MODELING OF AC BUSBAR CONTACTS

Ioan POPA* and Alin-Iulian DOLAN*

* University of Craiova, Faculty of Electrical Engineering, 107 Decebal str., Craiova
200440, Romania, E-mail: ipopa@elth.ucv.ro, adolan@elth.ucv.ro

Abstract. The paper presents a 3D magneto-thermal numerical model which can be used for the modeling and optimization of high currents busbar contacts for AC. The model is obtained by coupling of the magnetic model with the thermal field model. The coupling is carried out by the source term of the differential equation which describes the thermal field. The model allows the calculation of the space distribution of the electric and magnetic quantities (magnetic flux density, magnetic field, electric field and the current density) and of the thermal quantities (the temperature, the temperature gradient, the Joule losses and heat flux). A heating larger than that of the busbar appears in the contact zone, caused by the contact resistance. The additional heating, caused by the contact resistance is simulated by an additional source injected on the surface of contact, which is calculated using a model of contact resistance. The 3D model has been solved by the finite elements method in Flux software. The model was experimentally validated. Using the model, one can determine the optimal geometry of dismountable contact for an imposed limit value of the temperature.

Keywords: Numerical modeling, Coupled problems, Finite element method, Busbar contacts.

INTRODUCTION

The optimization of the busbar contacts (Fig. 1) for high currents (1000 – 4000 A), used in the design of electrical equipment in metal envelope, is possible by solving a coupled magnetic and thermal problem. The dismountable contact of a system of busbars has a non-uniform distribution of current density on the cross-section of the current leads in the contact region.

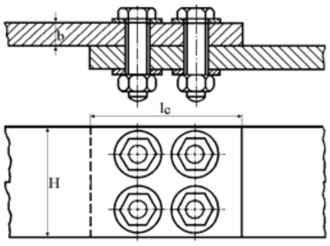

Figure 1. Typical Busbar Contact

NUMERICAL MODEL

The mathematical model used for obtaining the 3D numerical model has two components, the magnetic model and the thermal model, coupled by the source term, which varies according to the temperature.

Magnetic Model

The magnetic model is governed by a 3D model described by the equation for magnetic vector potential in harmonic hypothesis:

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \underline{\vec{A}} \right) + j\sigma\omega \underline{\vec{A}} = \underline{\vec{J}}_s . \tag{1}$$

where μ - the permeability, σ - the electric conductivity and $\underline{\vec{J}}_s$ - the source current density.

Thermal Model

The thermal model is governed by the thermal conduction equation in transient state:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda(T) \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y}\left(\lambda(T) \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z}\left(\lambda(T) \frac{\partial T}{\partial z} \right) + S(T) . \tag{2}$$

where λ - the thermal conductivity, ρ - the mass density.

The coupling between magnetic and thermal equation is realized trough power density $S(T)$ expresed by:

$$S(T) = j\omega^2 \sigma(T) \underline{\vec{A}}\underline{\vec{A}}^* . \tag{3}$$

where $\underline{\vec{A}}^*$ represent the complex conjugate of unknown $\underline{\vec{A}}$.

BOUNDARY CONDITIONS

The magneto-thermal analysis is performed by FEM using the governing equations (1) and (2) and the following boundary conditions:

$$A = 0 , \quad -\lambda \frac{\partial T}{\partial n} = h(T - T_\infty) . \tag{4}$$

where h - the convection coefficient, T_∞ - the ambient temperature.

NUMERICAL RESULTS AND EXPERIMENTAL VALIDATION

The 3D model was obtained using the software Flux 3D by coupling the AC Magnetics problem at 50 frequency of 50 Hz with the transient thermal problem [8].

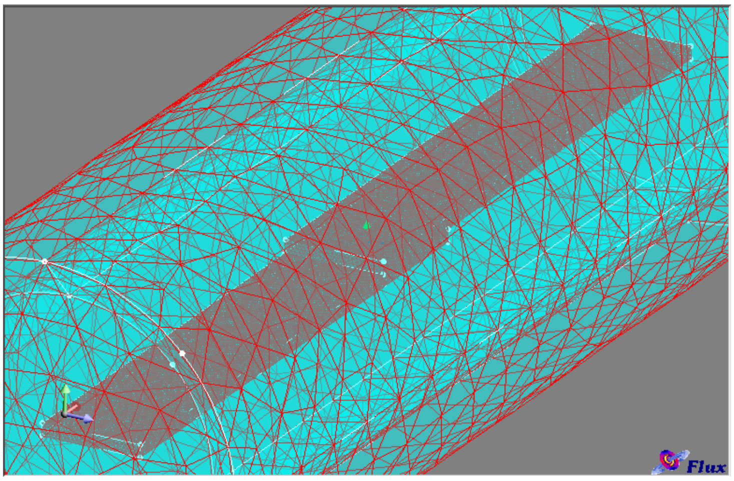

Figure 2. 3D mesh (269137 elements).

