Temperature Calculation of Overhead Power Line Conductors According to the CIGRE Technical Brochure 207

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***Abstract*—An overhead power line is a structure used in the electric power system to transmit an electrical energy. The performance of overhead power lines depends on their parameters. An important parameter of the power line in the power system is its thermal limit. This article deals with the temperature calculation of overhead power line ACSR conductors according to the methodology stated in CIGRE technical brochure 207. The calculated temperature is also verified by the measurement on a real power line. At the end of the article the maximum allowable current (ampacity) of ACSR conductors depending on climatic conditions is also calculated. Obtained results are compared with actual current limits (for summer and winter season) using by Slovak transmission system operators.**

Keywords—overhead power line, ACSR conductor ampacity, CIGRE technical brochure 207, ACSR conductor temperature

I. INTRODUCTION

Overhead power lines are an integral part of the transmission network. Overhead transmission lines operate at high voltages, so their parameters must meet certain limits to ensure safe operation. One of the most important factors that affect, for example the line sag, is the conductor's temperature. The conductor will cause irreparable damage when the heat generated by the current flowing exceeds the thermal limit. To prevent problems caused by thermal overload, it is necessary to set the maximum current at less risk of overheating in accordance with the carrying capacity. Current-carrying capacity (ampacity or ampere capacity) is the main parameter of the power line design and operation, this value is the maximum allowable current under the conservative meteorological conditions, that can flow through the power line (respectively conductor) without disturbing its mechanical and electrical properties. The maximum allowable current is determined by mechanical and electrical properties of the conductor, the ability of heat dissipation inside the conductor and ambient conditions [1]-[5].

Conductors are the most important part of power lines. Conductor requirements are very diverse and often contradictory. In addition to good electrical conductivity, their mechanical strength is also taken into account, they should be sufficiently resistant to chemical influences and climatic conditions. The temperature of conductors is dependent on climatic conditions (ambient temperature, wind speed and direction, intensity of the solar irradiance) and the value of the flowing current. Due to the temperature, the length of the conductor is changed, which affects the sag and mechanical stress of the conductor. If the temperature increases, the conductor extends and thus increases the sag and reduces the mechanical stress. If the temperature drops, there is an opposite phenomenon. The most widely used conductors of transmission power lines are ACSR (aluminium conductor steel reinforced or AlFe) conductors, the conductive part of which is aluminium. Manufacturers specify maximum operating temperature of ACSR conductors in the range of 90 °C to 110 °C [6].

The standard STN EN 50 341-1: Overhead electrical lines exceeding AC 45 kV. Part 1 determines the maximum temperature of the conductor, which is not recommended to choose less than 70 °C. The standard STN EN 50 341-1 states the maximum allowable current for the specified maximum temperature under the following conditions [7]:

- ambient temperature 35 °C,
- wind speed 0.5 m/s at a 45° angle of impact,
- global temperature of sunlight 1000 W/m²,
- absorption coefficient 0.5,
- emissivity coefficient 0.5.

Also, in some transmission power systems, different current limits are used for the summer and winter season. Based on long-term measurements of weather conditions (temperature, wind) around power lines it can be stated that for most of the year these weather conditions do not reach the values considered by the standard STN EN 50 341-1. Also, the set current limits for the summer and winter season represent much lower values than current values that can be power lines loaded under the actual conditions [8]. Reference [9] states that for most of the year, actual ampacity are about 10 % higher than the specified value.

References [9] and [10] define the terms of static and dynamic ampacity in different ways. In this article is used terminology according to [10].

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According to [9], the static ampacity represents the maximum allowable current for given (constant, unchanging) atmospheric conditions. The dynamic ampacity is defined as the possibility of short-term overloading of the power line (respectively conductors) with the respect of actual weather conditions, so that the temperature does not exceed the maximum allowable value. This short-term overload is related to the overload time.

According to [10], the static ampacity is a maximum allowable current calculated on the basis of conventional (presumed) atmospheric conditions (for example current limits for the summer or winter season). The dynamic ampacity is defined as the maximum allowable current determined when the conductor operates under real atmospheric conditions. In both cases (for both static and dynamic ampacity) it is a steady state.

