Stator Teeth Pairing Design Optimization of Dual Radial Flux Permanent Magnet Generator for Cogging Torque Minimization

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Abstract

Wind energy has been growing fast and is recognized as the most successful energy source among all the alternative energy sources. However, due to the low utilization rate, the spread of small-scale wind power generator is progressing slowly. In this paper, the stator teeth pairing design is studied to reduce the cogging torque of the dual radial flux permanent magnet generator for small scale wind turbines. The proposed method is capable to minimize the characteristic deterioration due to cogging torque reduction through an asymmetric design of teeth width. The proposed design method is verified through finite element analysis.

Keywords
Cogging torque reduction, Stator teeth pairing, Design optimization.

1. Introduction

Development of renewable energy used in urban environments is of growing interest to industry and local governments as an alternative to utility-based and non-renewable forms of electric production. In particular, Wind energy has been growing fast and is recognized as the most successful energy source among all the alternative energy sources [1-3]. However, due to the low utilization rate, the spread of small-scale wind power generator is progressing slowly.

The vibration and noise of the generator are caused by cogging torque produced by attraction force between rotor magnet and stator core. And it also determines the cut-in speed of wind turbine.

Various methods for reducing the cogging torque such as skew, notch, pole-arc and slot opening optimization have been studied in the existing studies, but they are not widely used due to the drawbacks of deteriorating the characteristics of the generator and difficulties in manufacturing [4-9].

Dual radial flux permanent magnet generator (DRFPMG) has higher efficiency and power density than conventional generator because of high output voltage and space utilization. Cogging torque of DRFPMG is can be easily canceled by cogging torque phase shift of inner and outer stator.

However, the complete cancellation is difficult due to the cogging torque difference between the inner stator and outer stator. In addition, there is a disadvantage that the cogging torque reduction amount is greatly changed according to the assembly tolerance due to the multi-pole structure.

In this paper, the stator teeth pairing design is studied to reduce the cogging torque of the DRFPMG for small scale wind turbines. The proposed method is capable to minimize the characteristic deterioration due to cogging torque reduction through an asymmetric design of teeth width.

The proposed method minimizes the cogging torque sum by designing the teeth width of the inner stator and the outer stator core asymmetrically. It is easier to manufacture than the method of offsetting the phase of the cogging torque of the conventional inner stator and the outer stator.

2. Dual radial flux permanent magnet generator

2.1 Structure of dual radial flux permanent magnet generator

DRFPMG is a combination of the inner wheel type generator and the outer ring type generator as shown in Fig.1. Due to these structural characteristics, the output density and the output voltage are higher than those of conventional generators.

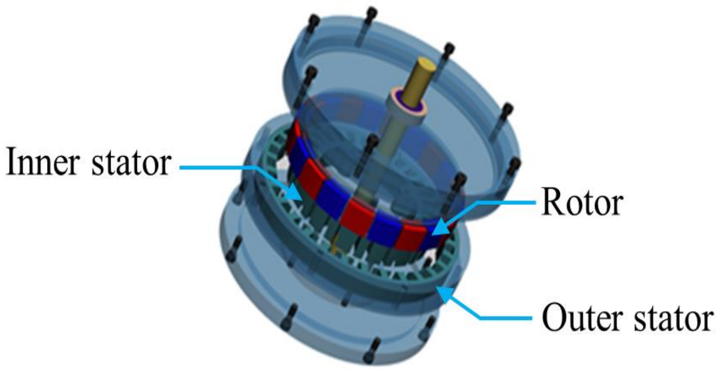

Figure 1. Structure of DRFPMG

2.2 Stator teeth pairing of dual radial flux permanent magnet generator

The DRFPMG is theoretically capable of reducing the cogging torque completely by canceling the cogging torque generated between the inner and outer stator and the rotor but the size of the cogging torque is different due to the difference in the air-gap diameters of the inner and outer stator as shown in Fig. 2.