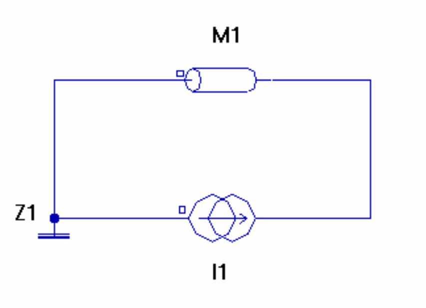

Figure 3. Electric circuit of busbar contact.

The mesh was realised using first order tetrahedral elements (Fig. 2). The injected current in busbar was modeled by a current source connected to a solid conductor using the module of electric circuits of Flux 3D (Fig. 3).

The Fig. 4, 5 and Fig. 7-9 present some numerical results and the experimental results are shown in Table 1.

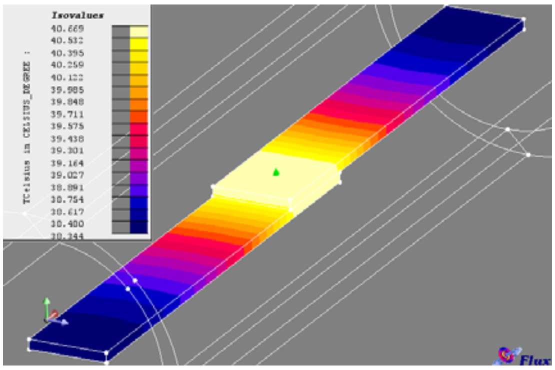

Figure 4. Temperature distribution in the contact region (in °C).

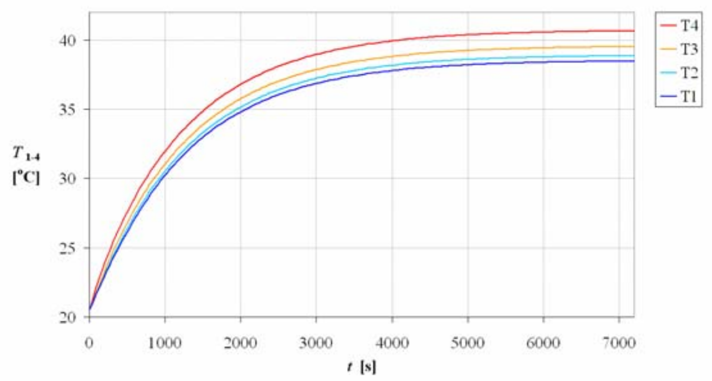

Figure 5. Time evolution of temperature in fixed points.

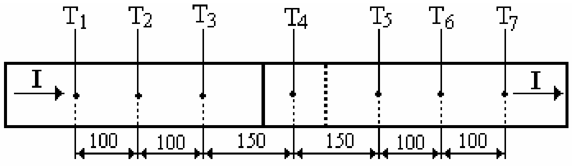

Figure 6. Points of temperature measurement.

Table 1. Experimental results

Point	T_1	T_2	T_3	T_4	T_5	T_6	T_7
T [°C]	38.2	38.7	39.7	39.9	39.6	38.6	38.2

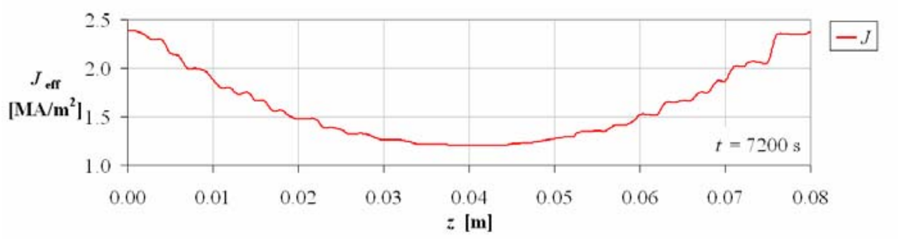

Figure 7. Transversal distribution of current density.

