

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/228887870>

# Numerical study of the thermal behaviour of bare overhead conductors in electrical power lines

Article · January 2011

CITATIONS

13

READS

616

5 authors, including:



**J.M. García De María**

Universidad Politécnica de Madrid

131 PUBLICATIONS 923 CITATIONS

[SEE PROFILE](#)



**Abderrahmane Bairi**

Université Paris Ouest Nanterre La Défense

137 PUBLICATIONS 1,462 CITATIONS

[SEE PROFILE](#)



**Ricardo Granizo**

Universidad Politécnica de Madrid

24 PUBLICATIONS 92 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Integrated Design for flood resilience [View project](#)

# Numerical study of the thermal behaviour of bare overhead conductors in electrical power lines

F. ÁLVAREZ GÓMEZ<sup>(1)</sup>, J.M. GARCÍA DE MARÍA<sup>(2)</sup>, D. GARCÍA PUERTAS<sup>(1)</sup>,  
A. BAÏRI<sup>(3)</sup>, R. GRANIZO ARRABÉ<sup>(1)</sup>

<sup>(1)</sup>Department of Electrical Engineering, <sup>(2)</sup>Department of Applied Physics  
E.U.I.T. Industrial, Universidad Politécnica de Madrid  
Ronda de Valencia 3 - 28012, Madrid  
SPAIN

<sup>(3)</sup>Laboratoire de Thermique Interfaces Environnement  
Département Génie Thermique et Energie; LTIE-GTE EA 4415  
Université Paris Ouest. 50, Rue de Sèvres, F-92410 Ville d'Avray  
FRANCE

e-mail: fernando.alvarez@upm.es, juanmario.garcia@upm.es, daniel.gpuertas@upm.es,  
abairi@u-paris10.fr, ricardo.granizo@upm.es,

*Abstract:* In order to optimize and increase the current carrying capacity of HV electrical overhead lines it is of great importance to analyze the thermal behaviour of the conductors under different operating conditions. This information will help to solve specific high demand or emergency situations ensuring that maximum temperature limits are not exceeded. In the present work the thermal behaviour of bare electrical conductors under different load and environmental conditions is analyzed by numerical simulation. A comparison between different calculation methods to determine the service temperature of these type of lines is also presented. The coincidence of the results for the different cases studied is remarkable, proving the validity and usefulness of the numerical method.

*Key words:* electrical power lines, bare overhead conductors, heat transfer, thermal behaviour, service temperature, numerical simulation, finite volume method.

## 1 Introduction

The demand of electrical energy supply is growing up continuously, therefore there is a need to increase the amount of power transmitted through electricity transmission and distribution lines. Considering environmental and economical aspects, the optimal solution for rising the power supply consists of increasing the capacity of new and existing electrical power lines.

The calculation of current carrying capacity of electric lines has been widely treated in the literature and is the subject of international standards.

Several research works deal with analytical and numerical methods for assessing the capacity and temperature rise of cables laid in ground, as in [1-5].

Overhead lines consisting of diverse bare conductors have also been treated in several studies including methods for increasing the rating (see [6-10]). Recently, Kopsidas and Rowland [11] have considered the effect of the increase in operating

temperature on the current carrying capacity, losses and sag and have evaluated the possibilities of increasing the power capacity of existing overhead lines. The capacity of these lines, especially short ones, depends on the maximum temperature allowed for a specific conductor in working conditions, assuming that the joint sleeves and joint compression clamps are in good conditions.

The conductor temperature depends on the load current through the cable, on the electrical characteristics of the conductor and on the weather conditions (sun, wind, ambient temperature, ice, etc.); some of these elements have been considered in the present study. The maximum temperature of a conductor determines the smaller allowed clearance and the maximum allowed losses of tensile force throughout the lifetime of the power line.

## 2 Problem Formulation

During the fulfilment of an electrical project for the installation of a new transmission or distribution overhead line, or for the extension of

an existing one, it is essential the knowledge of the thermal behaviour of the high voltage bare conductors [12] [13].

Two different types of procedures have been considered in this study, for the calculation of the maximum service temperature of an overhead power line under different working conditions.