In addition, Due to the multi-pole structure for obtaining a high voltage at low speed, it is necessary to precisely design the angle between the inner stator and the outer stator of the DRFPMG, and a high-level manufacturing technique is required for perfect implementation.

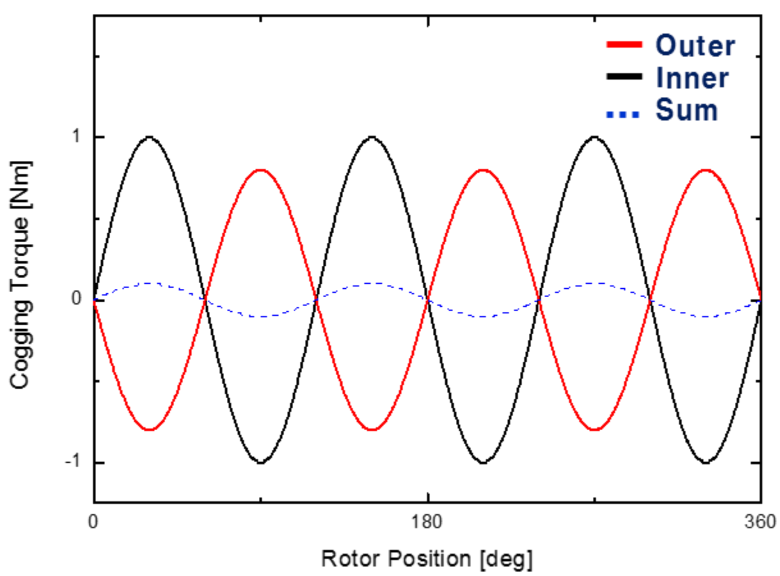

Figure 2. Cogging torque of DRFPMG

In this paper, we propose a method to minimize the sum of the cogging torque by designing the teeth widths of the inner stator and the outer stator asymmetrically.

In the conventional DRFPMG, the inner and outer stator teeth width is designed to be equal as shown in Fig. 3. However, when the proposed method is applied, the inner stator and the outer stator have different teeth width as shown in Fig. 4.

Since the magnitude and period of the cogging torque change as the width of the stator teeth changes, the cogging torque can be reduced by optimizing the tooth width combination of the two stators.

The proposed cogging torque reduction method has advantages that it is easier to implement than the existing cogging torque reduction method.

