temperature is exceeded for a long time, the material becomes more brittle and its service life is reduced.

Another limitation related to the increasing temperature of the conductor is its elongation, thereby reducing its height above ground level. The minimum safe height of conductors is set in standards for different types of environments. The minimum permitted height of the lines and the associated maximum temperature of the conductors are taken into account during the design and construction of the lines.

The size of the maximum allowed value of the current is determined by the mechanical and electrical properties of the conductor, its ability to dissipate the heat generated inside the conductor and by the surrounding conditions. Ambient conditions represent all climatic conditions of the environment, which include ambient temperature, wind speed and direction, and solar radiation intensity. The temperature of the conductors depends on the meteorological conditions and the magnitude of the passing current.

2. DEFINITION OF DYNAMIC AMPACITY OF OVERHEAD POWER LINES

When operating electrical lines, based on the STN EN 50 341-1 standard, the value of the maximum permitted current is used, determined for the highest design temperature of the conductor under the following conditions:

- ambient temperature +35°C,
- wind speed 0.5 m/s at an angle of 45° to the axis of the conductor,
- global solar radiation intensity of 1000 W/m^2,
- absorption coefficient 0.5,
- emissivity coefficient of 0.5 [2].

According to the standard STN EN 50 341-1, the highest design temperature of phase conductors for checking the shortest distances must be stated in the project specification. When determining the highest design temperature of conductors, the possible development of the use of the line must be taken into account at least during the design life of the line. For those lines where the cross-section of the phase conductors is primarily determined by the transmitted current (thermal aspects), it is not recommended to choose the highest design temperature of the conductor lower than 70°C.

In some transmission systems, different current restrictions are used for summer and winter. On the basis of long-term measurements of weather conditions (temperature, wind) in the lines' routes, it can be concluded that for most of the year they are far from reaching the design values, so the lines have considerable reserves in the permitted transmission capabilities. For a large part of the year, the actual ampacity is tens of percent greater than the indicated value.

Due to the fact that climatic conditions are constantly changing over time, the maximum permissible value of the conductor current also changes, so we are talking about the dynamic ampacity of the conductor.

The magnitude of the current at which the temperature of the conductor stabilizes at the maximum possible value is called the steady dynamic ampacity of the conductor.

Since the line has a certain thermal capacity, it can be used to overload the line for a short time so that the temperature does not exceed the permitted level. We call this short-term overload transient dynamic ampacity, which is related to the overload period [2, 3].

3. MATHEMATICAL MODEL FOR CALCULATING THE TEMPERATURE OF THE CONDUCTOR IN THE TRANSIENT STATE

In general, the climatic conditions and the current load of the conductors of the overhead power lines change depending on the time. In this case, the conductor is not always in thermal equilibrium, i.e. a certain amount of heat is accumulated in the conductor. The temperature of the conductor is not stable, as a transient event is taking place. The general equation of heat in the case of the transient thermal state of the conductor can be expressed by equation (1) [1]. The given equation expresses the fact that the heat accumulated in the conductor is equal to the difference of heat gain and heat loss in the conductor, i.e.:

$$m.c.\mathrm{d}T_s/\mathrm{d}t = P_J + P_s - P_c - P_r \tag{1}$$

where m – weight of conductor per unit length (kg/m), c – specific heat capacity of the conductor (J/(kg·K)), P_J – heating of the conductor by Joule losses (W/m), P_s – heating of the conductor by sunlight (W/m), P_c – cooling of the conductor by convection (W/m), P_r – cooling the conductor by radiation (W/m).

The derivation of the equations for the analytical calculation of the conductor's temperature over time is generally based on the assumption that the conductor is in thermal equilibrium at the time of the change in operating parameters. Therefore, the calculation of the conductor temperature includes the initial steady temperature of the conductor at the time of the change in operating parameters, as well as the so-called asymptotic temperature of the conductor after a step change in operating parameters. These temperatures can be determined from the solution of the steady thermal state of the conductor.

The asymptotic temperature represents the maximum possible temperature to which the temperature of the conductor can approach after stabilization, or the conductor reaches this temperature in infinite time. According to the analytical model, the conductor never heats up, or it will not cool to this temperature because it is an asymptote of an exponential function. The general course of the conductor temperature as a function of time after a sudden change of one operating parameter or several operating parameters at the same time can be expressed by equation (2) [4, 5]:

$$T_s \cong T_{sm} - (T_{sm} - T_{s1}).e^{-t/\tau} \tag{2}$$

where T_{s1} – steady temperature of the conductor over time $t = 0$ (°C), T_s – conductor temperature over time t (°C), T_{sm} – asymptotic temperature of the conductor in time $t = \infty$ (°C), τ – global time constant (s), t – time (s).