- Analytical and empirical thermal equations together with an iterative resolution technique [14] [15].

- Numerical method based on finite volume resolution technique.

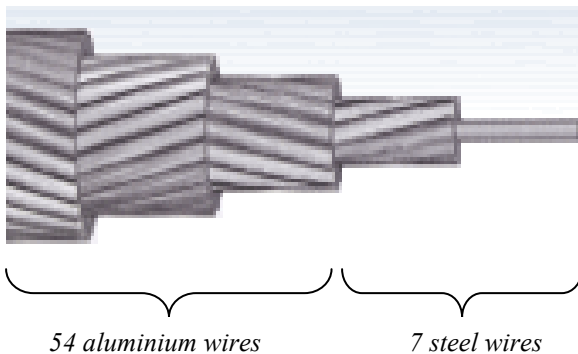
With the first method, the technical calculation procedures provided by the technical Cigré brochure [14] and the suitable IEEE Std [15], have been implemented in order to calculate the current temperature of bare overhead conductors.

The numerical study is performed with the help of the commercial code FLUENT-ANSYS that combines CFD with energy equations to solve complex heat transfer problems, comprising conduction, convection and radiation like in this case.

## 2.1 Type of cable studied and practical cases considered

For the thermal study, an aluminium steel standard cable has been selected. Dimensions and characteristics are as follows [16]:

- Cable code: 429-AL1/56-ST1 A.
- Type of conductor: 428-A1/S1A-54/7 “Zebra”.
- Total diameter: 28.6 mm.
- Diameter of aluminium and steel wires: 3.18 mm.
- Diameter of the steel core: 9.54 mm.
- DC Resistance (20 °C): 67.4  $\mu\Omega/\text{m}$ .



A few practical cases of the many considered, specifying the current load through the cable, the electrical characteristics of the conductor and the weather conditions are presented in Table 1.

Table 1. Practical cases considered.

CASE	1	2	3	4	5
Current (A)	600	970	600	650	600
Solar radiation (W/m <sup>2</sup> )	980	980	980	980	980
Height above sea level (m)	1600	1600	1600	1600	300
Ambient temperature (°C)	40	40	40	40	40
Angle of incidence of the wind (°)	90	90	90	90	90
Wind speed (m/s)	2	2	0,2	0,4	2
Absorption coefficient	0,5	0,5	0,5	0,5	0,5
Emissivity coefficient	0,5	0,5	0,5	0,5	0,5

## 3 Problem Solution

In order to implement the mathematical developments proposed by Cigré and by IEEE Std 738-2006 for the calculation of temperatures reached in overhead lines, the mathematical programme Mathcad and an iterative calculation method are used. For the finite volume method, the ANSYS DesignModeller software has been used to implement the geometrical model and the FLUENT-ANSYS [17] code to solve the governing equations and calculate the resultant steady-state temperature in the studied wires.

### 3.1 CIGRÉ Method. Calculation of Case 1

This method considers the heat balance equation:

$$P_J + P_M + P_S + P_i = P_c + P_r + P_w$$

Being  $P_J$ =Joule heating,  $P_M$ =magnetic heating,  $P_S$ =solar heating,  $P_i$ =corona heating,  $P_c$ =convective losses,  $P_r$ =radiative losses, and  $P_w$ =evaporative losses.

Each term is evaluated as follows

$$I_{dc} = I_{ac} \cdot \sqrt{1.0123 + 2.36 \cdot 10^{-5} \cdot I_{ac}}$$

Joule effect losses.

$$P_J = I_{dc}^2 \cdot R_{dc} \cdot [1 + \alpha \cdot (T_s - 20)]$$

Solar heating

$$P_s = \alpha_s \cdot S \cdot D$$

Harshness of the conductor surface

$$R_f = \frac{d}{2 \cdot (D-d)}$$

Convection losses

$$P_c = \pi \cdot \lambda_f \cdot (T_s - T_a) \cdot Nu_\delta$$

Being the Nusselt number calculated according to equations (13) to (15) in [14].

