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Switching Permanent Magnet Generator for Small Wind Turbine

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***Abstract*— This paper introduces a novel axial field flux switching permanent magnet generator for small scale wind turbine application. A 3-phase 12/10-pole machine designed and 3D finite element (FE) analysis used to investigation the back-EMF, open circuit flux linkage, winding inductance, cogging torque etc. results show good performance of proposed structure. Moreover the proposed structure is very suitable for the new manufacturing approaches such as soft magnetic composite (SMC) deployment, which is underway by the authors for the proposed generator in this paper.**

***Index Terms*— Axial field (AF), energy, flux switching (FS) finite element method (FEM), permanent magnet generator (PMG).**

I. INTRODUCTION

Among new technologies for reducing energy losses, distributed generation is getting more and more importance nowadays. One of the main tools to reach this aim is to use low-speed, low-power local generation or distributed generation. Water mill and wind turbine are two main candidates for realizing the above goal. Off-grid or stand-alone small wind turbines provide an attractive renewable energy source for remote communities and small businesses. These wind turbines help in reducing the stress on the grid, diminish the pollution [1] and save on fuel costs. In terms of efficiency and reliability, the direct-drive permanent magnet synchronous generator systems (PMSG) are among performances, extensive researches have been achieved [3-8]. In this paper we propose a novel axial field flux switching permanent magnet (AFFSPM) generator. Unlike the other types of this category, construction of this generator is straightforward and simple due to slotless stator segments. 3D finite element (FE) analysis has done and flux linkages, back- EMFs, inductances and other main variables are extracted. The outputs shows proper result for wind energy applications. Flux switching permanent magnet (FSPM) machines have gained wide applications in different areas. The most advantages of this structure are: simple and robust rotor, short end winding, high torque density, high efficiency, excellent flux-weakening capability, peak power, minimum volume, etc. [9-13]. Comparing recent works [14-17] reveal advantage of the new axial flux FSPM design in terms of: short axial length, high power and torque density with respects to previous structures.

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II. PROPOSED AFFSPM MACHINE

The AFFSPM generator as shown in Figure (1) has 12 circumferentially opposite magnetized NdFeB PMs and 12 simple and arc shaped segment as its stator. To drive the required magnetizing field we have put PMs between stator yokes. Rotor consists of 10 teeth shape segment which are arranged in harmony with the stator segments, both sides of stator. Each phase skewed winding surrounds its own segment. Two parallel rotors which are able to rotate around the stator have a small angular deviation with respect to each other.

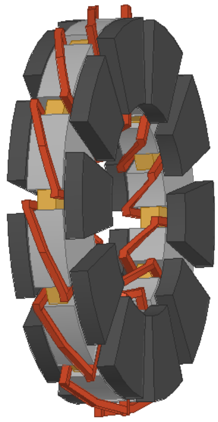

Figure 1- 3D View of Novel AFFSPMG

A cross section view gives a better understanding of the operating principle of this concept as shown in Figure (2). In part (a) of this figure, winding with black color shows the flux path which is from right to left and downward. In part (b) when the rotor moves, flux path changes and flow from right to left and upward. The periodical variation of flux linkage which is in harmony with rotor position will induce back-EMF in the coils.

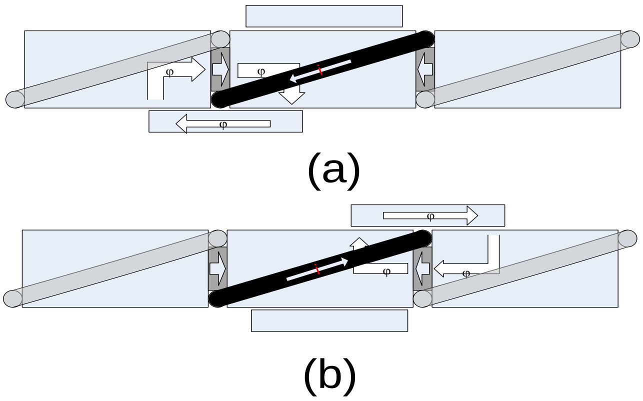

Figure 2-Operation Principle of AFFEPMG

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Although there are many possible ways to choose the ratio of the number of stator segments and rotor poles in PM machines [18-20], we used most popular combinations of 12/10 AFFSPMG based on[21]

$$\begin{cases} p_s = 4mk \\ p_r = \dfrac{2m-1}{2m} p_s \quad m \geq 2 \end{cases}$$

where p_s, p_r and m is stator pole number, rotor pole number and phase number respectively . In this way we could get a good result firstly for the no load output voltages and consequently for the cogging torques and output power. Because of flux switching occurs p_r times per each cycle therefore:

$$f = \frac{np_r}{60}$$

that f is output frequency and n is angular speed (rpm).