The temperature stabilization time of the conductor is determined by the so-called global time constant. The global time constant expresses the time interval during which the temperature of the conductor changes from the initial (steady) temperature to approximately 63.2% of the asymptotic temperature. The effects of changes in all operating parameters are included in the global time constant, i.e. climatic conditions, but also the current flowing through the conductor and can be determined from equations (3), (4) [2,3]:

$$\tau \cong 1/(1/\tau_I + 1/\tau_S + 1/\tau_V + 1/\tau_T) \tag{3}$$

where τ_I – time constant of the current (s), τ_S – time constant of the solar radiation (s), τ_V – time constant of the air flow (s), τ_T – time constant of the emission (s).

$$\tau \cong m.c.(T_{sm} - T_{s1}) / (\Delta P_J + \Delta P_s - \Delta P_c - \Delta P_r) \tag{4}$$

where ΔP_J – change in conductor heating due to current flow after a sudden change in current (W/m), ΔP_s – the change in solar radiation conductor warming following a change in global solar radiation intensity (W/m), ΔP_c – a change in the cooling of the conductor due to the flow after a sudden change in the speed and direction of the wind or the ambient temperature (W/m), ΔP_r – change in the cooling of the conductor due to radiation after a sudden change in the ambient temperature (W/m).

Equation (2) can be adjusted to equation (5), which defines the time during which the conductor warms up, or cools down to the required temperature [2]:

$$t \cong -\tau.\ln\left[(T_{sm} - T_s) / (T_{sm} - T_{s1})\right] \tag{5}$$

Equation (5) is mostly used in connection with the calculation of the time of short-term current overload of the conductor so that its maximum permissible temperature is not exceeded. In other words, the time during which the conductor heats up to the maximum allowed temperature at a given current value is calculated [4, 5].

4. APPLICATION OF THE DYNAMIC THERMAL MODEL UNDER REAL OPERATING CONDITIONS OF THE LINE

The mentioned dynamic thermal model of the conductor will be applied to conductor 352-AL1/59-ST1A with parameters according to Table 1 and Table 2.

Table 1 Technical specification of conductor 352-AL1/59-ST1A [3]

parameter	value
surface absorptivity coefficient	0,35 (−)
surface emissivity coefficient	0,35 (−),
alternating resistance at a temperature of 20°C	$0{,}0816 \cdot 10^{-3}$ ohm/m
temperature coefficient of resistance	$4{,}03 \cdot 10^{-3}$ 1/K,
specific heat capacity of steel at a temperature of 20 °C	481 J/(kg · K)
specific heat capacity of aluminum at a temperature of 20 °C	897 J/(kg · K)
temperature coefficient of specific heat capacity of steel	$1 \cdot 10^{-4}$ 1/K
temperature coefficient of the specific heat capacity of aluminum	$3{,}8 \cdot 10^{-4}$ 1/K

Table 2 Constructional parameters of conductor 352-AL1/59-ST1A [3]

parameter	value
outer diameter	$26{,}5\cdot10^{-3}$ m
weight of steel per unit length	0,5119 kg/m
weight of aluminum per unit length	1,116 kg/m
number of aluminum wires in layers	11 + 17
number of steel wires in layers	3 + 9
cross section of aluminum wires	351,86 mm^2
cross section of steel wires	58,9 mm^2
diameter of aluminum wires	4 mm
diameter of steel wires	2,5 mm

First, the impact of a sudden change in individual climatic conditions (ambient temperature, wind speed, intensity of solar radiation) and current on the conductor's temperature will be presented individually, and then the impact of a change in all operating conditions on the conductor's temperature will be analyzed simultaneously.

Fig. 1 shows the selected climatic conditions and the current flowing through the conductor (before and after the step change). It is assumed that the conductor is in thermal equilibrium before the change in parameters. It is also considered that after the change (during the entire investigated time interval) all operating conditions are constant.

