Design and Operation Performance Research of Brushless Doubly-Fed Generator with Cage Bar Assisted Reluctance Rotor

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Abstract

Brushless doubly-fed generator (BDFG) is particularly suitable for using in variable speed constant frequency wind power generation system due to its inherent characteristics. The two sets of stator windings with different numbers of magnetic poles are coupled by magnetic field modulation of a special rotor, so the rotor structure directly affects the performance of BDFG. In this paper, a cage-assisted reluctance rotor structure is presented to enhance the rotor coupling capacity and improve the efficiency of BDFG. Firstly, the structure characteristics of the proposed rotor are illustrated in detail. Secondly, the magnetic field modulation mechanism of the proposed rotor is analyzed. Then the operation performance of the proposed BDFG especially under sub-synchronous and super-synchronous mode is studied. Finally, a 25kW prototype is designed and manufactured to verify the advantages and feasibility of the proposed rotor structure. The experimental results show that the BDFG with the proposed rotor has some advantages such as strong magnetic field coupling ability, high efficiency, superior performance and so on.

Design and Analysis of Proposed BDFG

The two sets of stator windings with different numbers of magnetic poles are coupled by magnetic field modulation of a special rotor, so the rotor structure directly affects the performance of BDFG. In order to achieve electromechanical energy conversion, the number of rotor poles should be meet the requirement as

$$p_r = \omega_p + \omega_c$$

where, p_p and p_c are pole pair number of power winding and control winding, respectively. Therefore, the speed of BDFG can be written as

$$\omega_r = \left(\omega_p + \omega_c\right) / p_r$$

where, ω_p and ω_c are denote current angular frequency of power winding and control winding, respectively.

Fig. 3 shows the air-gap magnetic field distribution of the proposed BDFG and Fig. 4 shows the power flow chart of proposed BDFG.

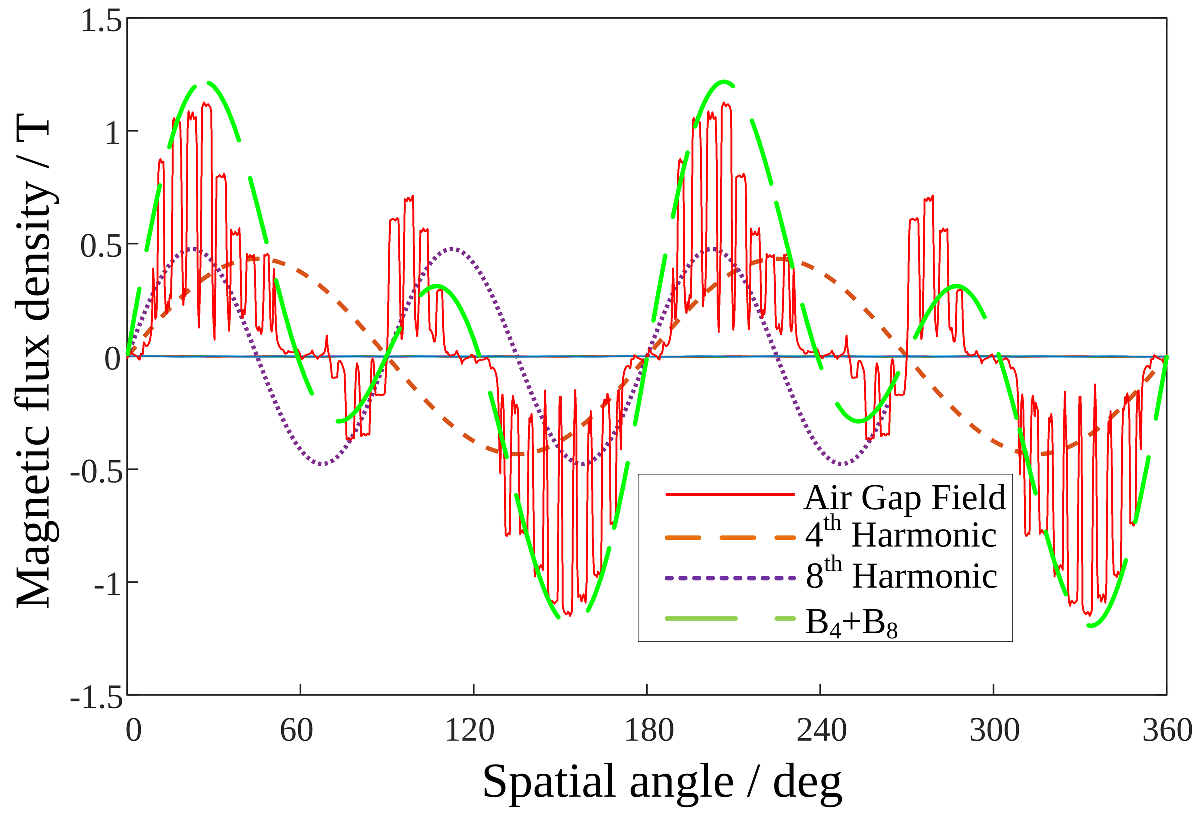
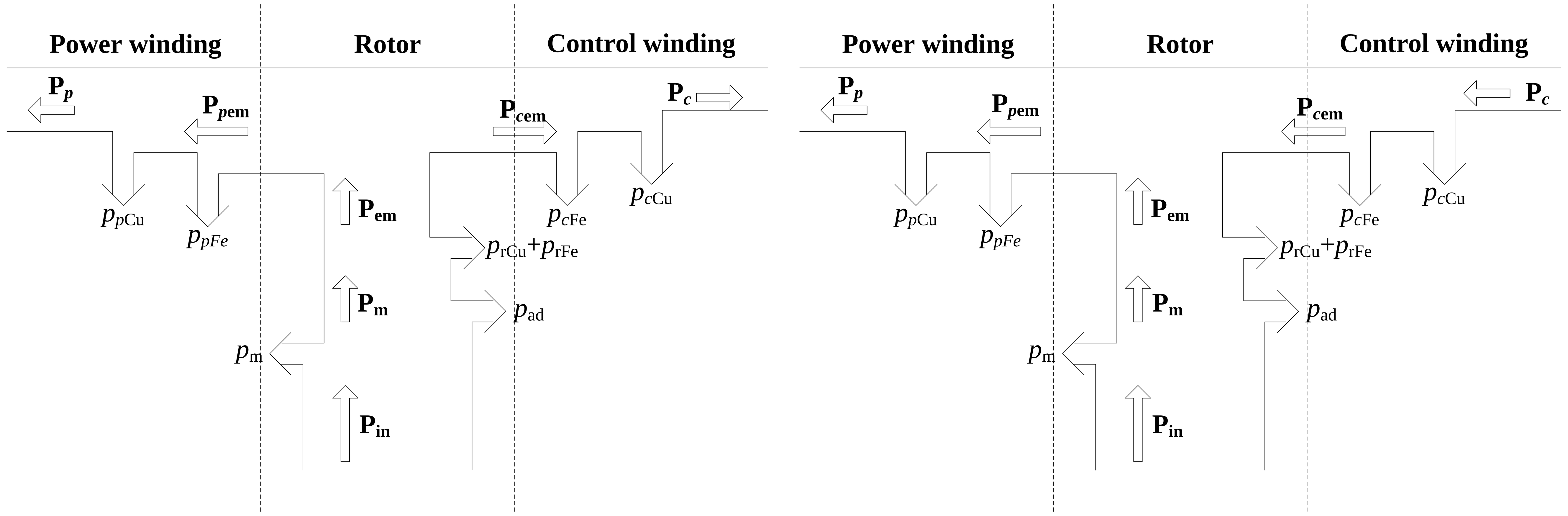