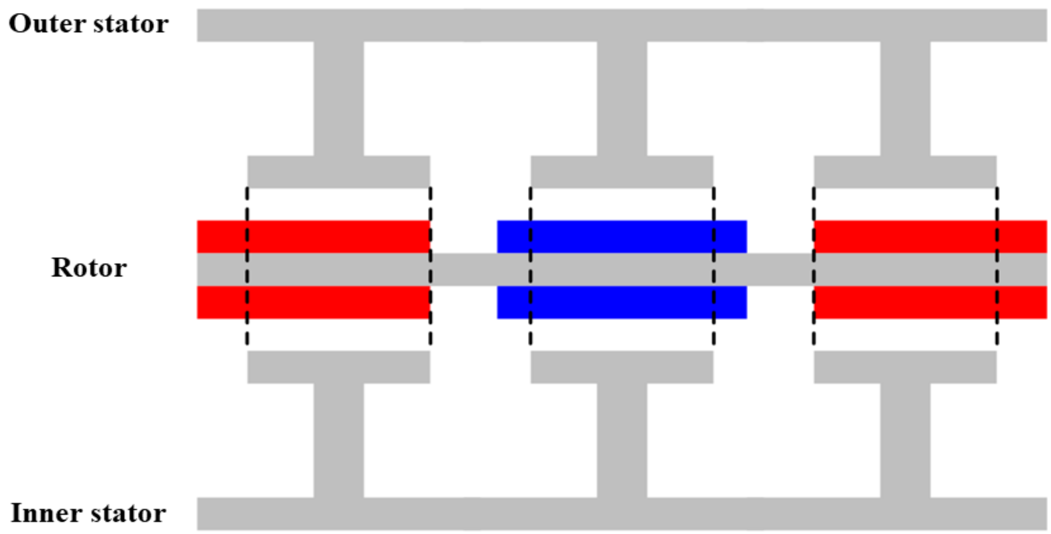

Figure 3. Conventional structure of DRFPMG

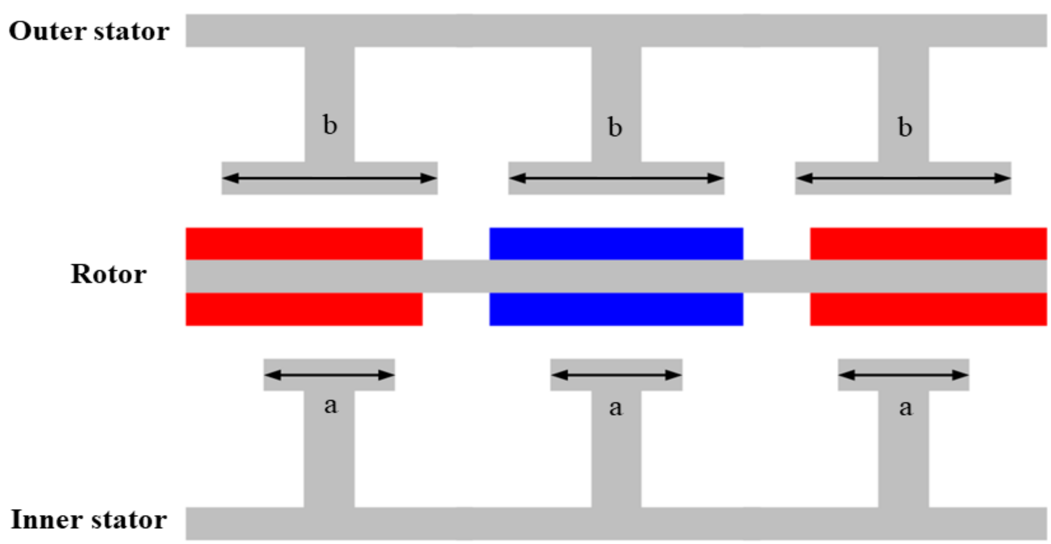

Figure 4. Proposed structure of DRFPMG

3. Finite element analysis

3.1 Modeling of DRFPMG

Figure 5 shows the initial model of DRFPMG for finite element analysis (FEA). The specifications of initial model are summarized in Table 1.

To verify the proposed cogging torque reduction technique, the shape of the permanent magnet was kept the same and only the tooth width of the inner stator and the outer stator was changed. The initial values are derived from the following equation.

$$\frac{2}{n\pi}\frac{N_S}{N_L}\sin n\,N_L\frac{a}{2}=0$$

In the above equation, *n* is an integer, N_s is the number of slots, N_L is the number of poles, and *a* is the width of the stator teeth.

