Dynamic Thermal Rating of Overhead Power Line Conductors

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***Abstract*—An overhead power line is a structure used in the electric power system to transmit 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 is focused on the research of steady-state and transient dynamic thermal rating (ampacity) of overhead power line ACSR conductors. This article deals with the thermal behavior of overhead power line conductors taking into account variations in weather conditions or current with time according to CIGRE Technical Brochure 601.**

***Keywords*—overhead power line, ACSR conductor, CIGRE Technical Brochure 601, dynamic thermal rating, ampacity.**

I. Introduction

One of the most important factors that affect power line operation, is the temperature of conductors [1]. If the heat generated by the current flowing exceeds the thermal limit, the conductor will be irreversibly damaged. To avoid power line conductors thermal damage, it is necessary to determine the maximum current that can flow through conductors [2]. Ampacity is the main parameter of the overhead power line design and operation, this value is the maximum amount of electrical current, that can flow through the power line (or conductor) without disturbing its mechanical and electrical properties [3]. Ampacity is determined by mechanical and electrical properties of the conductor, the ability of heat generation within a conductor and ambient conditions [4].

In some transmission power systems, different fixed and weather independent ampacity limits are used for the summer and winter seasons. The set current limits for the summer and winter seasons represent much lower values than the current values that can be loaded to power lines under the actual weather conditions [4]. Dynamic thermal rating (DTR) of transmission lines provides the actual ampacity of overhead lines based on real-time operating (weather/atmospheric) conditions. The main aim of DTR is to increase the ampacity of existing transmission lines, mitigate transmission line congestion, facilitate wind energy integration, enable economic benefits, and improve the reliability performance of power systems [5].

Several industrial standards deal with the calculation of the temperature and ampacity of overhead power line conductors. The most commonly used methods are described in the IEEE Standard for calculating the current-temperature relationship of bare overhead conductors [6], CIGRE Technical Brochure (TB) 207 [7] (2002) and its extended version CIGRE Technical Brochure (TB) 601 [8] (2014). According to Neil Schmidt [9], these methods provide similar results and they can be considered equivalent.

II. Thermal Balance Equations of Overhead Power Lines Calculation Methods

The thermal behavior of overhead power line conductors is based on the thermal balance between the gained and lost heat in the conductor due to the current load and environmental conditions [10]. There are two ways how to calculate the conductor temperature or dynamic thermal rating of overhead power lines [11].

Firstly, the basic thermal balance equation (model) used in steady-state conditions is represented by the quantities/powers on the left side causing the heating of the conductor. The right part of the equation is characterized by quantities/powers causing the cooling of the conductor [8], [12]:

$$P_\mathrm{j} + P_\mathrm{s} + P_\mathrm{m} = P_\mathrm{c} + P_\mathrm{r}\,, \tag{1}$$

where

- P_j is the heating of the conductor by the current flowing (Joule heating, W/m),
- P_s is the heating of the conductor by the sunlight (solar heating, W/m),
- P_m is the heating of the conductor by the magnetic effect (magnetic heating, W/m),
- P_c is the cooling of the conductor by the convection (convective cooling, natural and forced convection, W/m),
- P_r is the cooling of the conductor by the radiation (radiative cooling, W/m).

Secondly, if the thermal inertia of the conductor is considered (both ambient conditions and the current load of the power line vary with time), the following transient thermal balance equation (model) is used [11]:

$$mc\frac{\mathrm{d}T_\mathrm{s}}{\mathrm{d}t} = P_\mathrm{j} + P_\mathrm{s} + P_\mathrm{m} - P_\mathrm{c} - P_\mathrm{r}\,, \tag{2}$$

where

- m is the mass per unit length of the conductor (kg/m),
- c is the specific heat capacity of the conductor (J/(kg·K)),
- $\mathrm{d}T_\mathrm{s}/\mathrm{d}t$ is the conductor temperature time change (°C).

Based on thermal balance equations (1) and (2) two problems can be solved using the steady-state or transient thermal model [12]:

- Calculation of the conductor temperature when the electrical current is known.
- Calculation of the current (steady-state and transient DTR) that yields a given maximum allowable conductor temperature.