Fig. 3 Air-gap magnetic field distribution

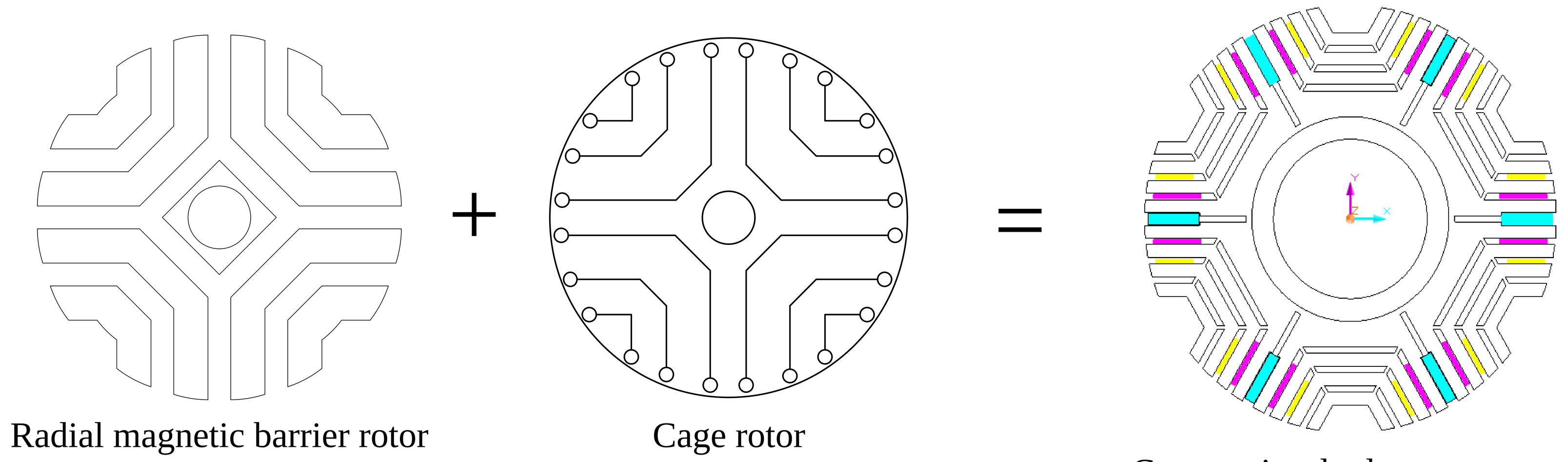


(a) Energy transmission in super-synchronous mode

(b) Energy transmission in sub-synchronous mode

Fig. 4 Power flow chart of proposed BDFG

Structure of Cage-assisted Reluctance Rotor



Radial magnetic barrier rotor + Cage rotor = Cage-assisted reluctance rotor

Fig. 1 Schematic diagram of cage-assisted reluctance rotor

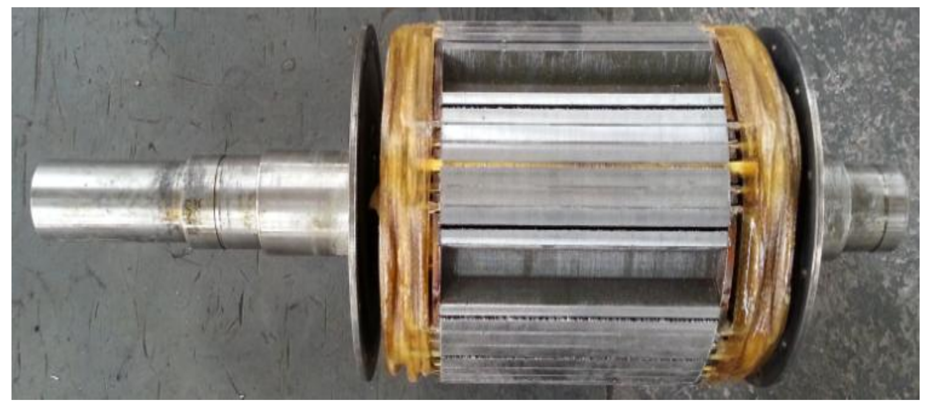


Fig. 2 Prototype of proposed rotor

As shown in Fig. 1 and Fig. 2, the proposed cage-assisted reluctance rotor is composed of magnetic barriers and cage bars. The magnetic barrier layers are used in the radial laminated reluctance rotor, and the short-circuit cages are added in the magnetic barrier reluctance rotor. The cage bars in the rotor are divided into common cage bar and concentric cage bar. Therefore, it has the advantages of both rotor structures such as simple structure, low losses, good starting performance, strong coupling ability, easy manufacturing process and so on.

Experimental Results and Discussion

Table 1 lists the specifications of the prototype, and Fig. 5 shows the experimental platform. In the system, the BDFG is driven by the induction machine. The BDFG is tested under sub-synchronous mode (300 r/min) and super-synchronous mode (700 r/min), and the efficiencies are shown in Fig. 6. According to Fig. 6, it can be known that the efficiency is higher when the BDFG is operated in super-synchronous mode.