According to the CIGRE, Technical Brochure 207: The thermal behavior of overhead conductors [11], the thermal equilibrium of the conductor with considering ambient conditions can be expressed by the power balance equation, where the left part of this equation is represented by the quantities (powers in W/m) causing the warming of the conductor (increasing the temperature of the conductor) and the right part of the equation is characterized by quantities (powers in W/m) causing the cooling of the conductor:

$$P_j + P_s = P_c + P_r , \qquad (1)$$

where

P_j is the warming of the conductor by the current flowing,
P_s is the warming of the conductor by the sunlight,
P_c is the cooling of the driver by the convection,
P_r is the cooling of the driver by the radiation.

The value of the maximum allowable current I_{max} of the conductor which temperature does not exceed the temperature T_s is determined by [11]:

$$I_{max} = \sqrt{\frac{P_c + P_r - P_s}{R_{20\,ac}\left[1 + \alpha\left(T_s - 20\right)\right]}} , \qquad (2)$$

respectively the actual temperature T_{act} of the conductor if the actual current I_{act} flows through the conductor:

$$T_{act} = \frac{P_c + P_r - P_s + I_{act}^2 R_{20\,ac}\left(20\alpha - 1\right)}{I_{act}^2 R_{20\,ac}\alpha} , \qquad (3)$$

where

T_s is the maximum permitted temperature of the conductor in °C,
T_{act} is the actual temperature of the conductor in °C,
I_{max} is the maximum allowable current of the conductor in A,
I_{act} is the actual current of the conductor in A,
$R_{20\,ac}$ is the ac resistance of the conductor at 20 °C in Ω,
α is the temperature coefficient of resistance in K^{-1}.

Aplication of the Maximum Allowable Current Calculation Depending on Ambient Climatic Conditions on ACSR Conductors

For purpose of this article there was chosen Line 1 of 90 km length between two electric power stations ES1 and ES2 (Fig. 1) at 400 kV voltage level.

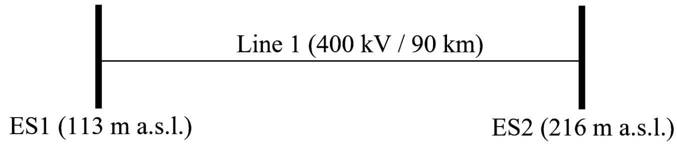

Fig. 1. Single-line diagram of the analyzed overhead power line (Line 1)

Within the Line 1, different types of conductors were used on different sections. There was 450 AlFe 6 in triple bond configuration used in the first section and 350 AlFe 6 in triple bond configuration used in the second section.

There are technical parameters of considered ACSR conductors used in Line 1 shown in TABLE I. Those parameters are used for the analysis of maximal allowable current value depending on ambient climatic conditions. For this analysis the maximum permitted conductor temperature T_s was considered of 80 °C with altitude of 216 m a.s.l.

TABLE I. Technical Specification of Analyzed ACSR Conductors

Type of ACSR conductor	350 AlFe 6	450 AlFe 6
Rope diameter (mm)	26.5	29.7
Diameter of aluminium strand (mm)	4.0	4.5
Ac resistance at 20 °C (Ω/km)	0.0816	0.0650
Temperature coefficient of resistance (K^{-1})	$4.03 \cdot 10^{-3}$	
Absorption coefficient (–)	0.65	
Emissivity coefficient (–)	0.35	

There were carried calculations of dynamic ampacity (as defined in [10]) for each 15 minutes of a day realized for the Line 1. Calculations were realized for the 20th March, 26th March and 30th May of 2018. There were two different measuring systems installed in ES2. Measured data were obtained with a recording interval of 15 minutes.

The following data were available from the measuring system no 1:

- ambient temperature (°C),
- intensity of the solar irradiance (W/m^2),
- RMS value of the current flowing through the Line 1 (A),
- wind speed (m/s).

The following data were available from the measuring system no. 2:

- ambient temperature (°C),
- temperature of the conductor 450 AlFe 6 (°C),
- RMS value of the current flowing through the Line 1 (A).

