



High Temperatures Impact on the Performances of Electrical Machines

Guerroudj Cherif, MENANA Hocine, TAKORABET Nouredine

Université de Lorraine, GREEN, F-54000 Nancy, France

Abstract –In this work, a detailed investigation is conducted on the influence of temperature on the performances of electrical machines operating under high-temperature conditions. The analysis is carried out on a synchronous reluctance motors (SyRM) using advanced magneto-thermal modeling, which accurately considers the influence of temperature on the electromagnetic and thermal behaviors of the machine. The strategy integrates both the magnetic non-linearity and the temperature-dependency of the electromagnetic and thermal properties of the materials. The numerical modeling is coupled to the circuit equations to consider voltage power supplies. The results highlight the efficacy and the performances of the developed electromagneto-thermal modeling approach.

Keywords -Electrical machines, High temperature, Electro-magneto-thermal modeling.

1. Introduction

Following the energy transition aiming to develop greener systems, the electrification of power chains is essential and is now widespread in all sectors, facing requirements on volume and weight in embedded systems leading to an increase in power densities and sometimes a cohabitation of the electrical systems with elements imposing high temperatures [1]. These unusual conditions change the design dogmas, requiring the consideration of coupled thermal and magnetic phenomena. Indeed, the design process necessitates magneto-thermal modeling considering the electromagnetic and thermal behaviors of materials under high-temperature conditions [1-11].

Electromagnetic and thermal phenomena develop in very different ways in both space and time, making this type of modeling complex and often computationally intensive, which is not in favor of design and optimization process. In some cases, it is necessary to locally synchronize the evolution of electromagnetic and thermal quantities [12], introducing additional constraints on the spatiotemporal discretization of the problem, as the spatial step is tied to the temporal step in time-domain numerical modeling. Since thermal phenomena evolve much more slowly than electromagnetic ones, a weak coupling strategy is typically used in this type of modeling. Structural complexity and movement add further challenges when magneto-thermal modeling is applied to electrical machines. Specific modeling strategies must be employed in such cases to achieve the best balance between accuracy and computation time, depending on the desired outcomes. The finite element method (FEM) is better suited for this type of modeling compared to analytical or semi-analytical (lumped parameter) methods, thanks to its ability to manage complex geometries and nonlinearities. In this context, this work presents a simplified magneto-thermal modeling approach for a switched synchronous reluctance machine operating at high temperatures. This type of machine offers several advantages such as robustness, which makes it widely used in embedded systems [1].

In the literature, the most commonly used strategy for modeling electrical machines operating at high temperatures, while accounting for magnetic and thermal phenomena, is the model in which the current density is imposed without any coupling with the external electrical circuit. This strategy simplifies the modeling process because it does not take into account the complexity of the overall electrical behavior of the system the interactions between the machine and the power supply circuit are not fully considered.

In this work, the strategy consists of modeling and numerically solving the magneto-thermal model considering the interactions between the machine and the power supply circuit (Fig.1). This approach is more complex because it integrates the interactions between the machine and the power system. The model must thus solve both the equations of the circuit and those of the machine, which increases the accuracy of the results, but also the computational load. Thus, the modeling strategy developed in this paper is specifically designed to reduce computation time.