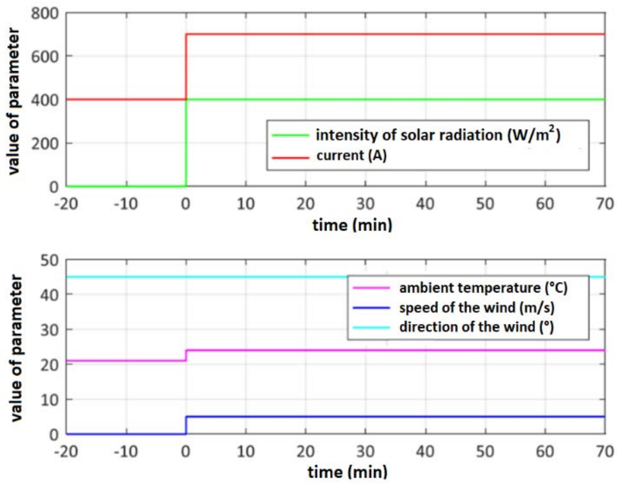

Fig. 1 Graphic display of climatic conditions and current flowing through the conductor before and after their step change

Fig. 2 shows the warming of the conductor as a result of an increase in the ambient temperature (from 21°C to 24°C).

This change results in an increase in conductor temperature. An increase in the ambient temperature will be manifested by a decrease in the heat output removed from the conductor, i.e. by reducing the cooling of the conductor by radiation and heat convection. There is a direct proportionality between the conductor temperature and the ambient temperature. The higher the ambient temperature, the higher the conductor temperature and vice versa.

Fig. 3 shows the course of cooling of the conductor due to the increase in wind speed. A change in wind speed from no wind to a wind speed of 5 m/s at an angle of attack of 45° is considered.

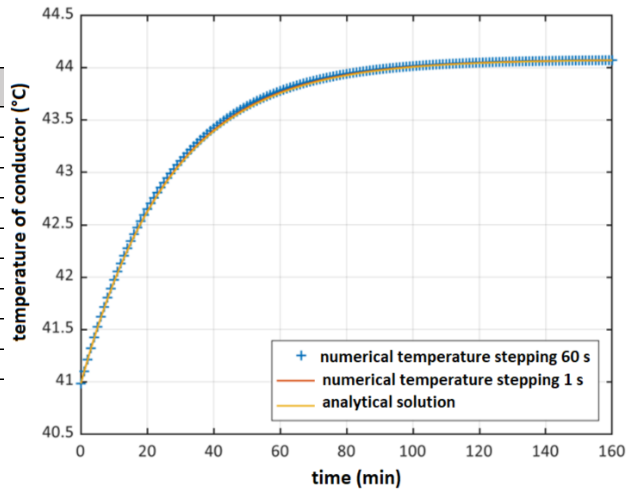

Fig. 2 Dependence of the conductor temperature on time after a sudden change in the ambient temperature

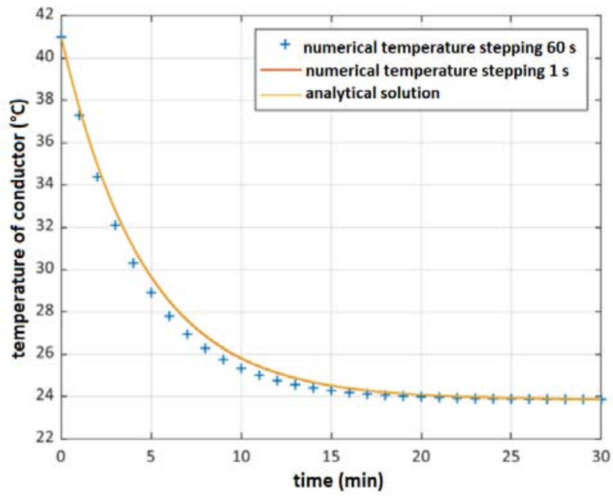

Fig. 3 Dependence of the conductor temperature on time after a sudden change in wind speed

This change results in an increase in the value of conductor cooling by convection, which leads to a decrease in the asymptotic temperature of the conductor. There is an inverse relationship between the conductor's temperature and the change in wind speed: the higher the wind speed, the lower the conductor's temperature.

Fig. 4 shows the heating curve of the conductor due to an increase in the intensity of solar radiation from 0 to 400 W/m^2.

There is a direct proportionality between the temperature of the conductor and the intensity of solar radiation: when the intensity of solar radiation increases, the temperature of the conductor increases and vice versa.

Fig. 5 shows the heating of the conductor after a sudden change in current from the initial value of 400 A to a value of 700 A.

It can be concluded that there is a direct proportionality between the temperature of the conductor and the current flowing through the conductor, i.e. when the current increases, the temperature of the conductor also increases due to Joule losses and vice versa.

