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ANALYSIS AND DESIGN OF AN AXIAL-FLUX CORELESS PERMANENT MAGNET SYNCHRONOUS GENERATOR WITH SINGLE STATORS AND DOUBLE ROTORS

Mehmet Recep MİNAZ[1]*, Mehmet ÇELEBİ[2]

[1] Electric-Electronic Engineering, Faculty of Engineering, Siirt University, Siirt Turkey
[2] Electric-Electronic Engineering, Faculty of Engineering, Atatürk University, Erzurum, Turkey

Abstract

In this study, permanent magnet axial-flux coreless synchronous generator is designed as single stators and double rotors and its electromagnetic and structural characteristics are analyzed. Core is not been used in the stator of the machine intended to be designed. Aim of this study is to provide reduction of iron loss. Moreover, easiness in the production stage of the machine is provided. Three-dimensioned electromagnetic analysis of the designed machine has been done through finite element method and transient solutions are suggested based on this. Within this study, arrangements have been made depending on certain standards in order that permanent magnets and coils obtain direct alternating current. The designed new axial-flux generator move as permanent speed of 500 rpm and so maximum voltage of approximately 100 V per phase is obtained. Furthermore, this machine does not need a gear system due to its design structure.

Key words: *Axial-flux generator, Permanent magnet, Generator, Single stator, Double rotor*

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Corresponding author, recminaz@gmail.com

1. Introduction

Electrical machines have started to be used almost within all areas nowadays. Every passing day, new studies take place in literature. New models are developed in these studies done. Within these developed models, increases in power density of the machine, change in the shape of design as well as size reductions and studies done depending on excitation types have gained speed. Studies have centred on axial-flux permanent magnet machines as different excitation types recently. Permanent magnet axial machines have been aimed to be analyzed due to reasons such as being highly efficient and economic and having ability to produce energy at low cost [1]. Micro wind turbine application has been conducted in a study by Pop et al. Here it has been found that after a comparison of axial and radial-flux permanent magnet generator, axial-flux permanent magnet has shown the best result. It has been discovered that axial-flux generator is less costly [2]. Reducing no-load momentum of the generator has been possible using skewed magnets in axial-flux permanent magnet [3]. It is a huge advantage that axial flux permanent magnet generator (AFPMG) has high efficiency, compact size and light weight compared to other applications. Main purpose of this type of machine design is to obtain the best of output power [4]. Furthermore, axial-flux permanent magnet generator with coreless stator is considered as machines having high power density for energy-generating systems [5].
What has been aimed to reveal within this study is that iron losses have reduced using coreless stator. Moreover, the machine has been made lighter. As core has not been used in the stator windings of the designed machine with coreless stator, stator iron losses have been eliminated completely. As there has not been used of the core in the stator, stator windings will not be influenced by core warm-ups. As the surfaces of the windings are in contact with air, it will be able to take the heat on the surface out more quickly. As the core is not used for the stator windings in this type of axial machine, production difficulty to arise from applications in such type of machines has been reduced. Though copper losses have increased here as the core has not been used in the stator, this newly designed machine provides production convenience. This design can be used to obtain alternating current without need for gear system during wind turbine applications. Besides, it is intended to be used in electric vehicles both as in-wheel motor and generator. Finite element method has been used for analysis in this study. Finite element method is a numerical method used in solving linear and nonlinear partial differential equation [6]. Design features of the designed machine have been given within the second chapter. The third chapter consists of electromagnetic analysis results of the machine. Consequences related to simulation depending on time have been given within the fourth chapter. The final chapter includes the conclusion.

2. The Design Features of the Machine

Main purpose of the machine design is to obtain the best of output power. Estimated value of the output power belonging to the designed machine can be calculated using the equality below;

$$P_{out} = \frac{15\pi^2}{8}\frac{f}{p}k_i k_p \eta(1+k_d)(1-k_d^2)B_g D_o^3 \tag{1}$$

In order that output power of the machine reaches maximum, rate between its dimensions should be as in $k_d = 1/\sqrt{3}$ [7]. Statement related to the relationship between the dimension and power in axial flux permanent magnet synchronous generator has been given within equality 1 [8]. The k_p here is electric wave form factor and calculated as $0{,}5$ in sinusoidal designs where k_i is current wave form and calculated as $\sqrt{2}$ for sinusoidal wave forms [9]. B_g refers to maximum flux density within the air gap. P refers to dipole number and f refers to the frequency. D_0 and D_i refers to inner and outer diameter respectively where k_d refers to the ratio of the inner diameter to the outer diameter. The designed axial-flux coreless permanent magnet synchronous generator is given in Figure 1. There are one coreless stators and two rotors within this design.

There exist two rotor discs in Figure 1. 12 permanent magnets have been placed into the single end of the lower and upper rotor discs. The stator winding has been placed between two rotor discs. The stator winding consists of 9 coils in total. Each phase in windings corresponds to three coils.

Rotor steel used for the machine has been made up of M19. There are 12 magnets in rotor steel. Magnets placed upon the rotors have been placed between each other with 30 degrees each. Do and Di values are 145 mm and 85 mm.