III. FE ANALYSIS

The finite element (FE) is a numerical method that essentially linked to computer science and engineering. In the electromagnetic problems FE analysis consist of discretization and solving of very complex and nonlinear Maxwell's equations in the 2D or 3D dimension spaces. The important equation that uses in this method is [22]:

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \vec{A}\right) = J_s - \sigma \frac{\partial A}{\partial t}$$

where A is potential vector, Js is current density and μ is permeability of the medium and σ is the conductivity. Other quantities like flux density, voltage, torque …etc. can be determined from this quantity. The main characteristics & sizes of 3D finite element analysis which was used in this structure (Figure 3) are given in table I. Figure 4 shows flux distribution of no load voltage in a stator segment.

Table 1 Dimension and Specification of Proposed AFFSPMG

Design parameter	***Value***
Outer diameter	180mm
Inner diameter	100mm
Stator numer of segments	12
Number of rotor poles (each side)	10
Rated speed	300rpm
Width of stator Back iron	20mm
Width of rotor pole	10mm
Rotor pole arc	26°
Width of Air gap (each side)	1mm
Number of turns per coil	300 turn
Permanent magnet dimension	40×10×10mm
Remanence	1.2T
Magnetic coercivity	890000 A/m

This analysis (in Figure 3) helps us to find the distribution of the flux over the bulk of stator and rotor magnetic path. As it is clear around the windings we are witnessing proper circulation of the magnetic fields which hint to sufficient use of the material.

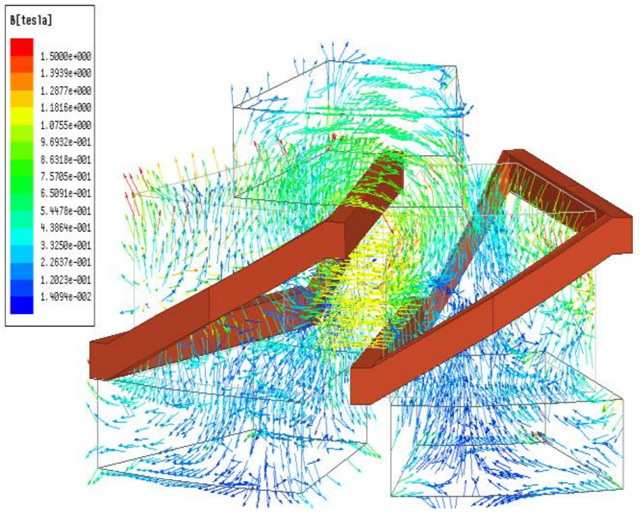

Figure 3- Open Circuit Field Distribution

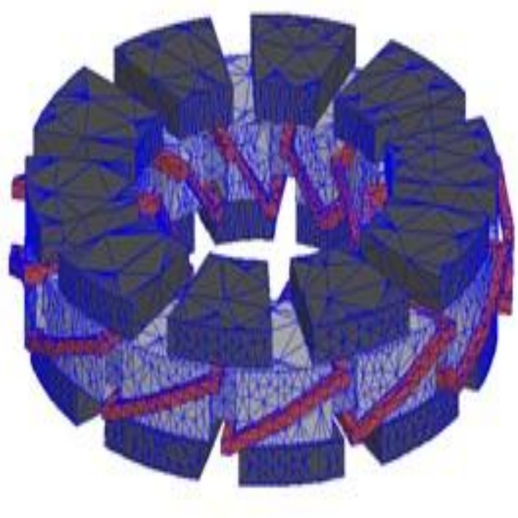

Figure 4-3D Finite Element Analysis

This 3-D (Figure 4) besides showing the used meshes for the simulation reveals the arrangement of the four main parts of the generator with respect to each other. The first one is stator which is the main part for relating the PMs flux to both rotor and winding.

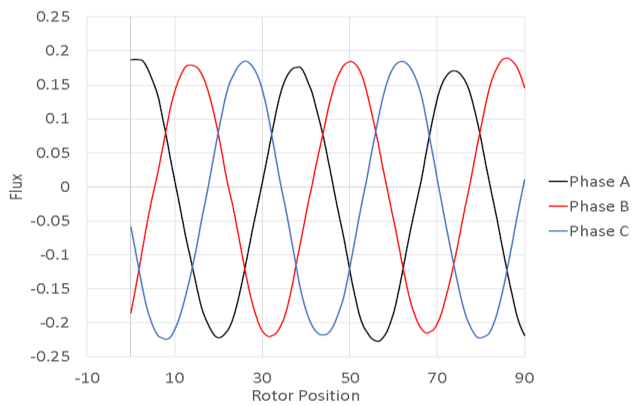

Figure 5- No Load Flux Density

The second one PMs which moreover meddling the stator segments is a proper holding place for windings. Third and fourth parts are rotor blades and windings respectively.

