Design Optimization of A Novel Scale-Down Hybrid-Excited Dual-PM Generator for Direct-Drive Wind Power Application

Qingsong Wang[1], Shuangxia Niu[1], *Member, IEEE* and Lin Yang[2]

[1]Department of Electrical Engineering, Hong Kong Polytechnic University, Hong Kong, q.s.wang@connect.polyu.hk
[1]Department of Electrical Engineering, Hong Kong Polytechnic University, Hong Kong, eesxniu@ polyu.edu.hk
[2]State Power Economic Research Institute, Beijing, China, eelinyang@163.com

This paper presents a novel scale-down hybrid-excited dual-PM generator, which is suitable for direct-drive wind power application. Two sets of consequent-pole PMs are used in the proposed design, one on the outer stator, and the other on the middle rotor. Both the two sets of PMs are separated by iron poles one by one, to form the PM-iron sequences, which can provide PM excitation and flux modulating simultaneously. Since both the outer stator and middle rotor have flux modulating effect, bi-directional flux modulating can be achieved. Besides the fundamental field components, some other major field harmonics are also synchronous due to the bi-directional flux modulating effect, and these harmonics can contribute to the electromagnetic generation, therefore the proposed machine can achieve high torque density and suitable for direct-drive applications. Field windings are employed on the outer stator, the air-gap field can be easily regulated by controlling the dc current, hence the proposed generator can maintain constant output voltage when the wind speed varies. Finite element method coupled with genetic algorithm is used to optimal design a scale-down prototype of the proposed generator, and its electromagnetic performances are studied in detail.

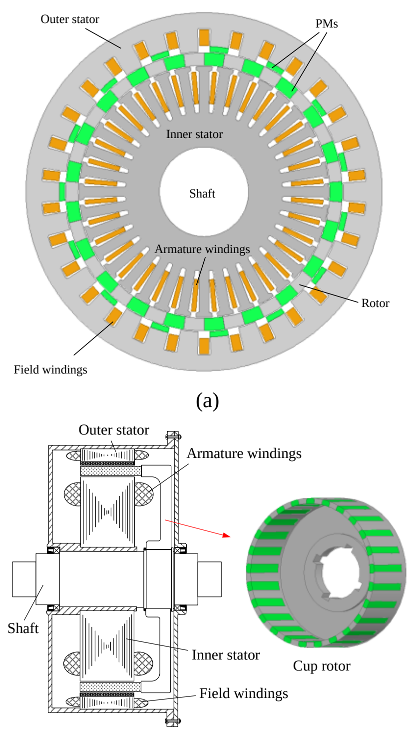
***Index Terms*—Dual-PM, genetic algorithm, hybrid-excited, optimal design, PM-iron sequence.**

I. Introduction

Due to the increasing concerns on environmental pollution and shortage of fossil energy, researches on the clean energy have attracted substantiate attention. As one of the promising energy sources, wind power is renewable and has huge reserves, and the development of wind power generators is being widely investigated[1-3].

To meet the torque requirement of wind power system, the output torque of the generator is usually amplified by a mechanical gearbox, which makes the wind power system bulky and inefficient. A magnetic-geared wind turbine has been proposed in [4], the outer rotor of the generator is directly connected to the inner rotor of magnetic gear. This wind turbine can achieve high torque density but still suffers from reduced efficiency drawback, because the magnetic gear will cause efficiency reduction. Therefore, wind power generators with high torque density and can realize direct drives need to be developed. Meanwhile, to maintain constant output voltage when the wind speed varies, good flux regulating capability is also an admiring feature for wind power generators [5].

In this paper, a novel hybrid-excited dual-PM generator concept is proposed, which can achieve high torque density and good flux regulating capability simultaneously, and very suitable for direct-drive wind power application. Both the stator and the outer rotor have flux modulating effect, namely bi-directional flux modulating, which can effectively couple the magnetic fields excited by the two sets of PMs and the armature currents. A scale-down prototype of the proposed generator is optimal designed using finite element method coupled with genetic algorithm, which is referred as FEM-GA coupled method. The electromagnetic performances of the proposed generator is investigated in detail.



(b)

Fig. 1. Configuration and mechanical structure of the proposed machine. (a). Configuration. (b). Mechanical structure.

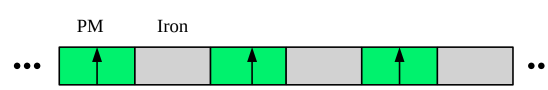


Fig. 2. Configuration of the PM-iron sequences.

II. Machine Configuration

Fig. 1 shows the configuration and mechanical structure of the proposed generator. It can be seen that the proposed generator consists of three parts, namely the inner stator, the outer stator and the middle rotor. Since the rotor is sandwiched between the two stators, cup rotor structure is used to facilitate the assembly. The PMs are employed on both the outer stator and the rotor, all the PMs are separated by the iron poles one by one, to form the PM-iron sequences as shown in Fig. 2, which can provide PM excitation and flux modulation simultaneously. Bi-directional flux modulating can be achieved since both the stator and the rotor have flux modulating effect, besides the fundamental field components, some other major harmonics are also synchronous and can contribute to the electromagnetic torque generation, therefore the proposed generator can realize high torque density and suitable for direct-drive application. The armature windings and field windings are housed in the inner stator and outer stator, respectively. The induced voltage can be easily regulated by controlling the field current, so the proposed generator can maintain constant output voltage when the wind speed varies.