III. Comparison of Calculated and Measured Temperature of ACSR Conductors Based on Ambient Conditions and Real RMS Current

This chapter presents calculation of temperature time courses of Line 1 conductors based on ambient conditions and measured RMS current values according to the equation (3). Calculations was realized for 20th, 26th of March and for 30th of May of 2018. Time courses of measured RMS currents flowing through the Line 1, for each above mentioned day is shown in Fig. 2.

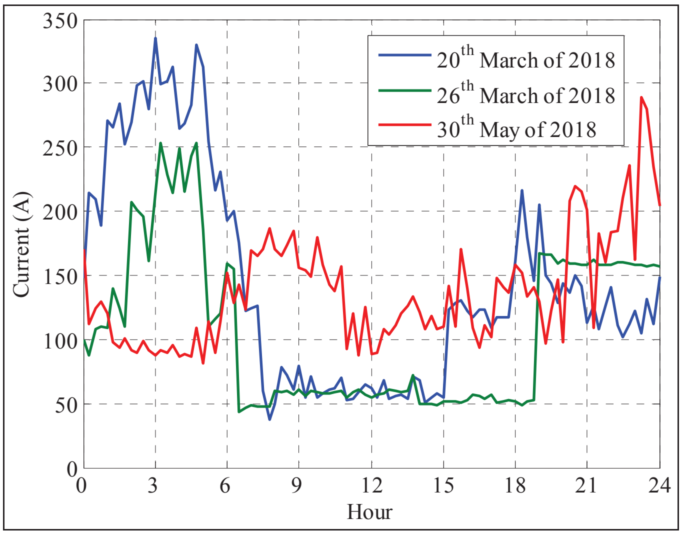

Fig. 2. Time course of the measured RMS current flowing through the Line 1 during days 20th, 26th of March and 30th of May of 2018

In Fig. 3, Fig. 4 and Fig. 5 are shown the measured intensity of the solar irradiance, wind speed and ambient temperature for three analyzed days necessary to calculate the actual temperature of the conductor.

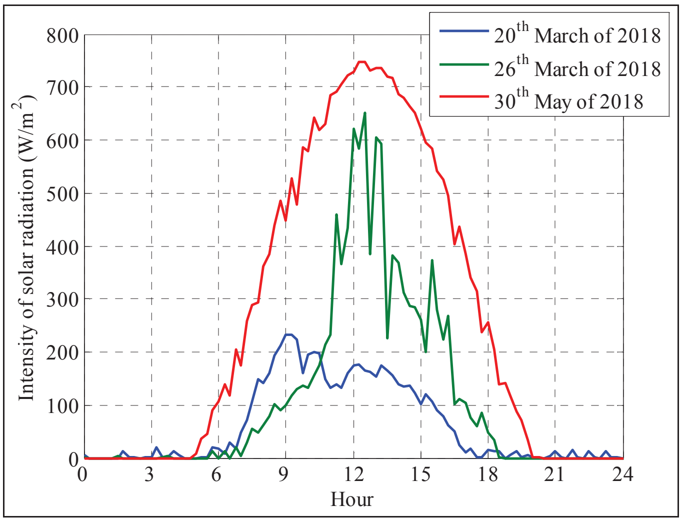

Fig. 3. Time course of the measured intensity of the solar irradiance during days 20th, 26th of March and 30th of May of 2018

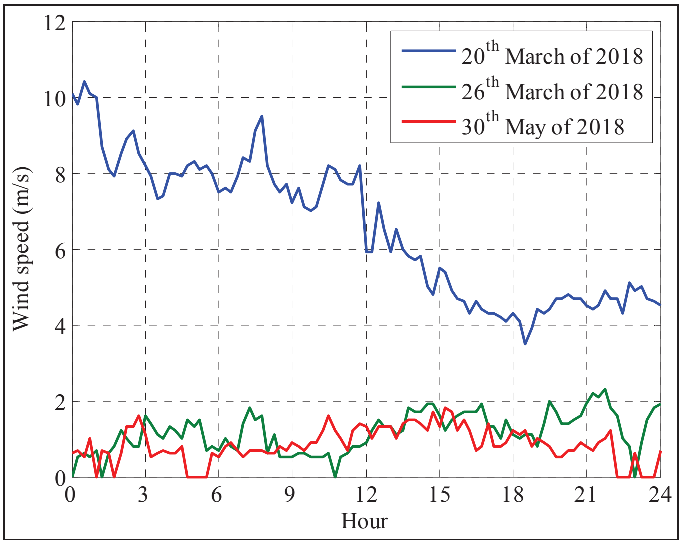

Fig. 4. Time course of the measured wind speed during days 20th, 26th of March and 30th of May of 2018