Radiation losses

$$P_r = \pi \cdot D \cdot \varepsilon \cdot \sigma_B \cdot [(T_s + 273)^4 - (T_a + 273)^4]$$

After opportune convergence the temperature in the cable for Case 1 is  $T_s=56.1$  °C, and the resultant numerical values, for heat balance are (with  $P_M=P_i=P_w=0$ ).

$$P_J + P_M + P_S + P_i = 42.427 \text{ W/m}$$

$$P_c + P_r + P_w = 42.487 \text{ W/m}$$

The temperature in the centre of the cable core according to equation (9) in [14] results 1.2 °C higher than in the external part of the cable.

Convergence temperatures for the rest of cases are given in table 3.

Table2. Physical data adopted.

$R_{dc}$ ( $\Omega/m$ )	Al temp. coeff. ( $K^{-1}$ )	Conductivity of the air (W/m K)	Relative air density	Kinematics viscosity of the air ( $m^2/s$ )
6.74E-5	3.9E-3	$2.42E-2+7.2E-5 \cdot T_i$	$e^{-1.16E-4 \cdot y}$	$1.32E-5+9.5E-8 \cdot T_i$

### 3.2 IEEE Method. Calculation of Case 1

The density, thermal conductivity and kinematic viscosity of the air are given by the equations (12) to (14) in [15].

The resistance has been calculated according to equation (10) in [15].

Convection losses at low and high wind speeds are respectively

$$q_{c1} = [1.01 + 0.0372 \cdot (\frac{D \cdot \rho_f \cdot V_w}{\mu_f})^{0.52}] \cdot k_f \cdot K_{angle} \cdot (T_c - T_a)$$

$$q_{c2} = [0.0119 \cdot (\frac{D \cdot \rho_f \cdot V_w}{\mu_f})^{0.6}] \cdot k_f \cdot K_{angle} \cdot (T_c - T_a)$$

For these two equations the maximum value has been used.

Radiation losses

$$q_r = 0.0178 \cdot D \cdot \varepsilon \cdot [\left(\frac{T_c + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4]$$

Solar heating.

$$q_s = \alpha \cdot Q_{se} \cdot \sin(\theta) \cdot A'$$

For Case 1, the heat terms of the balance equation are:

$$q_c + q_r = 39.552 \text{ W/m}$$

$$q_s + I^2 \cdot R(T_c) = 39.352 \text{ W/m}$$

Being  $I^2 \cdot R$ =Joule heating,  $q_s$ =solar heating,  $q_c$ =convective losses and  $q_r$ =radiative losses.

The temperature obtained after convergence in this case is  $T_c=54.6$  °C. Temperatures for the rest of the cases are given in table 3.

### 3.3 Finite Volume Method.

A numerical simulation study of the heat transfer phenomena taking place between the conductor and the environment is performed. We work on a 3D model of a cable immersed into air to which it exchanges heat by convection and radiation. The model also considers internal energy sources (Joule dissipation) in the steel core and in the layer-strand aluminum given by

$$P_J = I_{dc}^2 \cdot R_{dc} \cdot [1 + \alpha \cdot (T_s - 20)]$$

The meshing of the domain (shown in figure 1) is done with the ANSYS Mesh utility and the physical modeling is solved by using FLUENT [17]. The mesh is finer near the solid-fluid interface to take into consideration the viscous effects and to adequately reproduce the convective transfer between the surface of the cable and the environment. The size of the mesh is also optimized in order to minimize the computing time but simultaneously to obtain mesh-size independent solutions. After preliminary solution, refinement of the size mesh is done in the areas of greatest thermal gradient. Laminar regime is assumed to describe the fluid flow given the low Reynolds numbers involved. The viscosity and density of the air are calculated at the temperature of each elementary cell. The convergence is considered achieved when the difference between two successive iterations is less than  $10^{-4}$  for the velocity components and  $10^{-7}$  for energy. The boundary conditions are: known velocity and temperature of the incident air, known solar radiation heat flux on the cable surface,

$$-\lambda \left( \frac{\partial T}{\partial r} \right)_{r=D/2} = h(T_a - T) + q_s \quad (q_s = 0 \text{ for } \pi \leq \varphi \leq 2\pi)$$

The simulation provides, among other relevant information, a complete mapping of temperature and velocity, the convective heat fluxes at the surface of the cable, local values of Re and Nu numbers and local and average values of the heat convection coefficient  $h$ . These values are in good agreement with those provided by the other two methods using empirical expressions.