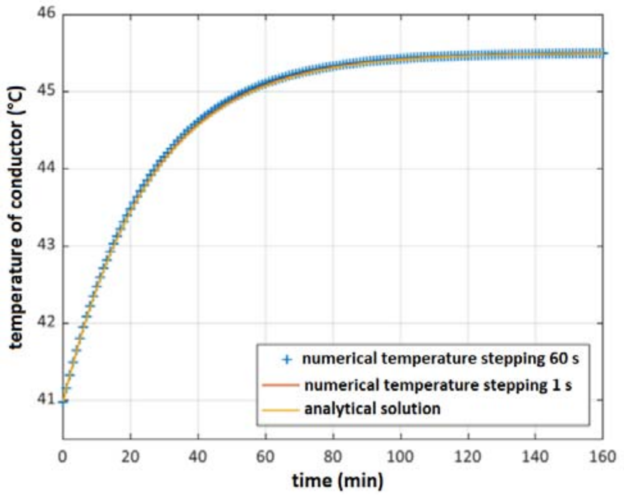

Fig. 4 Dependence of the conductor temperature on time after a step change in the intensity of solar radiation

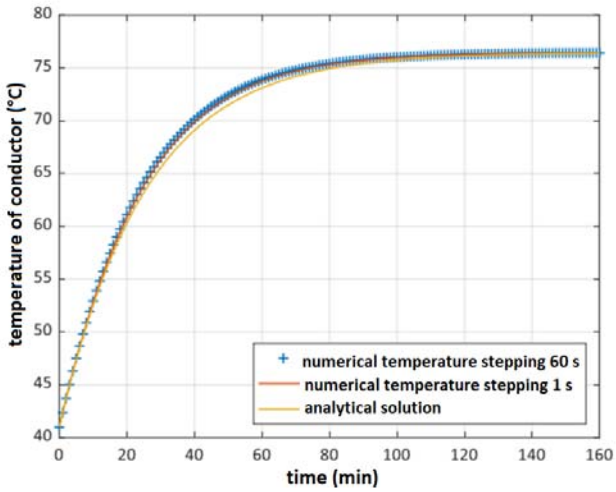

Fig. 5 Dependence of conductor temperature on time after a step change in current

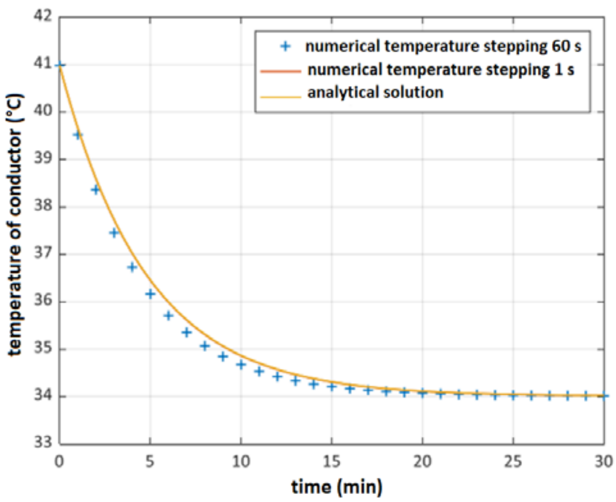

Fig. 6 Dependence of conductor temperature on time after step change of all operating parameters

Fig. 6 shows the dependence of the temperature of the conductor on time after the simultaneous step change of all operating parameters shown in Fig. 1.

If all operating conditions change, all heat outputs from the balance equation (1) will contribute to the change in conductor temperature. This simultaneous change of all parameters will cause cooling of the conductor due to the most significant effect, i.e. j. convection, which is mainly related to the change in wind speed. The warming of the conductor by Joule losses and solar radiation is not sufficient, as is the decrease in the degree of cooling of the conductor by radiation [3].

5. CONCLUSION

The aim of the publication was to analyze the influence of climatic conditions on the dynamic ampacity of overhead power lines. The obtained results show that individual operating parameters (climate conditions and current flowing through the conductor) have an effect on the temperature of the conductor and change over time. Specifically, the influence of operating parameters on the temperature of the conductor after their sudden change is investigated, i.e. j. dependence of conductor temperature on time. In the case of a sudden change in the ambient temperature, the intensity of solar radiation and the current, there is a direct proportionality between these parameters and the temperature of the conductor. There is an inverse relationship between the conductor's temperature and the change in wind speed: the higher the wind speed, the lower the conductor's temperature. In the case of a simultaneous change of all operating parameters, all thermal outputs that contribute to the heating/cooling of the conductor participate in the change of conductor temperature. The resulting warming/cooling of the conductor depends on the most significant influence. In the case discussed in this article, it is the effect of convection, which is mainly related to the change in wind speed.

Thanks to this mathematical model, it is also possible to calculate the so-called short-term overloading of the line so that the temperature does not exceed the permitted level. The deployment of dynamic ampacity calculation in dispatch control can significantly help in solving critical situations related to excessive line load.

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BIOGRAPHIES

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