Electromagnetic Analysis of a Novel Outer Rotor Permanent Magnet Generator

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Abstract— Newer types of synchronous generators were being developed for typical applications in the past decade due to the advancements in high power density permanent magnets. An outer rotor generator which can typically be applied for wind power and electric vehicle applications are proposed in this paper. The design of the structure is done through analytical calculations and the analysis to optimize the machine parameters are done through numerical analysis. This paper proposes the electromagnetic analysis of a novel outer rotor permanent magnet generator. The designed machine which has 18 slots and 20 poles generates a voltage of 150V when running at 1200 rpm.

Keywords— permanent magnet synchronous generator, torque density, cogging torque

Introduction

In the Permanent Magnet Synchronous Machine (PMSM), the rotor can be positioned in two ways which is in the inside (inner rotor type) and on the outside (outer rotor type). The key factor in designing a better machine lies in maximizing the power density of the machines. This is usually done through the optimization of parameters like the position and shape of the magnet with respect to the static electromagnetic field [1]. Placing the rotor on the outer surface yields a better torque compared to that of the inner rotor [2]. A fractional horse power outer rotor permanent magnet generator is designed and its electromagnetic design analysis is presented. Attempts by researchers on the study of placing the rotor in inner and outer surface is documented in the literature [3]. The outer rotor PMSM derives significant improvement due to the longer radius compared to the inner rotor design. They are found in significant applications such in mechanical cutters [4] and wind turbines [5-6]. The purpose of this research is to design an outer rotor structure generator that can be coupled with a wind turbine generator. The machine is designed with 18 slot and 20 poles catering to the three blade structure of the wind turbine in place. A detailed analysis of the electromagnetic analysis is presented in this paper.

Methodology

Fig.1 shows the flowchart of the methodology employed in the machine. The ratings of the generated voltage based on the sizing are computed using the Equation (1) to Equation (3). The generated voltage (Q) of the machine is derived as

\[ Q = \text{Magnetic loading} \left( B_{\text{avg}} \right) \times \text{Electrical Loading (ac)} \]  
\[ Q = 1.11 \times K_p K_d \left( B_{\text{avg}} DL \right) \left( \text{ac} \right) n_s 10^{-3} \]  
\[ Q = 1.11 K_p K_d \left( B_{\text{avg}} L \right) \left( \text{ac} \right) \frac{v_p}{n_s} 10^{-3} \]

where

\[ K_p: \text{Pitch factor} \quad K_d: \text{Distribution factor} \]

D: Outer diameter of the machine L: Stack length

\[ v_p: \text{Rotational speed} \left( = \pi D n_p \right) \]

\[ n_s: \text{Synchronous speed} \]

Fig.2 shows the cross section view of the designed machine and Fig.3 shows the exploded view of the design. Table 1 shows the corresponding values of the designed machine.

![Fig.1 Methodology used for the design of the machine](Image)

![Fig.2 Cross Section Area of Design](Image)

![Fig.3 Exploded View of Design](Image)

<table>
<thead>
<tr>
<th>TABLE 1. Designed Machine Parameter</th>
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<tr>
<td>Parameter</td>
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<tr>
<td>Outer diameter</td>
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<tr>
<td>Outer rotor inner diameter</td>
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<tr>
<td>Air gap length</td>
</tr>
<tr>
<td>Shaft diameter</td>
</tr>
<tr>
<td>Stack length</td>
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<tr>
<td>Turns per phase</td>
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<td>Rated current</td>
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The magnetic flux density for one pole pitch value is shown in Figure 5. This magnetic flux density computed through simulation confirms with the designed value earlier for proper excitation and operations of the proposed machine. The electrical parameters of the voltage, current and power are computed in order to conduct an analysis on the performance of the machine. The voltage and the power generated are calculated using a dummy resistive load and the rotor is rotated. The computation is done for both static and dynamic conditions. The voltage and power generated is then computed for various positions of the rotor when a constant current is applied. The same procedure is done with constant frequency applications and the rotor is rotated for various speeds.

Results and Discussion

Figure 6, shows that as the rotational degree value increases, the magnetic flux decreases slightly during the static condition. Figure 7 shows that as the voltage generated increases from 0 V to 25 V, there is a drastic increase in the magnetic flux. However, as the voltage increases further, there is only a slight increase in the magnetic flux. In a machine, when the voltage increases, this results in an increase in the magnetic flux as the voltage is proportional to the flux when the speed of rotation in a machine is fixed. Figure 8 shows that as the speed of rotation increases, there is a gradual linear increase in the voltage generated by the design because in DC machines, the speed of rotation is directly proportional to the voltage of the machine. Based on the graphs, it can be concluded that the voltage of the machine produced is 150V. The maximum power produced is 250W at 1200 rpm.

Conclusions

Through mechanical variations on the design, a better torque is produced when the diameter of the rotor is increased. By optimising the pole design a novel structure is proposed in this research. The electromagnetic design analysis of such a machine presents encouraging power density improvements. Initial investigations reveal a generated voltage of 150V when the design runs at 1200 rpm. This machine is ready for fabrication and is to be integrated with an application (in this case a small size laboratory wind turbine).

References