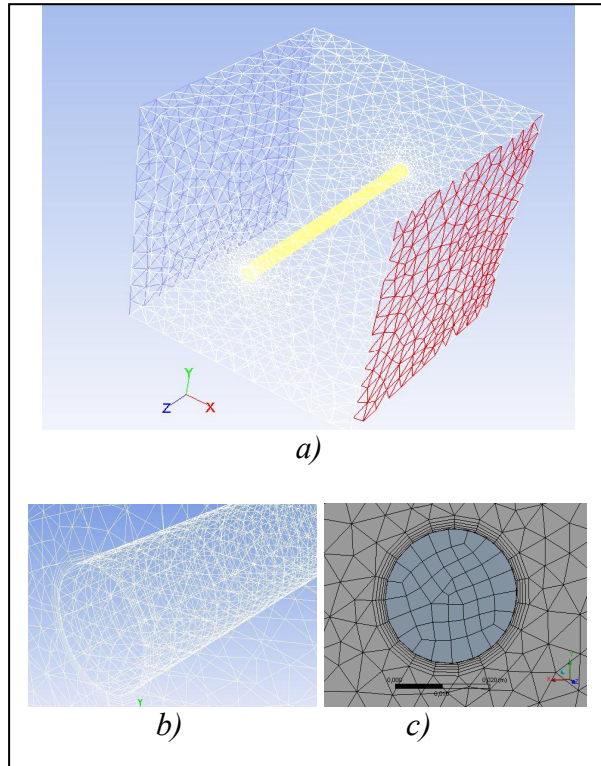


Figure 1. a) Mesh of the 3D model, b) part of the conductor and fluid, c) detail near the conductor-air interface.

## 4 Results

Temperatures calculated for the cables in the five cases are indicated in Table 3 and depicted in Fig.2. Differences with respect to the values obtained with Cigré procedure are given in Table 4

Table 3. Mean temperature reached by the conductor in the 5 practical cases considered.

CASE	1	2	3	4	5
CIGRÉ	56,1	75	78,8	74	55,7
IEEE	54,6	72,3	78,2	73,6	53,3
Numerical simulation	55	73	80	76	54
Current (A)	600	970	600	650	600
Wind speed (m/s)	2	2	0,2	0,4	2

Table 4. Percentage difference of the results with respect to those obtained with the Cigré method.

CASE	1	2	3	4	5
CIGRÉ (°C) Reference	56,1	75	78,8	74	55,7
IEEE (%)	2,67	3,6	0,76	1,87	4,31
Numerical simulation(%)	1,96	8	4,06	1,33	1,26

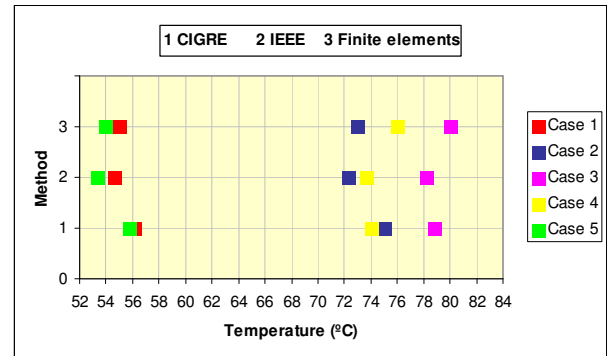


Figure 2. Temperatures of the conductor obtained with the three methods.

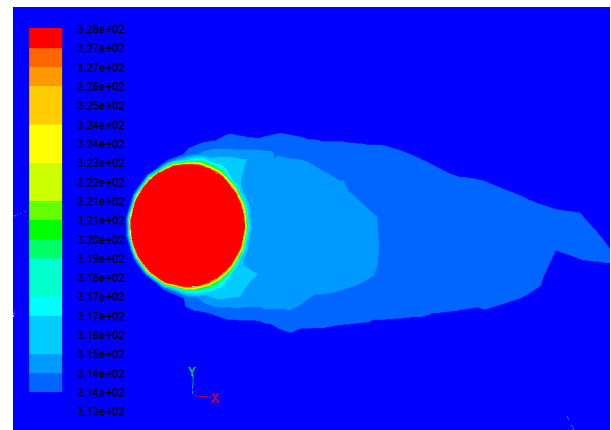


Figure 3. Distribution of temperatures in the conductor and the surrounding air obtained with Fluent-Ansys in case 1. Wind speed = 2m/s.