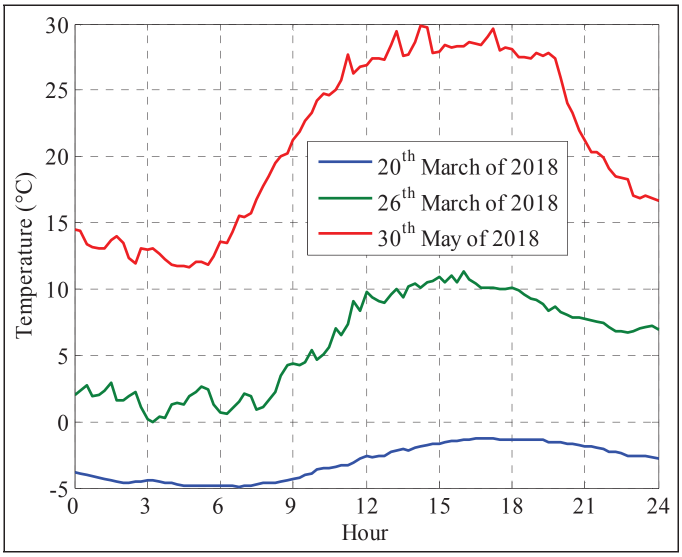

Fig. 5. Time course of the measured ambient temperature during days 20th, 26th of March and 30th of May of 2018

On Fig. 6, Fig. 7 and Fig. 8 it is possible to see comparison of the calculated and measured temperature of two conductors for each analyzed day. Calculated values represent the steady-state temperature of the conductor for each 15th minute of a day, it is possible to see sufficient correlation with measured values from the practical purposes point of view.

Since the wind angle was not available for the data provided, calculations of the conductor's temperature were realized particularly for a 0°, 45° and 90° angle of impact. The best correlation with the measured data was achieved when considering the wind angle of 45°, therefore results presented on Fig. 6, Fig. 7 and Fig. 8 relates to the wind angle of 45° only.

The deviation of the calculated temperature of conductors from the measured values was ranged:

- from –2.5 °C to 2.9 °C for 20th of March (Fig. 6), the mean deviation 0.2 °C,
- from –0.9 °C to 3.4 °C for 26th of March (Fig. 7), the mean deviation 1 °C,
- from –1.7 °C to 5.7 °C for 30th of May (Fig. 8), the mean deviation 3.4 °C.

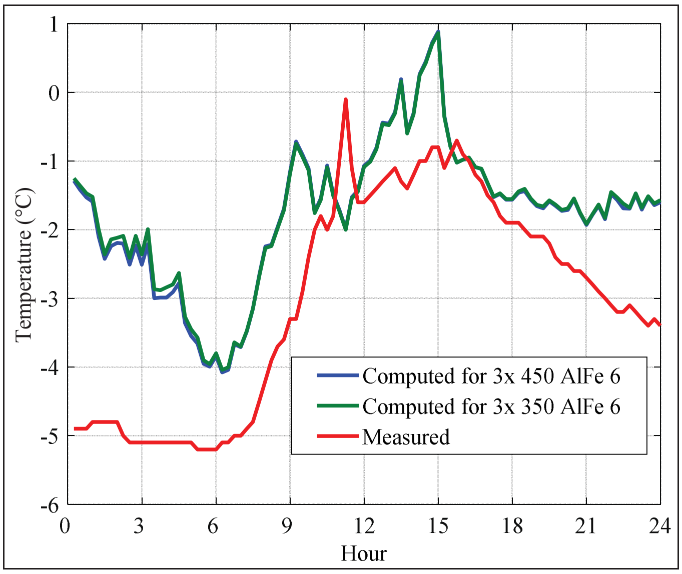

Fig. 6. Comparison between calculated and measured temperature of two conductors (350 AlFe 6 and 450 AlFe 6) with consideration of the wind speed with a 45° angle of impact for 20th of March of 2018

