ABOUT THE PERMANENT MAGNET SYNCHRONOUS MACHINE IN WIND POWER APPLICATIONS

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In wind power applications, the permanent magnet generators have become very attractive especially in small ratings. Wind power generates electricity from an unlimited source, the wind. This has many benefits including saving the environment because it does not rely on fossil fuels. Also, wind turbines do not require the large areas that conventional power stations require. The finite element method is a numerical method for solving electromagnetic field problems, which are too complex to be solved using analytical techniques, especially those involving non-linear material characteristics. This method is used to accurately predict the electromagnetic behavior of the designed machine.

Keywords: finite element method, permanent magnet machines, wind power generations, wind turbines.

1. Introduction

Permanent magnet (PM) machines are a well-known class of rotating and linear electric machines used in both the motoring and generating modes. PM machines have been applied to more demanding applications. PM machines have been used for many years in applications where simplicity of structure and a low initial cost were of primary importance. More recently, PM machines have been applied to more demanding applications, primarily as the result of the availability of low-cost power electronic control devices and the improvement of permanent magnet characteristics. In general, modern PM machines are competitive both in performance and cost with many types of machines.

The term permanent magnet machine is used to include all electromagnetic energy conversion devices in which the magnetic excitation is supplied by a permanent magnet. Energy converters using permanent magnets come in a variety of configurations and are described by such terms as motor, generator, alternator, stepper motor, linear motor, actuator, transducer, control motor, tachometer, brushless dc motor, and many others. Permanent magnet machines are rapidly finding numerous applications as alternators, automotive applications, vehicular

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electric drive motors, small appliances, and control motors, printed circuit motors and computer and robotics applications. The stator of the machine is identical to the stator of a multiphase AC machine. The new component is the rotor, which in contrast to conventional rotors relies on permanent magnets as the source of excitation rather than an electric current in windings. The optimum rotor configuration, rotor electromagnetic and mechanical design, and the stator electromagnetic design must be matched to achieve a higher efficient machine of the desired load characteristics, high power factor, and high efficiency and performance.

The PM machines can be surface mounted or exterior PM machines and interior PM machines. In buried or interior PM machines the machine is robust, rugged and well-suited for flux weakening control for a wide speed-torque range, essential for many applications. The surface mounted PM machine has magnets at the air gap surface and is liable to damage at high speeds or even in the assembly and fabrication process. The rotor structure for an interior PM rotor will tend to have a smooth rotor design similar to or better than induction machines. Thus, windage losses will be equal to or lower than those of conventional induction machines. In this work on present the performance of designed interior permanent magnet machine. The stator employed is of an equivalent induction motor, rated at the same power.

Permanent magnets have been extensively used to replace the excitation winding in synchronous machines [1], [2] with the well known advantages of simple rotor design without field windings, slip-rings and exciter generator, avoiding heat dissipation in the rotor and providing higher overall efficiency. The rotor design can be distinguished in three main types according to the magnet position, namely the “interior”, the “peripheral” and the “claw pole” type. For wind power applications in particular, multipole permanent magnet generators have become very attractive especially in small ratings.

Recent advances in power electronics enabling energy efficient drives have aroused the interest in using permanent magnet generators in small and medium systems for both autonomous and parallel operation with the electrical grid. In small scale systems the ferromagnetic material optimization in conjunction with standard shape low cost permanent magnets can provide attractive rivals to the common asynchronous generators [2]. For larger systems however the magnet cost constitutes an important parameter and further investigation is needed in order to compare all features of low price-low magnetization traditional magnets, such as ferrites, with new ones exhibiting greater magnetization but involving more important costs, such as neodymium alloys. Both cases of ferrite and neodymium alloy magnets have been considered with respect to their suitability for a 20 kW wind power system application.

