Efficient Approach for Angular Modelling of Electrical Machine by Reluctance Network

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Abstract —The aim of the paper is to make and to manage the modeling of electrical machines, taking into account of several rotor positions to analyze their harmonic influence on its performances (e.g. its torque, its losses)[1] on an electrical period of the machine in a sizing process by optimization. Using the established independent meshes of the initial reluctance network (RN), the paper proposes an algorithm to deal with all the topologies corresponding to every angular position to reduce the computation time, be more accurate and to improve the solving stability. The simulation results are compared to Finite Element simulation results.

I. Introduction

A. Design requires of electrical machines

A designer can use different kinds of models in order to size and optimize a device. Some of them, like finite-element model (FEM) or boundary element method, can be very precise, but need large computation time, limiting the number of parameters and constraints that can be taken into account in a sizing process by optimization. So the designer should also use an approach like the reluctance network approach, when it is necessary to deals fastly with a large number of parameters and many constraints [1]. The derivative calculation is also important for the sizing of the machine by optimization algorithm that allows to controlled very well large number of parameters and constraints, like sequential quadratic programming (SQP) using the model jacobian.

Traditionally, RN models of electrical machine are performed for specific positions of the rotor, e.g. *d-q* axis, using Park transformation for the calculation of the overall performances. The evaluation of the fundamental value of the torque and the back-emf are usually well estimated and sufficient for machine design. However, specifications may have severe constraints on torque ripple and back-emf harmonics for some applications like in transportation and in electric vehicle. Then, by taking into consideration those parameters during the optimization is very important in order to find the right optimal geometry. So, the reluctance network of machine needs to deals with the discretized rotation angulars (θ) of the rotor on

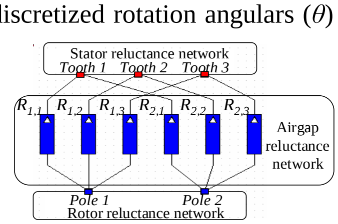

Fig. 1.Complete RN of three teeth and two poles machine

an electrical period. Thus, harmonics values of the torque and the back-emf will be available.

For the modeling of electrical machine by RN, the RN of a selected rotor position has to define. At less 20 positions have to be considered to deal with the computation of the main harmonic values [4]. According to the symmetries in the machine, there are more or less rotor positions to deal with. Furthermore, if a complete RN (e.g. one stator teeth is always interconnected with all pole of rotor) is used to compute every rotor position as in [1] and [3] (an example in Fig.1), the computation may have the numerical conditioning problem of the matrix when the local reluctance in the airgap R_{ij} linking a pole and a tooth became negligible (e.g. the distance between them increase). Therefore, for every selected rotor position, the accurate approach with few numerical problems is to define a specific RN for each rotor position. However, it may become nightmare to describe all these positions because it has numerous RN to be described, and set into equations. Therefore, in the next section, the paper proposes a generic approach to firstly help the RN description, to translate automatically the RN into equations, and secondly to simplify automatically all negligible local reluctance in the complete RN. This proposed approach allows to reduce the description time of the RN, to reduce the time of the generation computation code, to compute more quickly outputs and its derivatives, to also improve the solving stability of the RN (e.g. the matrix conditioning).

II. Proposed Generic Approach

A. A Tool for automatic generation of airgap reluctance network (ARN)

In order to help the description of RN, we have implemented a tool in Reluctool [2] for automatic generation and setting of ARN model using the pole number, the tooth number, the tooth width, the pole width as inputs (see Fig.2). This tool is inspired from the moving band concept used by FEM [5]. Whereas in FEM, the discretisation depends on the meshing, here it depends on the airgap reluctance network. For every angular position, an automatic meshing is generally used in FEM tools, whereas a simplification of the initial airgap reluctance network is chosen here.

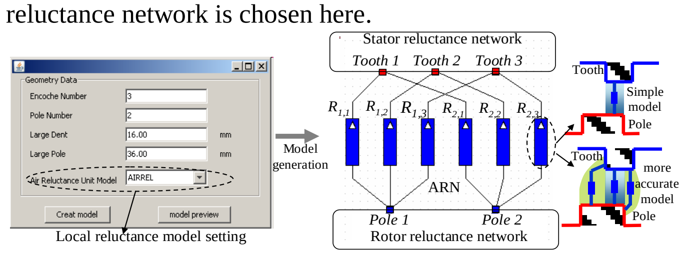

Fig. 2.Implimented tool for automatic generation and setting of ARN.

In this tool, the designer can define a local reluctance model between a pole and a tooth (see two examples at the right of Fig. 2). The ARN is connected to the stator network by tooth terminals and with rotor by pole terminals. This implemented tool will be detailed in the full paper.

