A Permanent Magnet Brushless Doubly-Fed Generator with Segmented Structure

Yongjiang Jiang, Jianzhong Zhang*, and Tianyi Li
School of Electrical Engineering, Southeast University, Nanjing, China
*Corresponding author: jiz@seu.edu.cn

The brushless doubly-fed machine (BDFM) has a great of advantages in the application of wind power generation. To improve the performances of the traditional BDFM, a new permanent magnet (PM) brushless doubly-fed generator (BDFG) with complementary structure is proposed in this paper. Compared with the traditional BDFM, there is an additional PM rotor providing excitation magnetic field for power and control windings. Benefiting from the absence of the exciting current and the excitation loss, the efficiency and the power density may be increased. The function of the field modulation rotor is same as that of reluctance rotor of the traditional BDFM, but the structure is simpler. In order to solve a series of problems due to the introduction of PM rotor and the field modulation ring, the segmented structure is adopted. Finally the performance of the proposed generator is verified by using finite element method.

***Index Terms*—brushless doubly-fed machine, segmented structure, double-rotor machine, magnetic gear, wind power generation.**

I. Introduction

IN RECENT YEARS, brushless doubly fed machine (BDFM) for wind power generation has become the focus of domestic and foreign scholars to cancel the slip rings and brushes [1]. As it is same with the doubly fed induction generator (DFIG), only a part-size converter is needed in the BDFM system. However, it has some disadvantages, such as complicated rotor structure, high harmonic distortions, low power density and low efficiency, which limit the application of the BDFM.

In order to improve the performance of the traditional BDFM, a new PM brushless doubly-fed generator (BDFG) is proposed in this paper. And segmented structure is adopted to solve the high cogging torque and the asymmetrical three-phase no-load electromotive force (EMF) due to the introduction of the PM rotor and field modulation ring.

II. Topology and Operation Principle

A. Topology of the PM BDFG

Field modulation ring is the key functional component of the coaxial magnetic gear [2]. It is used for the transmission of torque between two rotors whose rotational speed and pole-pair number are different. Field modulation principle of the field modulation ring is the same as that of the reluctance rotor of the BDFM. So it could be introduced to the BDFM for insteading of the reluctance rotor. And the PM inner rotor is introdued to provide the excitation magnetic field for the power and control windings, as shown in Fig. 1.

B. Operation Principle

Supposing the pole-pair numbers of the power winding, control winding, field modulation ring and PM rotor are pp, pc, Ns and pPM, respectively. Through the modulation effect of the outer rotor, the magnetic field generated by PM rotor could be converted into a series of space harmonics. According to the principle of coaxial magnetic gear, pc=Ns-pPM, pp= pPM, and the effective harmonics magnetic field in the outer airgap can be approximately considered as [3]

$$\begin{cases} B_p = a_0 c_0 \times \cos(p_{PM}(\theta - \theta_{ir} + \theta_{ir0})) \\ B_c = \dfrac{a_1 c_1}{2} \times \cos\begin{pmatrix} (N_s - p_{PM})\theta - (N_s\theta_{or} - p_{PM}\theta_{ir}) \\ +(N_s\theta_{or0} - p_{PM}\theta_{ir0}) \end{pmatrix} \end{cases} \quad (1)$$

where a_0, c_0, a_1, and c_1 are constants. θ_{ir0} and θ_{or0} are the initial mechanical angular positions of the inner and outer rotor, respectively. θ_{ir} and θ_{or} are the mechanical angular positions of the inner and outer rotor, respectively. θ is the mechanical angular position in the outer airgap.

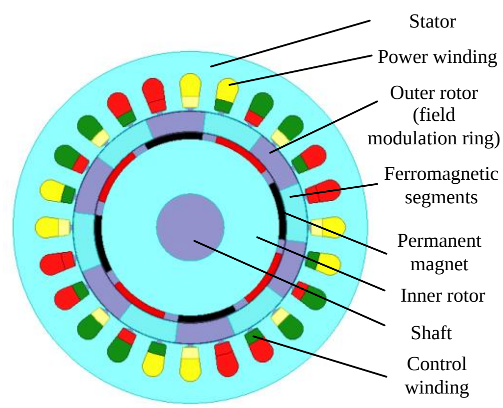


Fig. 1 Topology of the proposed PM BDFG

According to equation (1), when pc=Ns-pPM and pp= pPM, the PM rotor could provide appropriate excitation magnetic field for the power and control windings, respectively. According to the principle of magnetic gear, the speed of the outer rotor is

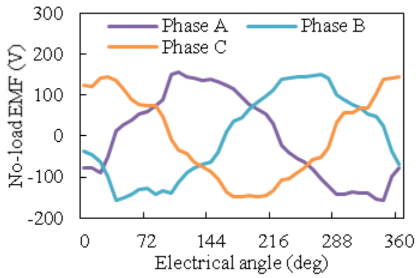
$$n_{or} = \frac{60(f_s + f_c)}{p_p + p_c} \quad (2)$$

where f_s and f_c are the frequency of the current input to power winding and control winding, respectively. It is same as that of the traditional BDFM.