2. Electrical generator

In small and medium scale wind power applications considered hereafter, the gear box can be avoided by using a convenient multipole permanent magnet generator. In such applications permanent magnet machines are usually connected through a rectifier stage either to a battery bank or to the dc bus of an inverter producing 50 Hz power to the grid [3]. At the design stage, both ferrite magnets involving "interior" type machine structure and Neodymium alloy magnets with "peripheral" machine construction merit to be considered. The main generator dimensions of either machine configuration are derived by using classical formulae while the optimization of the permanent magnet dimensions is performed through a finite element modeling procedure.

Due to recent development in permanent magnet materials, especially Nd-Fe-B, high efficiency PM generators can be utilized for wind applications. On analyzed a permanent magnet generator with 8-pole. The generator that is being used will be rated at 5 kW and using Nd-Fe-B for the field excitation.

Figure 1 shows the cross section and the flux distribution of the designed machine.

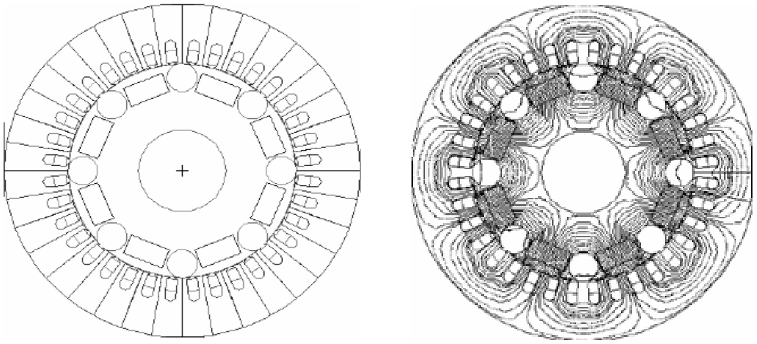

Fig. 1. a) Cross section of the wind generator and b) the flux distribution.

Figure 2 shows the cogging torque of the machine when it is excited only with the permanent magnet.

Figure 3 shows the magnetic flux density around the core. In the case of wind generator the cogging torque is a very important parameter as it is the parameter that can define the minimum strength of wind that can be enough to move the rotor of the generator.

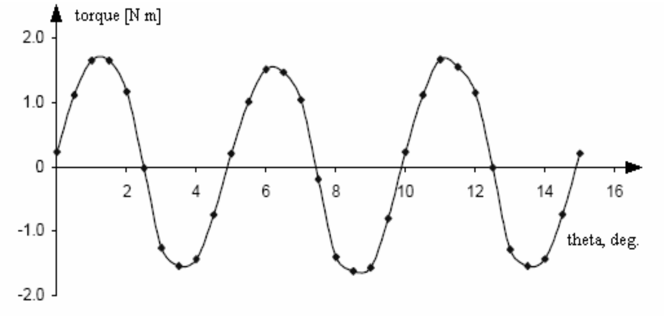

Fig. 2. The torque of wind generator.

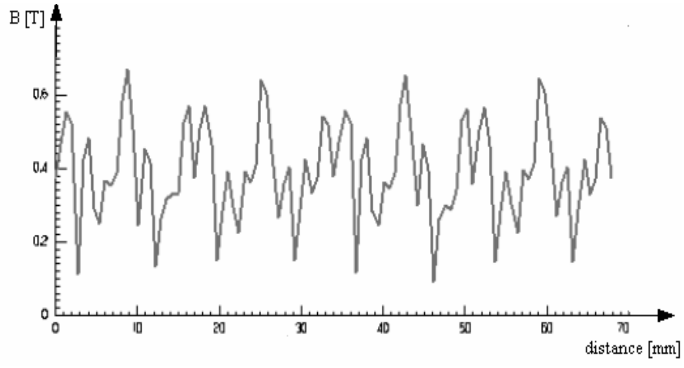

Fig. 3. The magnetic flux density in the stator yoke.

Wind turbines can be divided into two basic configurations depending on the position of the rotor: horizontal axis and vertical axis (Darieus type) wind turbines (HAWTs and VAWTs, respectively). Both types use aerodynamic lift to extract power from the wind. They also have the same sub-systems.