III. DESIGN OPTIMIZATION AND PERFORMANCE ANALYSIS

FEM-GA coupled method is used to optimal design the proposed generator, its flowchart is shown in Fig. 3. The objective of optimization is to realize the highest output voltage when the generator runs at a fixed speed. The overall diameter and axial length is fixed at 160mm and 60mm, respectively. The electromagnetic performances of the proposed generator after optimization is investigated using FEM.

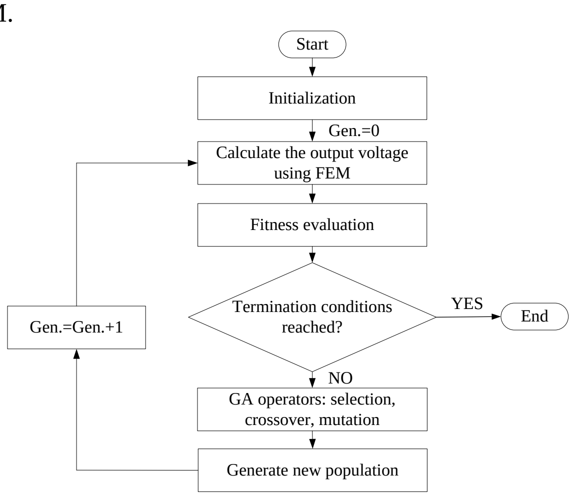


Fig. 3. Flowchart of the FEM-GA coupled method.

Fig. 4 shows the flux density in the inner air-gap when applied with different DC currents. One can find that the air-gap can be regulated effectively. The no load back EMF when the proposed generator runs at 143rpm, 429rpm and 1287rpm are calculated and shown in Fig. 5. It can be observed that without flux control, the back EMF is proportional to the machine speed and will increase with the increasing of machine speed. With flux control by controlling the DC field current, the proposed generator can maintain constant back EMF when the rotating speed varies. The torque capability of the proposed generator is investigated at motoring mode, and the torque-angle waveforms are given in Fig. 6. It can be seen that the output torque can also be regulated effectively. The maximum torque reaches 92Nm, the corresponded torque density is 76.7kNm/m^3, which is significantly larger than traditional surface PM and insert V-type PM synchronous machines.

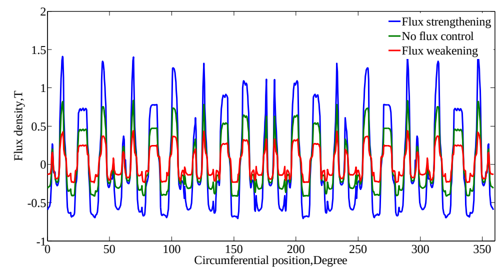


Fig. 4. Flux density in the inner air-gap.

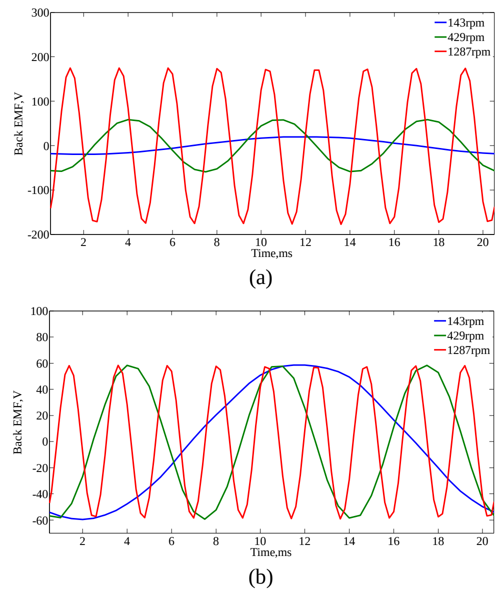


Fig. 5. No load back EMF waveforms. (a). Without flux control. (b). With flux control.

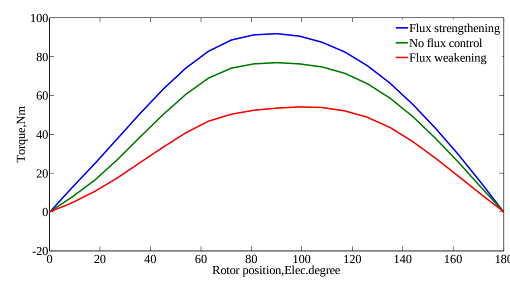


Fig. 6. Torque-angle waveforms.

REFERENCES

[1] F. Ying, K. T. Chau, and S. Niu, "Development of a New Brushless Doubly Fed Doubly Salient Machine for Wind Power Generation," *IEEE Trans.Magn.*, vol. 42, pp. 3455-3457, 2006.

[2] Q. Wang and S. Niu, "Overview of flux-controllable machines: Electrically excited machines, hybrid excited machines and memory machines," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 475-491, 2017.

[3] Y. Chen, P. Pillay, and A. Khan, "PM wind generator topologies," *IEEE Trans. Ind. Appl.*, vol. 41, pp. 1619-1626, 2005.

[4] L. Jian, K. Chau, and J. Jiang, "A magnetic-geared outer-rotor permanent-magnet brushless machine for wind power generation," *IEEE Trans. Ind. Appl.*, vol. 45, pp. 954-962, 2009.

[5] C. Yu, K. Chau, and J. Jiang, "A flux-mnemonic permanent magnet brushless machine for wind power generation," *Journal of applied Physics*, vol. 105, p. 07F114, 2009.