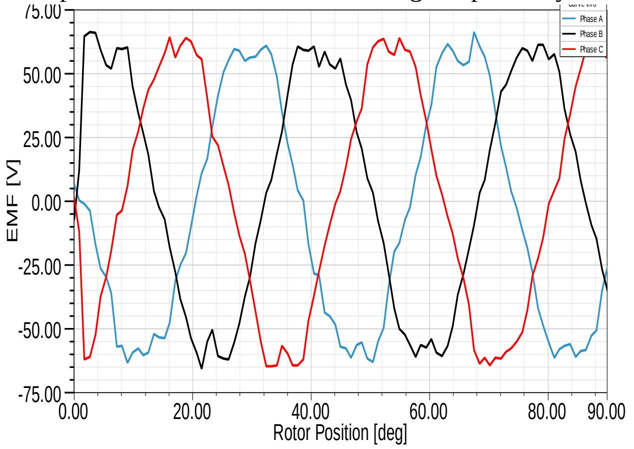

Figure 6- Back-EMF

One of the most important characteristics of the PM generators for e.g. wind energy applications is the cogging torque. Figure 7 shows the very small amounts for this resisting force which is vital parameters in designing the whole wind turbine system. The less amount of the cogging torque the better response to the startup of the turbine blades is expected.

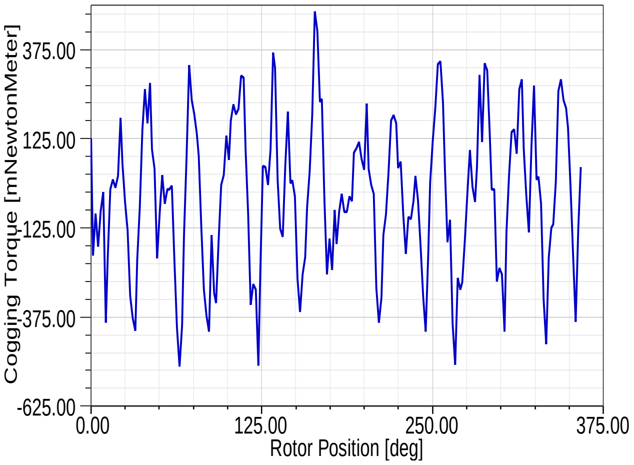

Figure 7-Cogging Torque

In the Figure 8 the main results of the simulation is indicated. Here the output power for different loads is brought. The voltage starts from 54V with current near 0.4A. As the load increases voltage drops to 18V and the current reaches to 1.8A.

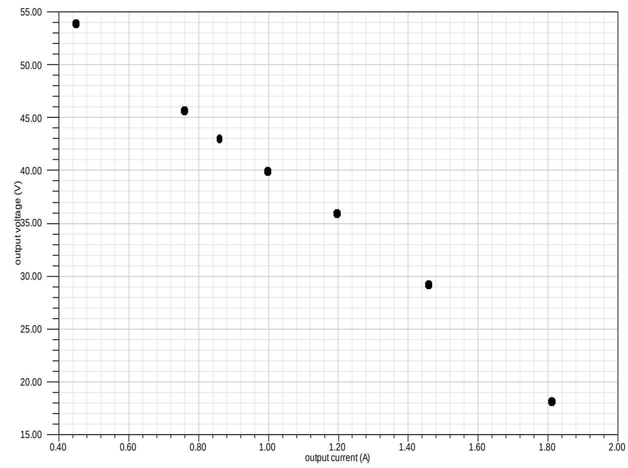

Figure 8-External Voltage and Current under Different Loads

This is for one phase and using these peak values of the sinusoidal waves, one may get total three phase power for any desired load.

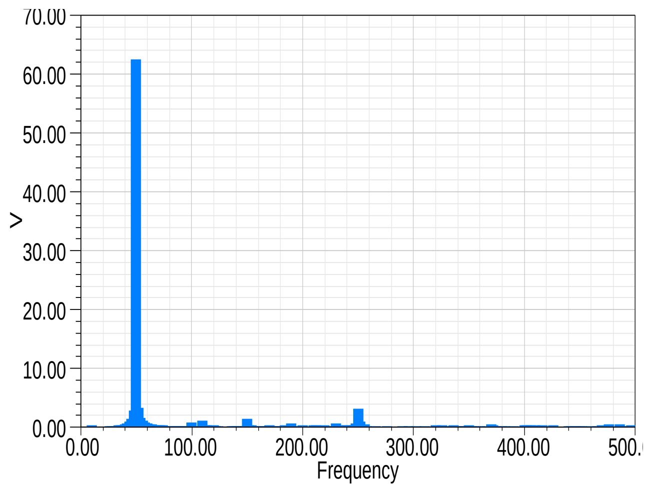

Figure 9- Harmonic Content of No Load Voltage

Figure 9 shows another advantage of the proposed system. As it is obvious the amount of the unwanted harmonics are not comparable with desired main one.

IV. CONCLUSIONS

Extensive research for reducing energy losses by low speed permanent magnet generators is underway around the world. This approach is preferred due to high gained efficiencies and also low costs. Another important advantage of this structure is to reduce the risk of permanent magnets destruction due to increasing of the temperature. Permanent magnets are sensitive to high temperature and as in the proposed structure we have them in the fixed part of the generator, it is possible to get heat out of them. The compromising results encouraged the authors to speed up the construction of the SMC prototype of the (AFFSPM) generator which enables us to further investigation about the outcomes of tested variables such as cogging torques and voltage harmonics.

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