B. Automatic simplification of the network model (ASNM)

In order to reduce the computation time and avoid the matrix conditioning problem in the solving of the RN. The generic approach preferred to use a specific RN for each rotor position. So, a set of rotor positions has to be defined before to generate the model. However, any change of ARN is not predictable because when the geometry parameters of machine change, the ARN topology implicitly changes. This aspect will be explained in the full paper. Therefore, the paper proposes an approach that finds a specific model for any value of θ by simplifying all the negligible local reluctances in the ARN of the generated initial complete model.

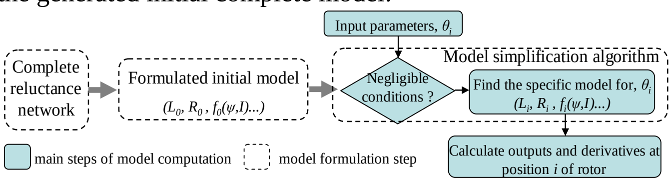

Fig. 3.ASNM approach

Fig. 3 shows the model formulation process and also the model computation steps of ASNM approach. In the formulation process, the initial complete model is formulated only one time by a initial independent mesh matrix L_0, initial implicit system $f_0(\psi,I)$, initial reluctance matrix R_0. Then, the model simplification algorithm is integrated. For a computation with a value of θ_i, this simplification model algorithm allows to verify the negligible conditions to find the specific model of θ_i, with L_i, R_i, $f_i(\psi,I)$, based on the initial model. This model simplification algorithm will be detailed in the full paper. In this way, the change of the ARN of the initial model is reduced for every value of θ.

III. Application of The Generic Approach

In order to apply the implemented approach in Reluctool, the paper deals with the model of a Permanent Magnet Synchronous Machines with 12 teeth and 8 poles (12/8 PMSM)

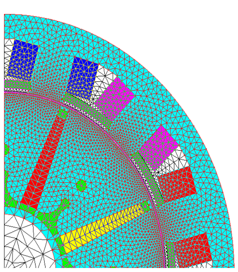

Fig. 4. ¼ Mesh of the 12/8 PMSM

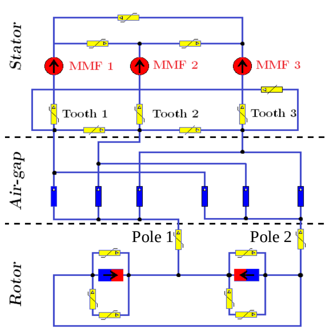

Fig. 5. ¼ Reluctance network of the 12/8 PMSM

[1]. The maximal current (RMS) of the coils is 63.6A. The number of turns of the coils is 50. The air-gap length is 0.9mm. Other parameters of this machine will be presented in the full paper. Fig. 4 presents the FEM of the PMSM. The initial complete RN is shown in Fig.5. The local model of the air reluctances in the network uses Fourier series (see in [1]). Then, three models are defined: FEM, RN without ASNM and RN with ASNM. Fig. 6 shows the torques of the PMSM calculated for 25 positions of rotor by three models.

As it can be observed, the torque values calculated by two RN models are almost identical and good accordance with FEM results. Table 1 compares the computation time of the three models and the derivative computation time of the two RN models with 25 positions of rotor. The results show that the

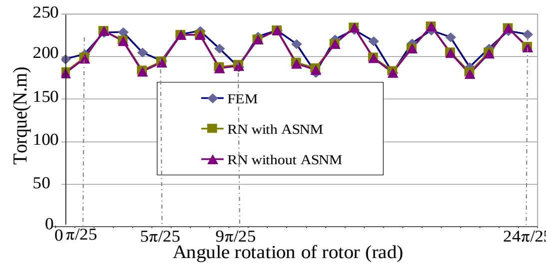

Fig. 6. Torque of the machine calculated by three methods

two RN models are very fast compared to FEM. Furthermore, the ASNM accelerated more the computation of model. The ASNM reduces the computation time by 35% and the derivative computation time of RN without ASNM by 50% although the percentage of eliminated reluctances is less than 5% each angule rotation of rotor. In other application where the RN is larger, this percentage can be higher. So the reduction of computation time is more significant.

TABLE I
COMPARISION OF COMPUTATION TIME OF THREE MODELS

Method	Computation time	Derivative computation time
FEM	250(seconds)	unavailable
RN without ASNM	0.680(seconds)	2.3 (seconds)
RN with ASNM	0.440(seconds)	1.1 (seconds)

IV. Conclusion

The proposed approach allows to automatically generate the airgap reluctance network and to mostly efficiently calculate the reluctance network for any rotor position, in a same generated model. This approach gives a simple network description, a good numerical stability, a precise and fast computation and is currently applied for sizing by optimization using the jacobien.

Acknowledgments

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V. References

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