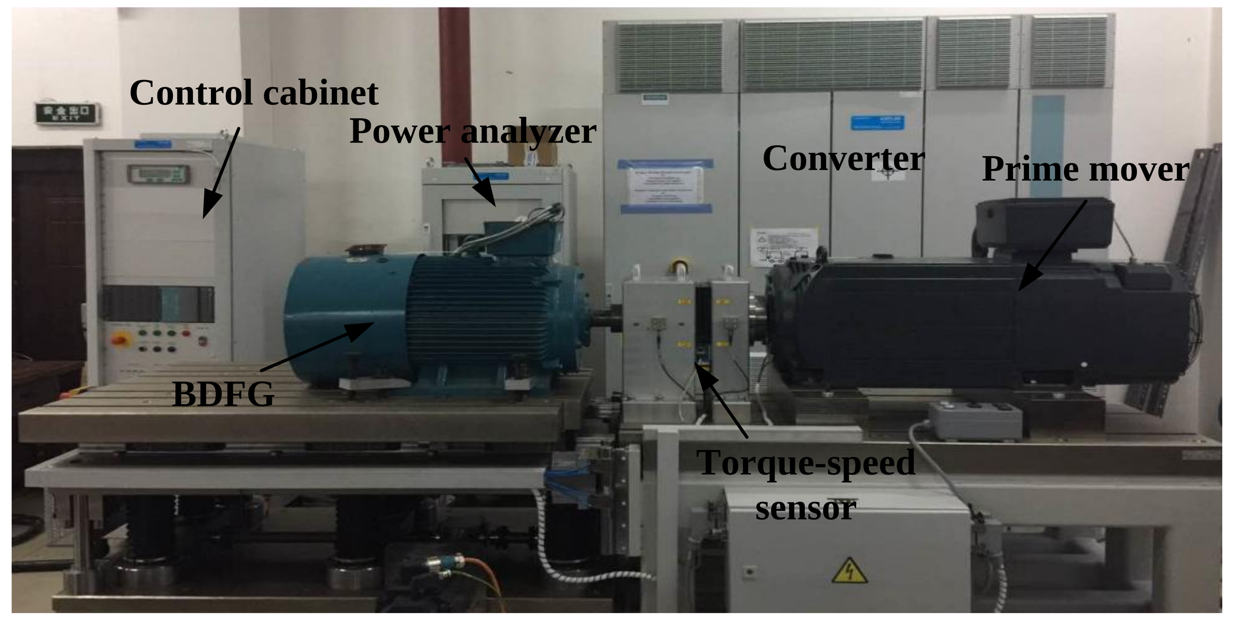


Fig. 5 Experimental platform

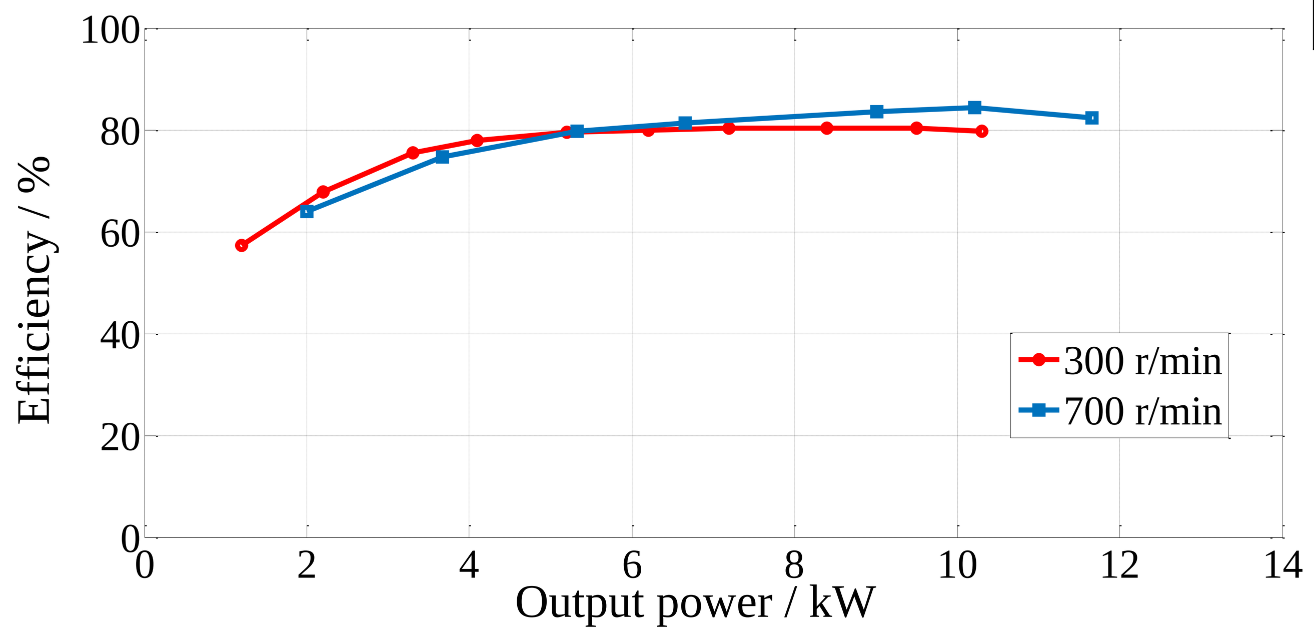


Fig. 6 Efficiency of proposed BDFG under doubly-fed operation mode

Table 1. Specifications of prototype BDFG

Parameter, Symbol (Units)	value
rated power, P_N (kW)	25
stator voltages, $[V]_{p,c}$ (V)	[380, 380]
rated speed, n (r/min)	1000
natural speed, n_0 (r/min)	500
pole pair, $[p]_{p,c}$	[4, 2]
frequency of stator $[f]_{p,c}$ (Hz)	[50,50]
Stator inner diameter D_{i1}(mm)	400
Stator outer diameter D_1(mm)	285
Core length l_{ef} (mm)	225
Number of stator slot Z	72
Air gap width δ(mm)	0.5

Conclusion

In this paper, a cage-assisted reluctance rotor is proposed to improve the coupling ability. The structure characteristics and magnetic field modulation mechanism of the proposed rotor are illustrated. The operation performance of the BDFG is analyzed and verified by a 25kW prototype. The experimental results show that the proposed BDFG has good performance.

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