Applied Thermal Engineering 111 (2017) 95–102

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Study of different mathematical approaches in determining the dynamic rating of overhead power lines and a comparison with real time monitoring data

P. Castro *, A. Arroyo, R. Martinez, M. Manana, R. Domingo, A. Laso, R. Lecuna

University of Cantabria, Department of Electrical and Energy Engineering, Av. Los Castros s/n, 39005 Santander, Spain

HIGHLIGHTS

- Study of dynamic rating of overhead lines obtained by CIGRE and IEEE standards.
- Results validated with real-time monitoring of an overhead line for more than a year.
- Precise measurements significantly improve the accuracy of estimated temperature.
- An equilibrium between accuracy and mathematical complexity should be reached.

ARTICLE INFO

Article history:
Received 17 June 2016
Revised 14 September 2016
Accepted 15 September 2016
Available online 15 September 2016

Keywords:
Thermal rating
Ampacity
Overhead line temperature
Weather parameters
Real-time monitoring

ABSTRACT

Electricity generation is changing as new, renewable and smaller generation facilities are created, and classic topologies have to accommodate this distributed generation. These changes lead to the creation of smart grids in which advanced generation, information and communication technologies are needed.

Information metering is important, and one of the most important grid parameters to be measured and controlled is the temperature of overhead conductors due to their relation to the maximum allowable sag of the line.

The temperature and current of an overhead conductor and the weather conditions surrounding the cable are measured every 8 min for more than a year. With these data, the accuracies of the different algorithms presented in the standards (CIGRE TB601 and IEEE 738) are studied by implementing them in MATLAB®.

The use of precise measurements of solar radiation and low wind speeds with ultrasonic anemometers, improves the accuracy of the estimated temperature compared with the real measured conductor temperature. Additionally, using dynamic algorithms instead of assuming a steady state analysis increases the accuracy. However, an equilibrium between the accuracy and mathematical complexity should be obtained depending on the specific needs.

1. Introduction

The current needs of global energy management are increasingly challenging due to the fast changes of our society. The electric sector has to address the addition of new and renewable sources of energy to the energy mix and to be able to include them into the grid, while maintaining the principles of robustness, security and reliability. Electricity generation is also changing, and as new and smaller generation facilities are created, classic topologies have to accommodate the distributed generation [1]. On the other hand, energy consumers are moving from being passive to active by increasing their interactions with energy systems. All of these changes point to the creation of smart grids, in which advanced generation, information and communication technologies are needed [2].

Information metering is one of the critical points of these smart grids, and accurate knowledge of the electric grid state and environmental conditions of the surroundings are crucial for operating the line as efficiently as possible [3]. One of the most important grid parameters to be measured and controlled is the temperature of the overhead conductors due to their relation with the maximum allowable sag of the line.

---

* Corresponding author.
E-mail address: pablo.castro@unican.es (P. Castro).

http://dx.doi.org/10.1016/j.applthermaleng.2016.09.081
1359-4311/© 2016 Elsevier Ltd. All rights reserved.

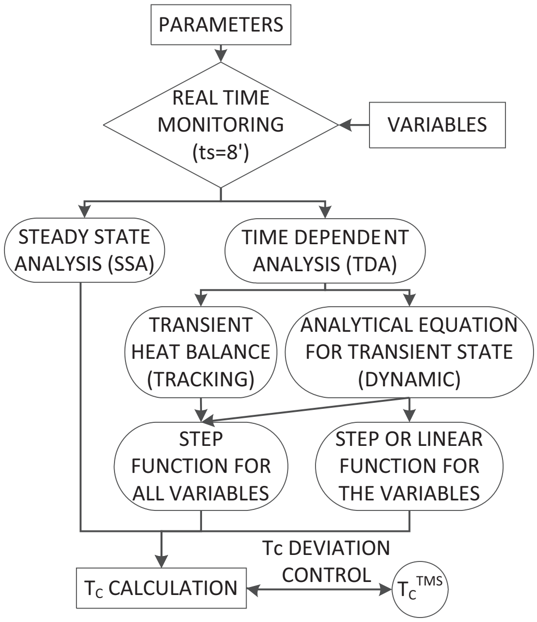

Fig. 1. Flow chart of conductor temperature calculations of electrical overhead lines.

This paper presents the results of real-time monitoring of the environmental conditions, current and temperature of an overhead power line for more than a year and compares these results with the different algorithms presented in the standards CIGRE TB601 and IEEE 738 [4,5] to estimate the thermal rating and temperature of the conductor. This study is focused on the influence of the accuracy of the parameters involved in the thermal rating equations and the way in which they are implemented in the algorithms. The MATLAB® software is used to solve the thermal rating and calculate the temperature of the conductor.