III. Comparison of the Temperature Calculated by CIGRE TB 601 with Real Temperature Measurement on ACSR Conductors under Laboratory Conditions

Several temperature measurements were performed for two ACSR conductors (352-AL1/59-ST1A, 429-AL1/52-ST1A). Technical parameters of these ACSR conductors are shown in [12]. Temperature measurements were carried out in a laboratory using simulation without and with the presence of wind (speed 2 m/s at a 90° angle of attack). Ambient temperature was recorded at these measurements, assuming height above sea level of 208 m, intensity of solar radiation of 0 W/m^2. Measurements were carried out from the ambient conductor temperature to the steady-state conductor temperature at different steady-state RMS values of the current flowing through the conductor. One of these measurements for the conductor 352-AL1/59-ST1A and current of 600 A is shown in Fig. 1. In the first step, the conductor temperature was determined without considering the influence of wind. In the second step, the presence of wind was simulated for the same conductor and approximately the same current value [12].

Fig. 2 and Fig. 3 show temperature dependencies on the RMS current flowing through the conductor 352-AL1/59-ST1A at wind speed 0 m/s or 2 m/s, and intensity of solar radiation 0 W/m^2 (calculated according to TB 601 and TB 207). Fig. 2 and Fig. 3 also show the actual measured current and temperature values of the analyzed conductor. Differences between measured and calculated temperature values were also caused by considering only one (average) ambient temperature value (23 °C for no-wind simulation, 24 °C for considering wind influence). Temperature calculation according to TB 207 and TB 601 does not differ too much. The basic equations in these standards (TB) are the same, but TB 601 considers more precise equations for some of the variables needed to calculate the conductor temperature (see [12]).

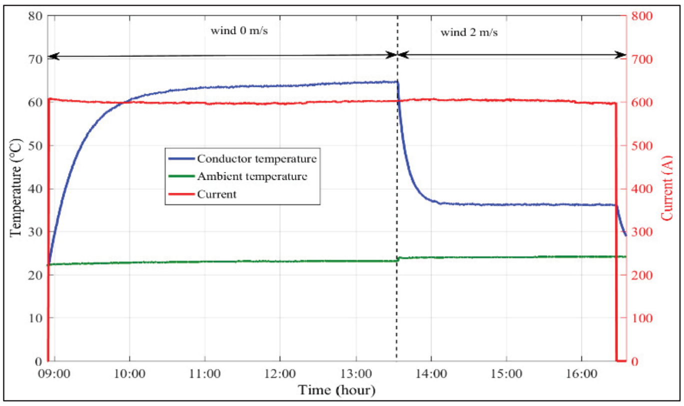

Fig. 1. Current and temperature time variations during real measurement with the conductor 352-AL1/59-ST1A [12].

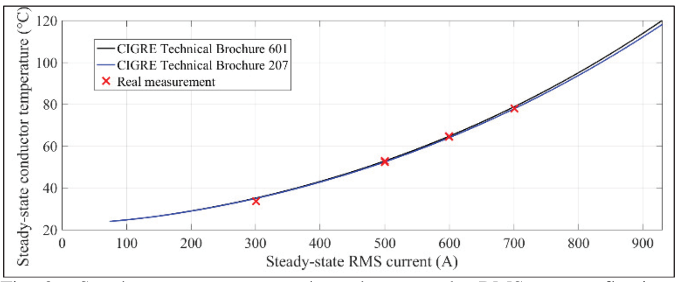

Fig. 2. Steady-state temperature dependence on the RMS current flowing through the conductor 352-AL1/59-ST1A at a wind speed 0 m/s, intensity of solar radiation 0 W/m^2, ambient temperature 23 °C [12].

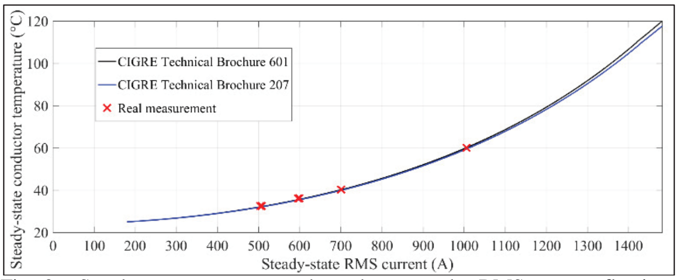

Fig. 3. Steady-state temperature dependence on the RMS current flowing through the conductor 352-AL1/59-ST1A at a wind speed 2 m/s (90° angle of attack), intensity of solar radiation 0 W/m^2, ambient temperature 24 °C [12].

IV. Conclusion

The mathematical description of the impact of climatic conditions on power line conductors (temperature/DTR) is stated in CIGRE TB 601. The main objective of recent research mentioned in this article was to analyze this standard (TB 601) and to determine the conductor steady-state DTR, taking into account actual climatic conditions. The main aim of future research is to examine the transient DTR of overhead power line conductors.

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