Geometric structure of the magnets is as shown in Figure 3. These types of designed magnets are more advantageous to prevent the heat and more suitable to obtain a straight sinusoidal wave. Permanent magnet used in axial flux permanent generator is Neodymium. Length of the neodymium magnet is 50 mm and its thickness is 8 mm. Representation of flux paths of the magnets have been given in Fig. 4.

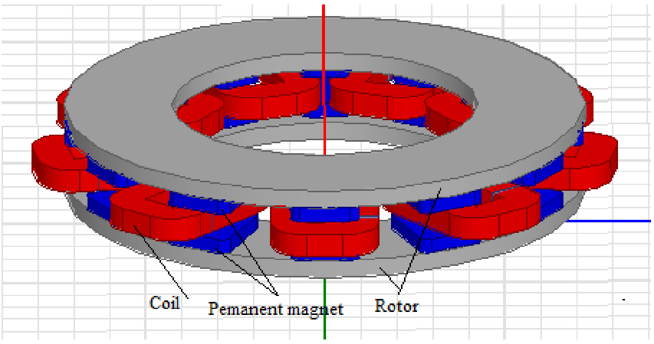

Fig. 1. Appearance of axial-flux permanent magnet generator. Permanent magnets: in dark blue colour. Rotors: in grey colour. Stator windings: in red colours.

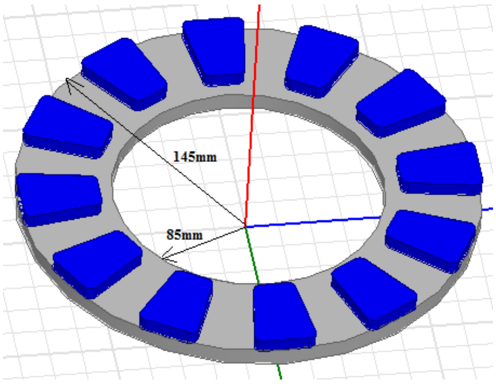

Fig. 2. Geometry of side rotors of axial flux permanent magnet generator.

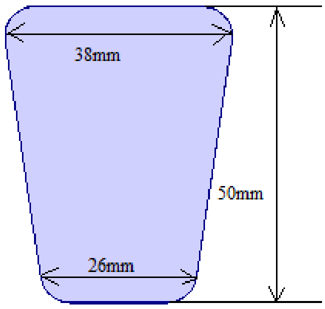

Fig. 3. Geometry of permanent magnet of axial-flux permanent magnet generator.

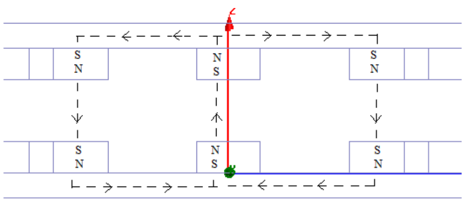

Fig. 4. Appearance of arrangement of the magnets and flux paths as S-N-S-N.

Generator stator designed within this study has a coreless structure. For the rotor core, steel which is of M-19 class and frequently used in electric machines. The steel used for core is not a linear material. While making solution, the analysis program applied makes solution using B-H curve. B-H curve of M19 steel is shown in Figure 5.

24 trapezoidal permanent magnets (NdFeB) and 9 coreless coils in total have been used in the machine shown in Figure 1. 12 magnets have been placed into the single end of the two rotors for each. There an

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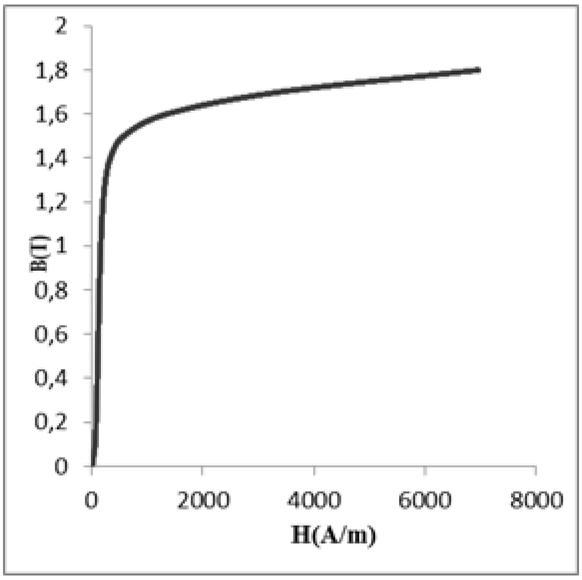

Fig. 5. B-H curve of M19 core material.

air gap of 1mm between the magnets placed upon the stator and rotor. Average magnetic flux density is approximately 0,68 Tesla. As a consequence of all these parameters, power estimated according to equality 1 is approximately 770 W.

