Finite Element Analysis of Cogging Torque in Low Speed Permanent Magnets Wind Generators

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Abstract. This paper deals with the finite element estimation of cogging torque oscillations that occur in multi-pole permanent magnets synchronous wind generators.
The numerical analysis is carried out using a 2D plane-parallel finite element model of the machine and afterward a more elaborated 3D model able to take into account the skewing of the stator slots. The numerical results are discussed and compared with experimental measurements.
This paper presents also the influence of the magnetization characteristics of stator and rotor cores as well as the influence of the magnetization orientation of the permanent magnets of the generator on the cogging torque values.

Keywords

Finite element analysis, cogging torque.

1. Introduction

Among the non-conventional renewable energy sources, wind energy presents the largest potential of conversion into electrical energy, being able in the future to ensure a large part of all the energy need of the planet.
A key role in the conversion chain of wind energy into electricity is played by the electrical generator. A privileged position among electrical machines that can be used as generators in wind applications is occupied by the directly driven multi-pole permanent magnet synchronous generator [1]-[4]. This type of converter has a large number of poles and can generate electricity at low speeds by operating directly mounted on the main shaft of the wind turbine.
A special attention in the design of the multi-pole permanent magnet synchronous generators should be paid to the reduction of cogging torque oscillations. A proper design of the generator that permits to start the wind turbine at reduced wind speeds of about 2.5 – 3 m/sec. supposes to keep the cogging torque values in the range of 1.5 – 2.5% out the rated torque [4]. These constraints require reliable finite element based numerical models of the machine able to deal with the delicate aspect of the cogging torque evaluation.

The physical support for this study is represented by a synchronous generator designed and built by the Research Institute for Electrical Machines (ICPE-ME), Bucharest, Romania, characterized by the main data: rated power 7.5 kW, rated speed 200 rpm, 36 stator slots and 26 rotor poles, lamination stack length 140 mm with an inclination angle of stator slots of 8.4°, airgap thickness 0.85 mm. The permanent magnets are mounted on the outer rotor surface and unidirectionally magnetized.

2. Plane-parallel 2D model of the machine

The 2D plane-parallel finite element model of the machine equipped, Fig. 1, is based on the magnetic vector potential formulation.
The stator and rotor laminations are made of soft magnetic material characterized by saturation magnetization B_s = 1.8 T and initial relative magnetic permeability μ_r = 500. The permanent magnets are made of NdFeB with μ_r = 1.1, and remnant magnetic flux density B_r = 1.0446 T.
By solving the 2D magneto-static field problem for several stator/rotor positions we obtain the cogging torque oscillations both for unidirectional and for radial magnetization of permanent magnets, Fig. 2.

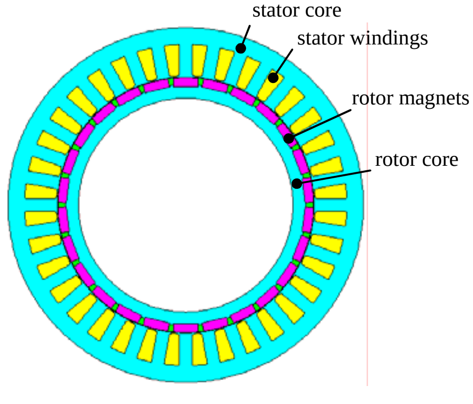
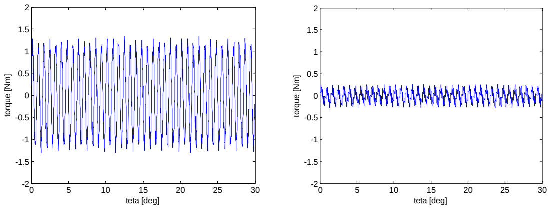


Fig. 1. 2D FEM computation domain.



a) b)

Fig. 2. Cogging torque versus stator/rotor position;
a) unidirectional magnetization; b) radial magnetization.

The numerical results in Fig. 2 prove that the cogging torque values for radial magnetization of permanent magnets are smaller than the values corresponding to the unidirectional magnetization.
The simulation results for two types of soft magnetic materials with different initial magnetic permeability values proved that this material property may influence notably the cogging torque values.

3. Magneto-static 3D model of the machine

A method for reducing the cogging torque oscillations consists in skewing the stator laminations with a properly chosen inclination angle. This constructive solution requires a 3D FEM model that in our case was treated using the magnetic scalar potential formulation. The 3D FEM numerical results of the cogging torque for different relative rotor/stator positions are presented in Fig. 3.

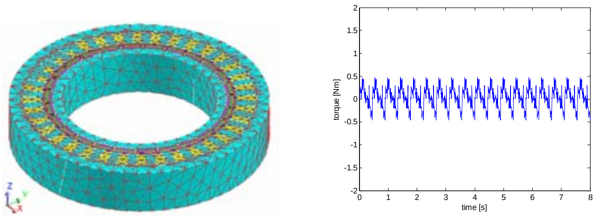


Fig. 3. 3D FEM model and cogging torque oscillations (processed results).

4. Experimental validation

In order to validate the 3D numerical simulation results we used an experimental facility implemented in the ICPE-ME workshops, consisting in the studied synchronous generator rotated with a slow velocity, Fig. 4, and a specialized torque transducer with automatic data recording system. The measurement data, Fig. 4, numerically processed to eliminate the friction torque influence on the cogging torque results, are in good agreement with the 3D FEM results shown in Fig. 3.

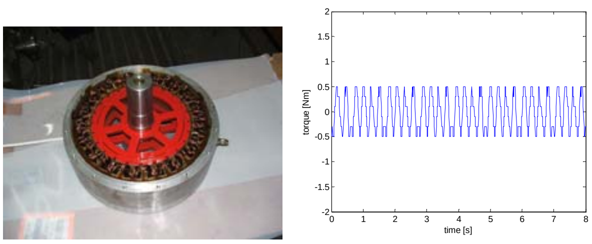


Fig. 4. Experimental model of the studied generator and measured cogging torque oscillations (processed results).

5. Conclusion

This study proves the utility and versatility of finite element based models in the optimal design of multi-pole permanent magnet synchronous generators by the prediction of the cogging torque oscillations, quantity that can influence the proper wind turbine operation.
The numerical results proved that the cogging torque results obtained in case of a generator with straight slots can be reduced by skewing the stator slots with a proper inclination angle.
The sensitivity analysis of the influence of magnetization orientation of permanent magnets proved that the cogging torque oscillations are more reduced in case of a radial orientation than in case of unidirectional orientation of permanent magnets.
The construction of magnetic armatures of the generator using soft magnetic materials with higher initial relative magnetic permeability leads to higher cogging torque values.
The 3D FEM results (peak-to-peak values) are in good agreement with the experimental measurements results obtained on a dedicated stand in the ICPE-ME workshops.

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