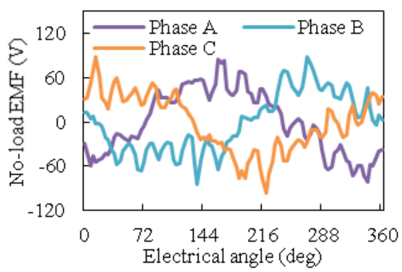
C. Introduction of Problem

Not like the conventional three-phase electric machine, the different speed between the excitation source and the synchronous speed caused to the asymmetrical EMF of the outer three phase winding in one electric cycle, as shown in Fig.

2. For the existence of PM and field modulation ring, the cogging torque is large, as shown in Fig. 3.



(a)



(b)

Fig. 2 No-load EMF of the three phase outer winding
(a) power winding; (b) control winding

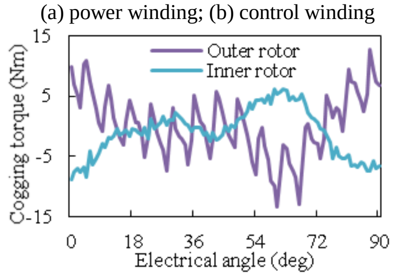


Fig. 3 Cogging torque of the PM BDFG

D. *Segmented Structure*

For there is three phase, the generator is divided to three segments, to make the magnetic circuit of the three-phase winding symmetry. According to equation (1), the angle difference between the segments satisfied the following equal

$$\Delta\theta_{or0} = p_{PM}\Delta\theta_{ir0} / N_s \quad (5)$$

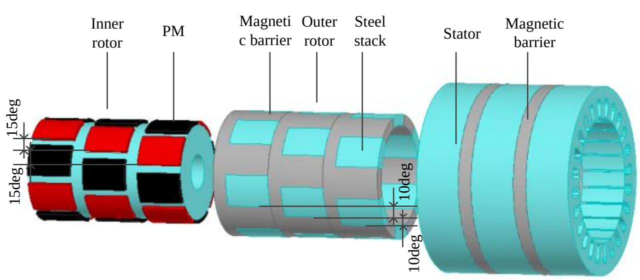


Fig. 4 The structure of the PM BDFG with segmented structure

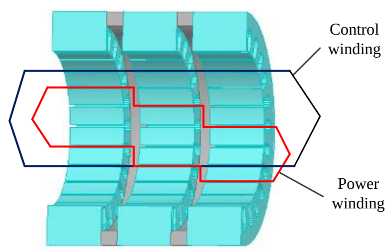
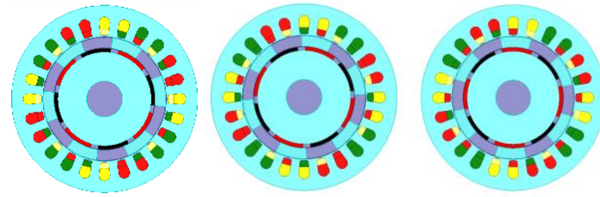


Fig. 5 Stator winding configuration

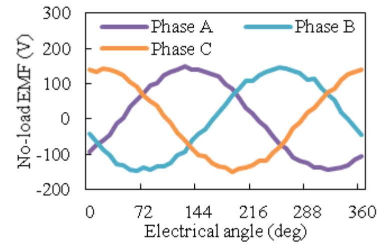
III. Finite Element Analysis

According to the previous analysis, three models are established for three segments is established, as shown in Fig. 6, where. The result of simulation is shown in Fig.7.

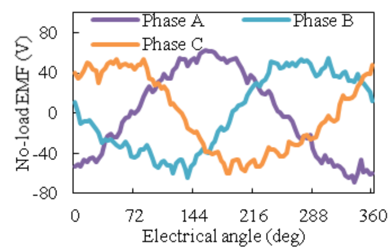


(a) (b) (c)

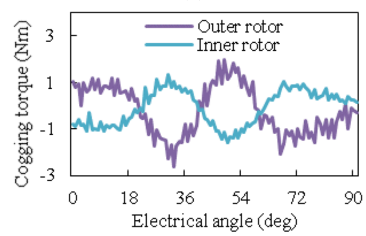
Fig. 6 The structure of segmented stator and rotor.
(a) segment 1 (b)segment 2 (c) segment 3



(a)



(b)



(c)

Fig. 7 No-load EMF and cogging torque
(a) power winding; (b) control winding; (c) cogging toroque

IV. Conclusions

In this paper, in order to minimize the cogging torque and asymmetrical EMF, a PM BDFG with segmented structure is proposed. The theoretical analysis and the details of the solution are discussed. Finally the effectiveness is verified by the FEM.

References

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