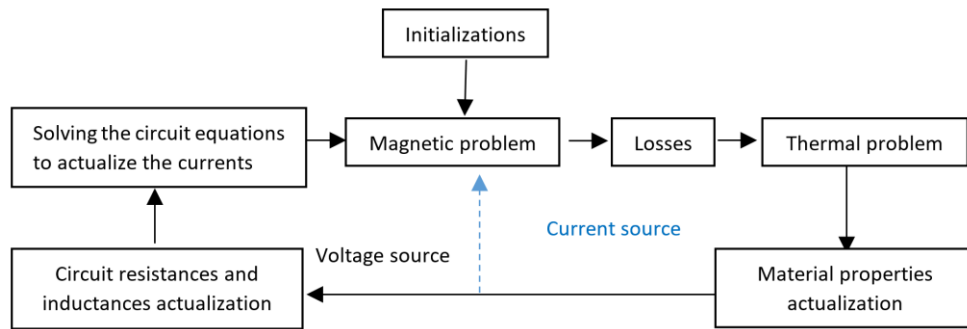


Fig. 1. Magnetothermal modeling strategy

Bibliography

- [1] Y. Xu and Z. Zhang, "Regenerated Energy Absorption Methods for More Electric Aircraft Starter/Generator System," in *IEEE Transactions on Power Electronics*, vol. 38, no. 6, pp. 7525-7534, June 2023.
- [2] Z. Li, Z. Chen, H. Qin, C. Feng and Q. Ming, "Optimal Current Control Strategy of a Four-Phase Doubly Salient Electromagnetic Motor applied to Transportation Electrification," in *IEEE Transactions on Transportation Electrification*
- [3] M. D. Noh, M. J. Gi, D. Kim, Y.-W. Park, J. Lee, and J.-W. Kim, "Modeling and Validation of High-Temperature Electromagnetic Actuator", *IEEE Trans. Mag.*, Vol. 51, No. 11, 8003504, Nov. 2015.
- [4] My-Ismaïl Lamghari-Jamal, Javad Fouladgar, El-Hadi Zaim, Didier Trichet, "A Magneto-Thermal Study of a High-Speed Synchronous Reluctance Machine.", *IEEE Trans. Mag.*, Vol. 42, No. 4, pp. 1271-1274, Ap. 2006.
- [5] Yonghong Huang, Fengxiao Huang, Ying Zhang, Chi Chen, Ye Yuan, and Jianhua Luo, "Thermal Characteristics Analysis of Single-Winding Bearingless Switched Reluctance Motor", *Progress In Electromagnetics Research M*, Vol. 86, 59–69, 2019.
- [6] Yukun Sun, Binbin Zhang, Ye Yuan, and Fan Yang, "Characteristics of Switched Reluctance Motor under Different Working Conditions", *Progress In Electromagnetics Research M*, Vol. 74, 11-23, 2018.
- [7] Payam Shams Ghahfarokhi, Ants Kallaste, Anouar Belahcen, Toomas Vaimann, Anton Rassõlkin, "Hybrid thermal model of a synchronous reluctance machine." *Case Studies in Thermal Engineering* 12, 381–389, 2018.
- [8] Amel Adouni & Antonio J. Marques Cardoso, "Thermal Analysis of Synchronous Reluctance Machines—A Review", *Electric Power Components and Systems*, 47(6-7), 471–485, 2019.
- [9] Norio Takahashi, Masayuki Morishita, Daisuke Miyagi, and Masanori Nakano, "Examination of Magnetic Properties of Magnetic Materials at High Temperature Using a Ring Specimen", *IEEE Trans. Mag.*, Vol. 46, No. 2, pp. 548-551, Feb. 2010.
- [10] Junquan Chen, Dong Wang, Siwei Cheng, Yu Wang, Yonghong Zhu, and Quan Liu, "Modeling of Temperature Effects on Magnetic Property of Nonoriented Silicon Steel Lamination", *IEEE Trans. Mag.*, Vol. 51, No. 11, 2002804, Nov. 2015.
- [11] Junquan Chen, Zihua Chen, Dong Wang, Leitao Wu, Xiaoqin Zheng, Florian Birnkammer, and Dieter Gerling, "Influence of temperature on magnetic properties of silicon steel lamination." *AIP ADVANCES* 7, 056113-7, 2017.
- [12] K. Alitouche, H. Menana, J. Khalfi, et al. Contribution to the Magneto-Thermal Modeling of SRM Operating at High Temperatures. *European Journal of Electrical Engineering/Revue Internationale de Génie Electrique*, 2021, vol. 23, no 2.