## 5 Conclusion

The results obtained with the proposed calculation methods, allow characterizing the thermal behaviour of transmission and distribution lines for different operation conditions, and provide the temperature reached by the conductors under different load regimes and weather conditions.

In addition, the comparison between the different results obtained for each case studied, has proved that the final temperature obtained with the three methods is very similar (with a deviation of less than an 8% obtained in the worst of the cases). The

coincidence in the results is better for low wind speeds.

Finally, the implementation of a simulation method based on the finite volume methods means, once the method is implemented, a valid and complete way to characterize the thermal behaviour of an overhead line, increasing the possibilities of calculation under many different load and external conditions.

### References

- [1] Anders G. J. *Rating of Electric Power Cables in Unfavorable Thermal Environment.*, 2005, Wiley-IEEE Press
- [2] Deb A.K. *Power line ampacity system: theory, modeling, and applications.* New York: CRC Press; 2000.
- [3] Nahman J., Tanaskovic M. *Determination of the current carrying capacity of cables using the finite element method*, Electric Power Systems Research 61, 2002, 109–117
- [4] Al-Saud M.S., El-Kady M.A., Findlay R.D., *A new approach to underground cable performance assessment*, Electric Power Systems Research 78 (2008) 907–918
- [5] M.A. Hanna, A.Y. Chikhani, M.M.A. Salama, *Thermal analysis of power cables in multi-layered soil. I. Theoretical model*, IEEE Trans. Power Delivery 8 (1993) 761–771.
- [6] Davis, M. W., *A new thermal rating approach: the real time thermal rating system for strategic overhead transmission lines, Part IV.* IEEE Transactions on Power Apparatus and Systems, vol. PAS-99, 1980, pp. 2184-2192
- [7] Black, W. Z. and Byrd, W. R., *Real-time ampacity model for overhead lines*, IEEE Transactions on Power Apparatus and Systems, vol. PAS-102, No. 7, 1983, pp. 2289-2293.
- [8] Black, W. Z. and Rehberg, R. L., *Simplified model for steady-state and real-time ampacity of overhead conductors*, IEEE Transactions on Power Apparatus and Systems, vol. 104, 1985, pp 29-42.
- [9] Saied M. M. *Assessing the dynamic rating of overhead transmission lines*, European Transactions on Electrical Power Volume 17, Issue 5, 2007, pp 526–536,
- [10] Albizu, I., Mazon, A.J., Zamora, I. (Eds.): *Methods for increasing the rating of overhead lines*, Power Tech, 2005 IEEE, Russia, 2005
- [11] Kopsidas K., Rowland S.M., *Evaluating opportunities for increasing power capacity of existing overhead line systems*, IET Gener. Transm. Distrib., 2011, Vol. 5, Iss.1, pp. 1-10.
- [12] Overhead electrical lines exceeding AC 45 kV. Part 1: General requirements. Common specifications. EN 50341–1, European Standard. October 2001.
- [13] Reglamento sobre condiciones técnicas y garantías de seguridad en las líneas eléctricas de alta tensión. ITC-LAT-07. Ministerio de Industria, España. Ed. Creaciones Copyright, Madrid 2009.
- [14] *Brochure on thermal behaviour of overhead conductors.* Cigré Study Committee 22 Working Group 12. September 2001.
- [15] *IEEE Standard for calculating the current-temperature of bare overhead conductors.* IEEE Std 738-2006. Transmission and Distribution Committee of the IEEE Power Engineering Society.
- [16] *Conductors for overhead lines. Round wire concentric lay stranded conductors.* EN 50182, European Standard. May 2001.
- [17] <http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/ANSYS+FLUENT>.