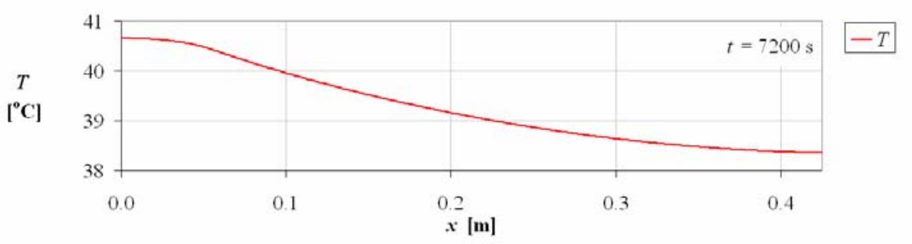

Figure 8. The distribution of temperature along the half busbar.

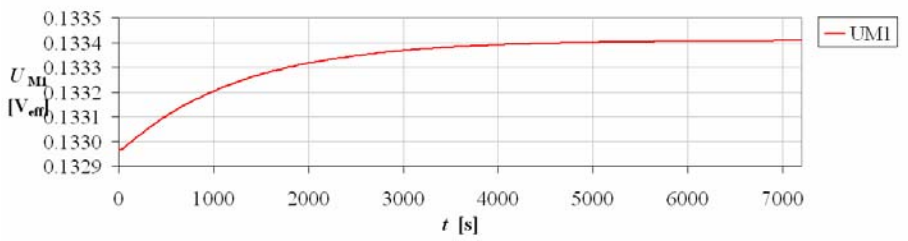

Figure 9. Time evolution of electromotive force on the bar system.

The numerical temperature field in busbar system (Fig. 4) was experimentaly validated (Table 1) in seven points ($T_1 - T_7$, Fig. 6). The relative error in point T_4 is $1.92\,\%$. The time evaluation of calculated temperature in the points $T_1 - T_4$ is presented in Fig.5 and in Fig. 7 – 9 are presented, respectively, transversal distribution of current density, the distribution of temperature along the half busbar, and the time evolution of electromotive force on the bar system.

CONCLUSIONS

The presented model can be used for the optimization of the current leads of high currents with variable cross-section, such as the dismountable contacts of busbar. Numerical model created allows evaluation of the maximum temperature in the contact area as a function of the tightening force of the dismountable contact.

ACKNOWLEDGEMENTS

The authors wish to thank the CEDRAT Groupe (France) kindly enough to make available for a month and half a software license of FLUX through which we obtained the 3D results presented in this article.

REFERENCES

[1] G. Meunier. *Electromagnétisme et problèmes couplés*. Hermes Science, Paris, 2002.

[2] I. Popa, I. Cautil, D. Floricau. Modeling and Optimization of High Currents Dismountable Contacts. WSEAS Transaction on Power Systems, Issue 9, Volume 1, 2006, pp. 1641 - 1646.

[3] Gh. Hortopan. *Aparate electrice de comutație* (in Romanian). Editura Tehnică, Bucureşti, 1993.

[4] S. Schofy, J. Kindersberger, H. Lobl. Joint Resistance of Busbar-Joints with Randomly Rouggh Surfaces. Procedings of 21th Conference on Electrical Contacts (Zurich), 2002, pp. 230 - 237.

[5] Z. Feng, S.S. Babu, M.L. Santella, B.W. Riemer, J.E. Gould. An Incrementally Coupled Electrical-Thermal-Mechanical Model for Resistance Spot Welding. Procedings of 5th International Conference on Trends in Welding Research, (Pine Mountain, GA, 1-5 June), 1998. pp. 1 - 6.

[6] I.Popa, A.I Dolan. Numerical Modeling of DC Busbar Contacts. Facta Universitatis (NIS) Serie: Elec. Energ. vol. 24, no. 2, August 2011, pp. 209-219.

[7] P. Lall, Shinde Darshan; B. Rickett, J. Suhling. Finite element models for simulation of wear in electrical contacts. 11th Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, ITHERM 2008, pp. 836 – 841.

[8] CEDRAT Groupe. *Flux 10.3, Guide d'utilisation – volume 3, Les applications physiques*. 2009.