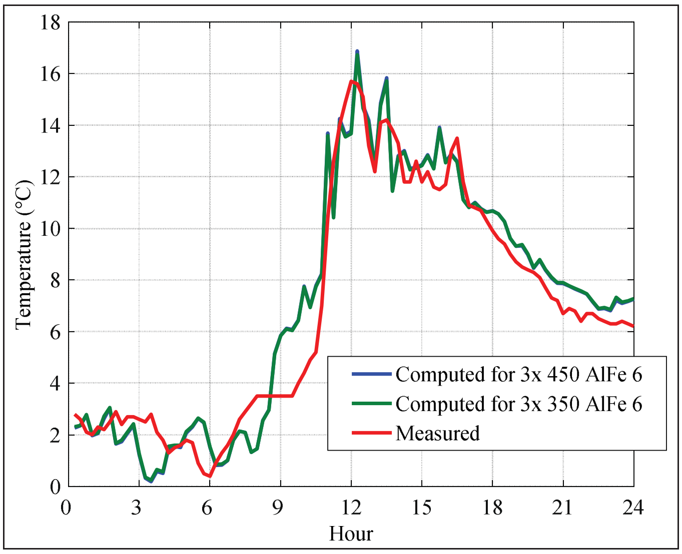

Fig. 7. Comparison between calculated and measured temperature of two conductors (350 AlFe 6 and 450 AlFe 6) with consideration of the wind speed with a 45° angle of impact for 26th of March of 2018

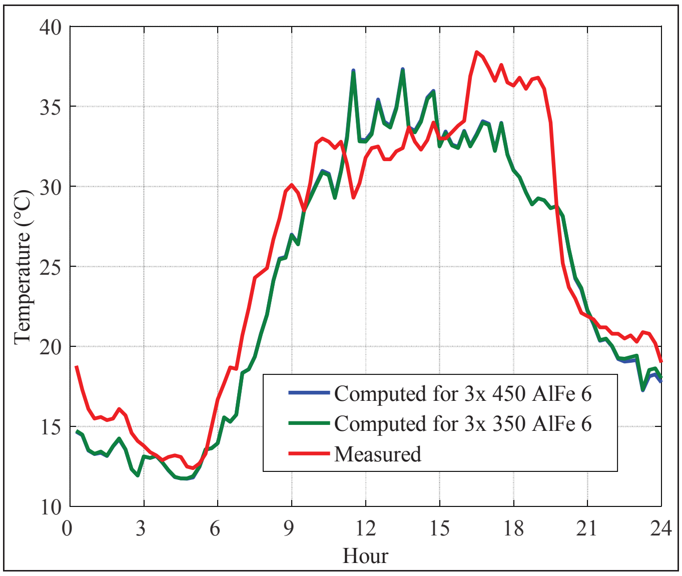

Fig. 8. Comparison between calculated and measured temperature of two conductors (350 AlFe 6 and 450 AlFe 6) with consideration of the wind speed with a 45° angle of impact for 30th of May of 2018

IV. Calculation of the Maximum Allowable Current of ACSR Conductors with and without Consideration of Wind Influence

In this chapter were carried out calculations of maximum allowable current values (to achieve the maximum conductor operating temperature of 80 °C) based on the CIGRE Technical Brochure 207 (the thermal behavior of overhead conductors [11]) described in previous section.

Fig. 9, respectively Fig. 10 shows the time course of maximum allowable RMS current flowing through the Line 1 (for each 15 minutes of a day) with, respectively without consideration of the wind influence for 30 May 2018. All of these values were calculated according to equation (2) to achieve the conductor temperature of 80 °C. Limits marked with the red and magenta lines are used by transmission system operators in the present as summer and winter season current limits (present static ampacity consideration according to [10]).