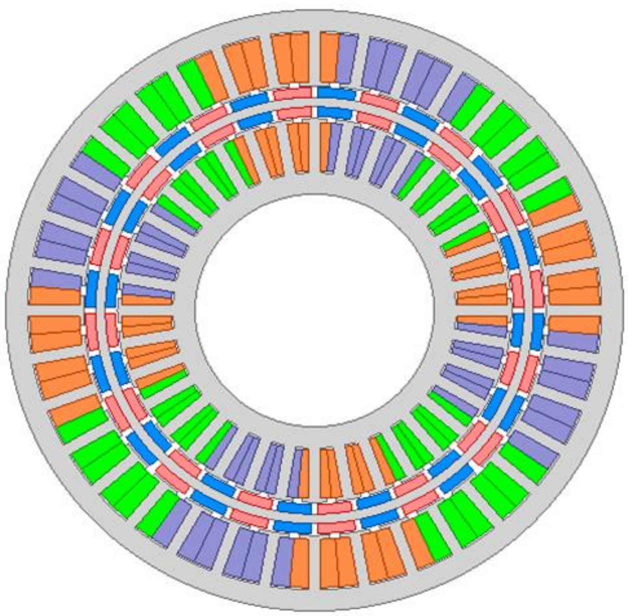

Figure 5. Initial model

Table 1. Specifications of initial model

Parameter	Value
Rated speed [rpm]	300
Rated power [kW]	3
Outer diameter [mm]	310
Stack length [mm]	50
Air-gap length [mm]	1
Number of slots	36
Number of poles	32

3.2 FEA results

Figure 6 shows the cogging torque analysis result according to the variation of the slot teeth width combination. From the analysis results, it was confirmed that cogging torque was reduced by up to 67% by applying the proposed method, and the efficiency is maintained as shown in Table 2.

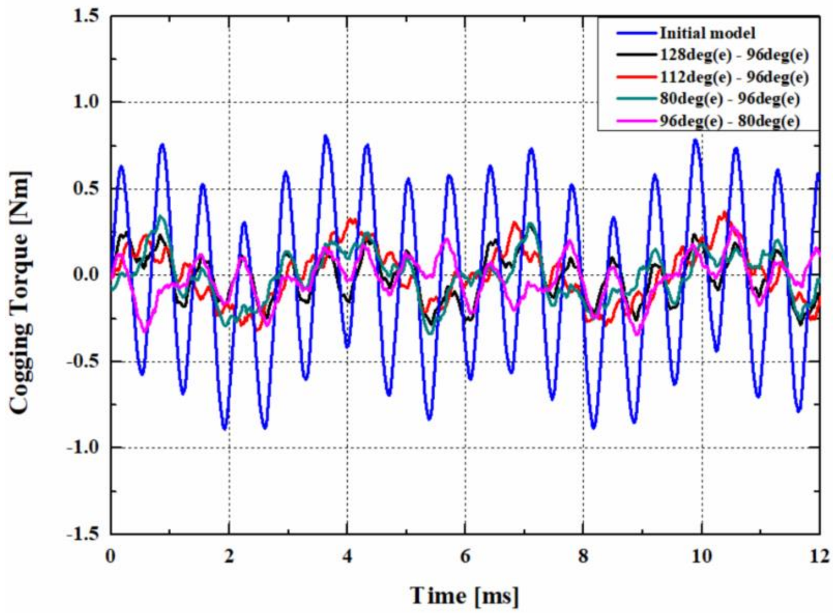

Figure 6. Cogging torque analysis result according to stator teeth width combination

Table 2. Comparison of output characteristics of initial and optimized model

Parameter	Initial	Optimized
Speed [rpm]	300	300
Torque [Nm]	121.9	122.8
Cogging torque [Nm]	1.8	0.59
Output voltage (inner) [Vrms]	84.6	86.4
Output voltage (Outer) [Vrms]	174.8	173.8
Output current [Arms]	6.1	6.2
Input power [W]	3829	3856
Output power [W]	3402	3431
Efficiency [%]	88.8	88.9

4. Conclusion

The aim of this study is to minimize the cogging torque of DRFPMG through a stator teeth pairing optimization. As a result of optimization, the cogging torque is reduced about 67[%] compared with the initial model. By applying the proposed cogging torque reduction method, the cogging torque can be reduced without degrading the efficiency.

Acknowledgements

This research was supported by Korea Electric Power Corporation. (Grant number: R18XA06-50)

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Biographies

Jin-Hyung Yoo was born in Changwon, Korea, in 1986. He received the B.S degree in electrical engineering from Gyungsang National University and M.S degree from Kyungnam University Gyeongnam, Korea, in 2012, 2015 respectively. He is currently an assist manager at Rotec Co., Ltd. His main research interests are energy conversion machine and power conversion device design, control and application.

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