2.1. Finite element model

The Finite element method is a numerical method of solving linear and non-linear partial differential equations. It offers an accurate and powerful design tool, allowing material properties, nonlinearities and structural details to be taken into account. The method basically involves the discretisation of the machine cross section into smaller finite elements. The spatial variation of magnetic potential throughout the machine is described by a non-linear partial differential equation derived from Maxwell equation [5].

Once the basic structure of the machine has been determined, the second step of the shape optimization is performed by introducing the finite element model. In this work a two dimensional analysis has adopted and the fundamental magnetic field equation is:

$$\mathrm{rot}(\upsilon\,\mathrm{rot}A) = J_0 + \mathrm{rot}(\upsilon_0\, M)\,, \tag{1}$$

where A is the magnetic vector potential, υ is the magnetic reluctivity, J_0 is the current density and M is the magnetization.

Ferromagnetic iron non-linear characteristics are taken into account while the relative geometry variation with the rotor rotation is considered through mesh regeneration in the air gap. For calculation purposes the demagnetization characteristic of the permanent magnet is conveniently simulated by means of a shifted one by the coercitive force (H_c) crossing the origin and an appropriate equivalent current density [2].

The electromagnetic torque T is derived by using the two axes theory as follows:

$$T = p(\psi_{ds} I_{qs} - \psi_{qs} I_{ds})\,, \tag{2}$$

where p is the number of pole pairs, ψ_{ds} and ψ_{qs} is respectively the direct and quadrature axis fluxes linked with the stator windings while I_{ds} and I_{qs} are respectively the direct and quadrature axis currents. The finite element model enables the performance determination of the machine through a detailed field analysis including the torque variation with the rotor rotation as well as the design improvement by means of the permanent magnet shape modification.

The finite element method (FEM) can be used to change the structure of the machine, the material properties, and the excitation in the rotor and the stator of machine. The solution of a continuum problem by the FEM process always follows an orderly step-by-step process [4]. The finite element model contains information about the device to be analyzed such as geometry (subdivided into finite elements), materials, excitations, and constraints. The material properties, excitations, and constraints can often be expressed quickly and easily, but geometry is usually difficult to describe. The finite elements can be very small where small geometric details exist, such as s and can be much larger elsewhere.

3. Permanent magnet optimization

The optimization of the permanent magnet shape is performed by using a perturbation technique of the magnet main dimensions at the final design stage. For the shake of simplicity only rectangular magnet cross section on considered. The cost function used involves torque maximization for a given volume of permanent magnet.

The general moving boundary approach used in [3] could have equally applied in this problem but the objective function evaluation with the mesh modification render the method extremely time consuming. Another important feature is that the number of design variables and constraints involved in such an optimization procedure can be relatively high while the mesh congruency and regularity must be continuously checked.

6. Conclusions

The permanent magnet wind generator is analyzed using the finite element method. A methodology for the design of permanent magnet generator for wind power applications comprises a preliminary design stage by means of standard formulae and an optimization stage involving a two dimensional finite element model.

REFERENCES

[1]. *A. Cladas, A. Tegopoulos*, "Optimization of permanent magnet generator for wind power applications", Proceedings of the International Workshop on Electric and Magnetic Field, 2002, pp. 165-169.

[2]. *T. Higuchi, J. Oyama*, "Optimization procedure of surface permanent magnet synchronous motors", IEEE Trans. On Magnetics, **vol. 33**, no. 2, 2004, pp. 1943-1946.

[3]. *A. Kladas, A. Savini*, "Application of global optimization strategies to the shape design of a transformer winding", Advances in Engineering Software, 2001, pp. 121-125.

[4]. *J. Rizk, M. Nagrial*, "Finite Element modeling of permanent magnet machines", Conference on Modeling and Simulation, 2002, pp. 259-299.

[5]. *J. Misaim, K. Aramaic*, "Finite Element Force calculation: comparison of methods for Electric Machines", Mag-24, no. 1, 2004, pp. 447-450.