In the case of 450 AlFe 6 conductor, with consideration of the wind influence (Fig. 9), it is possible to observe that the calculated maximal current was above current limit stated by transmission system operators for the winter season. In the case of 350 AlFe 6 conductor, without consideration of the wind influence (Fig. 10), it is possible to observe that the calculated current was most of the day above current limit stated by transmission system operators for the winter season.

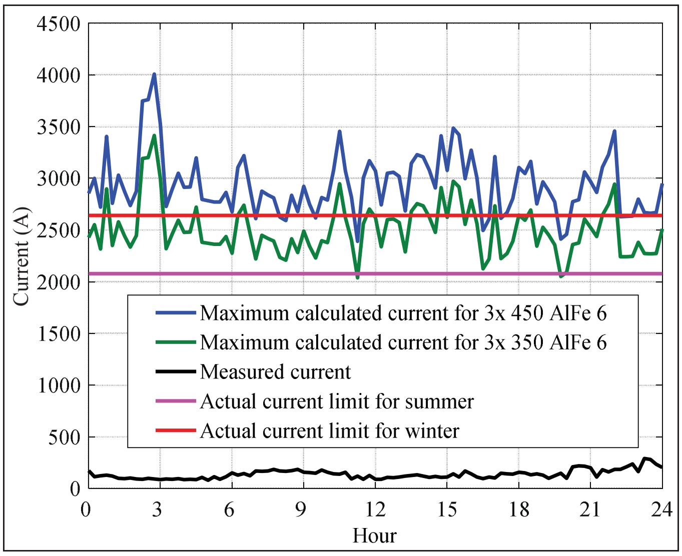

Fig. 9. Time course of the calculated maximum allowable current of two conductors (350 AlFe 6 and 450 AlFe 6) with consideration of the wind influence for 30th of May of 2018

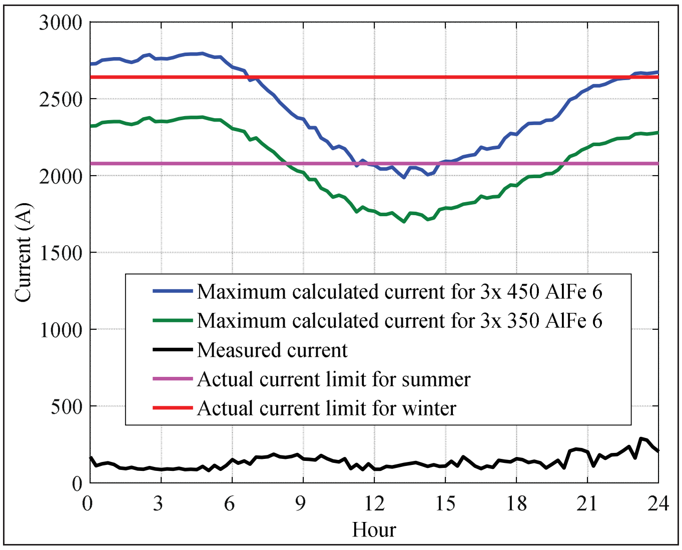

Fig. 10. Time course of the calculated maximum allowable current of two conductors (350 AlFe 6 and 450 AlFe 6) without consideration of the wind influence for 30th of May of 2018

V. CONCLUSION

With increasing demand for electric power it is necessary to transfer that produced electricity to end consumer. One of possibility is to build new overhead power lines, however this approach is economically demanding. Another option is to increase (better use) the ampacity of existing overhead power lines.

In terms of determining the maximum current loads of individual elements of the transmission system, taking into account particular climatic conditions, it can be stated that with the CIGRE Technical Brochure 207 methodology it is possible to determine the maximum current load of ACSR conductors even for 15-minute time interval. The main task of the article was to verify the methodology for calculating the maximum current load of overhead power lines (respectively ACSR conductors), taking into account specific weather conditions, by the comparison of the measured and calculated conductor's temperature. Within this task, the procedure for calculating the maximum current load according to the CIGRE methodology seems to be suitable for maximum available current calculations even for 15-minute time interval.

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