3. Electromagnetic Properties of the Machine

Distribution of magnetic flux density for 3D model is given in Figure 6. Flux density values formed around the magnet have been given. Flux density in windings and steels has been measured as 0,8-0,9 Tesla.
Direction of the flux path within the arrangement of the magnets is shown in Figure 7. Arrangements of the permanent magnets here are in the form of N-S-N-S and S-N-S-N. Accordingly, while flux path of the dual magnet group on z plane is mostly up, flux path of the permanent magnet group both at its right and left is the opposite. For a clearer appearance of the flux path, it had been shown in Figure 5 without steel and permanent stator.

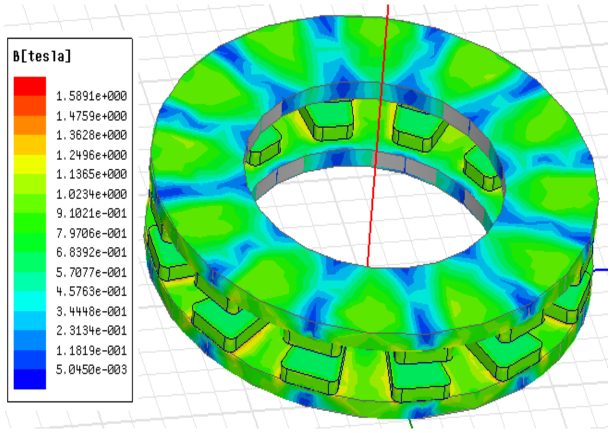

Fig.6. Distribution of magnetic flux density for axial flux permanent magnet generator.

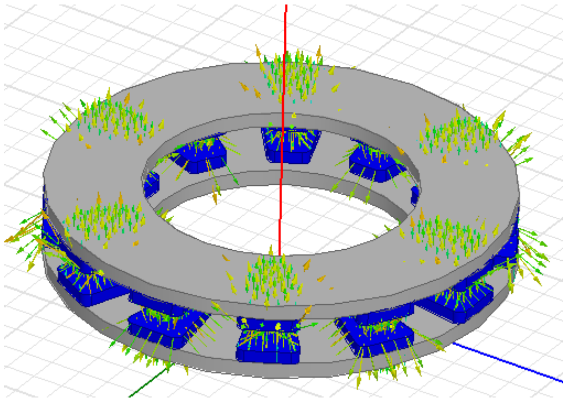

Fig.7. Appearance of magnetic flux path for axial flux permanent magnet generator.

4. The Simulation Results for the Machine

Current and voltage values according to the simulation results of the new designed machine have been given below. They have been given according to the angular velocity at 500 rpm of the machine.
Within the Fig. above, coils belonging to each phase and their relationships with each other have been given. There are three coils per phase for each stator winding here. 3 coils in total have been used for each phase. Resistance has been determined as 1.72 ohm in total for one phase of stator. The permanent magnets used are trapezoidal, phase voltage and current wave form to be obtained time-dependently have been demonstrated in Figure 8, 9 respectively.
It is observed that within the simulations results the output signal is in the form of alternating current. One of the advantages of the new designed machine is that generated wave form is at quite a good level.

Data to be obtained at speed of 500 rmp, roughly 100V voltage and roughly 5A current are in Figure 8, 9 respectively.

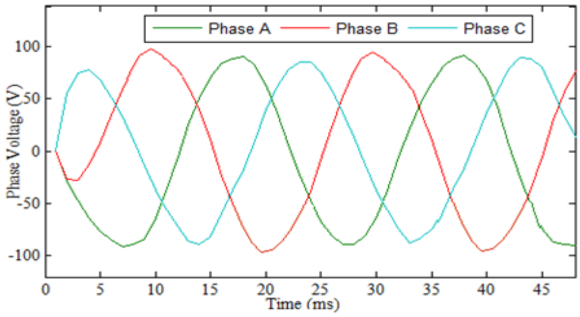

Fig. 8. Voltage value for A-B-C phase of axial-flux permanent magnet generator.

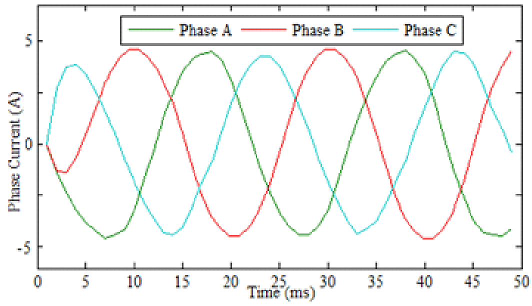

Fig. 9. Current value for A-B-C phase of axial-flux permanent magnet generator.

5. Conclusion

Aim of this study is to analyze the structurally different and alternating-current generating axial-flux coreless permanent magnet synchronous generator design through the finite element method and to present its performance. Application of axial-flux coreless permanent magnet synchronous generator with two rotors and single stators has been given. Within this study, due to the form of design there will be much convenience in production. Though the designed machine is coreless, a high power density has been obtained. That the output wave forms are close to sinusoidal reveals that design data related to the machine have been properly chosen. 9 coils and 24 magnets have been used in the machine and according to the simulation results at 500 rpm, the machine generates approximately 750 W power. The designed generator within this study offers a solution for both in-wheel motor-generator in electric vehicles and wind power applications.

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