2. Thermal models and mathematical approaches

The thermal behaviour of an overhead conductor is obtained as the balance of gained and lost heat due to the weather conditions around the conductor and its electrical load [6]. The main sources of gained heat come from Joule heating, including magnetic effects, and solar radiation. On the other hand, the principal sources of lost heat are convection and cooling radiation to the surroundings. The detailed expressions that are used to calculate each contribution are obtained from the standard CIGRE Dec. 2014 [4] and explained as follows:

Joule Heating (P_j) The Joule heating gain per unit length for conductors is obtained from:

$$P_j = k_{sk} I^2 R_{dc} \tag{1}$$

where k_{sk} is the skin effect factor, I is the RMS conductor current and R_{dc} is the direct current resistance per unit length.

Magnetic Heating (P_m) A steel-cored conductor causes heating in the steel core (P_{core}) and heating due to the redistribution of the current densities in the layers of non-ferrous wires (P_{redis}).

$$P_m = P_{core} + P_{redis} \tag{2}$$

The magnetic effects are only relevant for steel-cored conductors with one or three aluminium layers and high current densities.

Solar Heating (P_s) The solar heating per unit length is estimated by the standard as:

$$P_s = \alpha_s D I_t = \alpha_s D\left[I_b\left(sin(\eta) + \frac{\pi}{2} F sin(H_s)\right) + I_d\left(1 + \frac{\pi}{2} F\right)\right] \tag{3}$$

Table 1
List of parameters.

Parameters	Description
$D = 0.0218$ m	Outside diameter of conductor
$D_1 = 0.008$ m	Core diameter
$y = 622$ m	Altitude
$\phi = 43°$	Latitude
$\delta_l = 31°$	Line angle
$F = 0.1$	Albedo
$N_s = 1$	Clearness Ratio
$\alpha_s = 0.5$	Absorptivity
$\epsilon_s = 0.5$	Emissivity
$m_s = 0.319$ kg/m	Steel mass per unit length
$m_a = 0.722$ kg/m	Aluminium mass per unit length
$c_{s,20} = 460$ J/kg K	Specific heat capacity of steel at 20 °C
$c_{a,20} = 880$ J/kg K	Specific heat capacity of aluminium at 20 °C
$\beta_s = 1 \cdot 10^{-4}$ 1/K	Temp. coefficient of steel specific heat capacity
$\beta_a = 3.8 \cdot 10^{-4}$ 1/K	Temp. coefficient of aluminium specific heat capacity
$\lambda_a = 240$ W/mK	Aluminium thermal conductivity
$K_{sk} = 1.025$	Skin factor
$R_{20} = 0.1194$ Ω/km	Conductor resistivity per unit length at 20 °C
$\alpha_{20} = 4.1 \cdot 10^{-3}$ 1/K	Linear resistivity coefficient at 20 °C

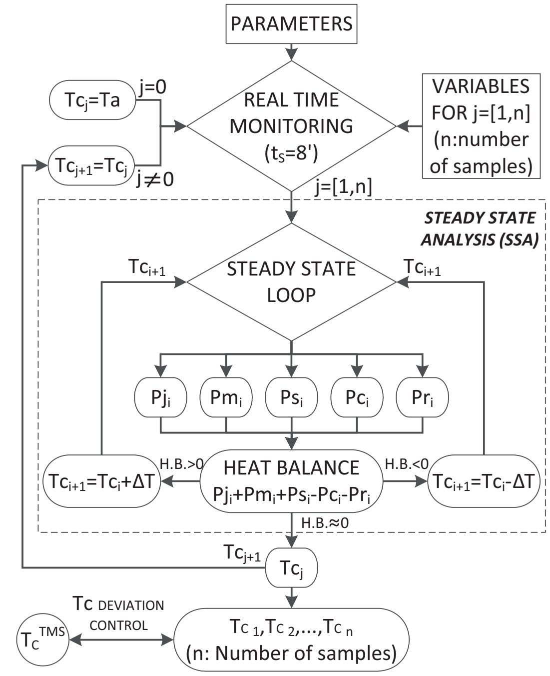

Fig. 2. SSA flow chart.

where α_s is the absorptivity of the conductor surface, I_t is the global radiation intensity, D is the outside diameter of the conductor, η is the angle of the solar beam with respect to the axis of the conductor, F is the albedo, H_s is the solar altitude, I_d is the diffuse sky radiation to a horizontal surface and I_b is the direct solar radiation on a surface normal to the sun's beam. I_t can be estimated by considering the worst case situation using its maximum expected value or can be directly measured with a pyranometer.

Convective Cooling (P_c) The convective heat loss can be expressed as a function of the dimensionless Nusselt number (Nu) as follows:

$$P_c = \pi \lambda_f (T_s - T_a) Nu \tag{4}$$

where λ_f is the thermal conductivity of air, T_s is the conductor surface temperature and T_a is the ambient temperature. Depending on the type of air flow and speed and direction of wind, different Nusselt correlations are used by the standard.