Rotor Losses Research of Brushless Doubly-fed Machine with Hybrid Rotor

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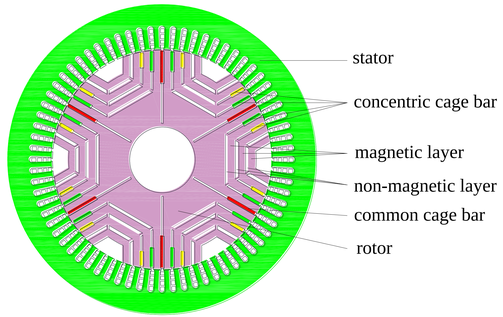
Abstract

Brushless doubly fed machine (BDFM) is a new type of adjustable-speed machine developed in recent years. It has broad application prospects in the field of variable frequency speed regulation and wind power generation. However, the traditional loss calculation method is no longer applicable due to the special structure and complex magnetic field distribution of BDFM. A novel hybrid rotor structure which has better coupling ability than the commonly used rotor structures such as cage rotor, wound rotor and reluctance rotor is presented but it also increases the difficulty of rotor loss calculation. In this paper, in order to calculate the rotor loss accurately, the time-stepping finite element models of rotor iron loss and copper loss of BDFM with hybrid rotor are established by considering the influence of skin effect, harmonic magnetic field and eddy-current loss. Based on the finite element model of the iron losses of rotor, the iron losses (hysteresis loss, eddy-current loss and added loss) is simulated and analyzed. The equivalent circuit of hybrid rotor cage bar is presented and based on the model of copper loss, the rotor copper loss is calculated and simulated.

Introduction

BDFM is a new type of machine with special structure, which has the advantages of reliable operation, adjustable power factor, small capacity converter and so on. Two independence stator windings which have different pole-pairs are placed in the same stator slots. The energy conversion is achieved by the magnetic field modulation of the rotor. Since core loss and copper loss have a significant effect on effiency and temperature distribution, So it is vital to accurately obtain rotor losses component in an optimal design procedure. In this paper, the simulation model of BDFM with hybrid rotor is established and analyzed, and the simulation results of the rotor core loss and copper loss are obtained.

Constructure and Parameter



The hybrid rotor is obtained on the basis of magnetic barrier rotor, i.e., the conductive cage bars are added on the center of the salient pole, and both ends of the rotor are fixed with a conductive ring.

Parameters	Value
Rated power /kW	25.8
Pole-pair number of power winding	4
Pole-pair number of control winding	2
Pole-pair number of rotor	6
Stator outer diameter /mm	400
Stator inner diameter /mm	285
Rotor outer diameter /mm	284
Rotor inner diameter /mm	85
Stack length /mm	225
Stator slots	72
Ratio of magnetic and non-magnetic layer	79

This kind of rotor adopts radial laminated structure. The losses calculation of BDFM with hybrid rotor is more complex than traditional AC machine because of the abundant harmonics, and it reduces the eddy current loss. In addition, due to the existence of cage bar in the rotor, the copper loss calculation is more difficult than the reluctance rotor.

Analysis of Rotor Copper Loss and Core Loss

The rotor copper loss calculation should be considered due to the existence of cage bar in the rotor.
The proposed rotor equivalent circuit of concen tric cage bar and common cage bar is shown in Fig.1.

Due to the power winding and control winding are both random coil with small wire diameter, the skin effect can be neglected. Therefore, the rotor copper loss P_{Cu} can be expressed as

$$P_{Cu} = \sum_{i=1}^{6}\sum_{j=1}^{2}(I_{ij}^2 R_j + I_{i3}^2 R_l + 2I_{ci}^2 R_{c3}) \qquad (1)$$

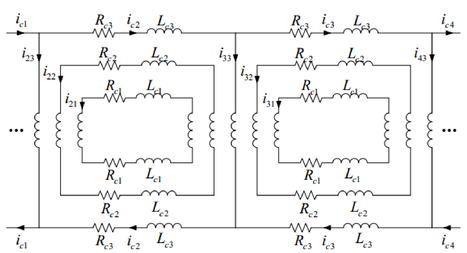


Fig.1 Equivalent circuit of hybrid rotor cage bar

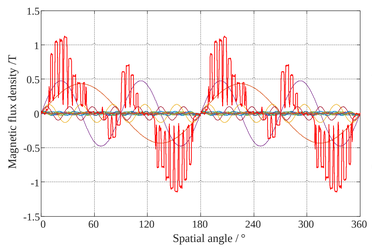


Fig.2 Air-gap magnetic field and its spatial harmonic spectrum of the BDFM with hybrid rotor (control winding is supplied with a 13.5 A, 50 Hz current source, power winding is open-circuit and rotational speed is fixed at 1000 rpm)

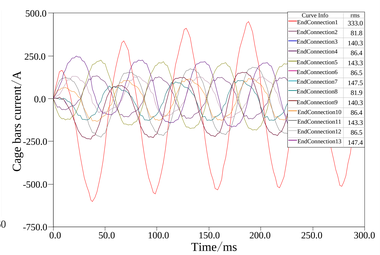


Fig.3 Hybrid rotor cage bars current

According to Fig. 3, it canbe seen that the cage bar current is simulated by finite element method. Therefore, the rotor copper loss can be calculated.

According to Fig.2, it can be seen that the harmonic contents of BDFM are more than that of the conventional machine, so it needs to consider the influence of harmonics on the core loss.
The magnetic field in the iron core varies with the time and space, so the effect of harmonic magnetic flux density, alternating magnetization and rotating magnetization need to be taken into account when calculating the BDFM core loss.
The rotor core loss includes hysteresis loss, eddy-current loss and added loss.

Results

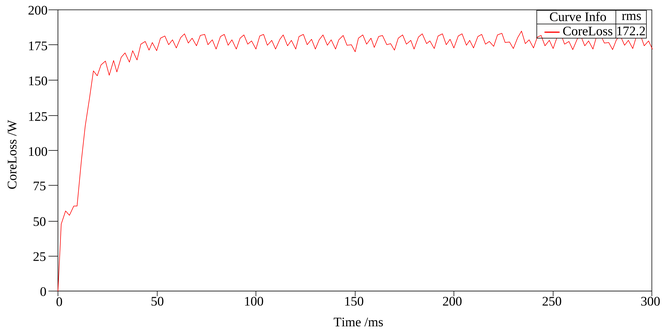


Fig.4 The rotor core loss curve of BDFM with hybrid rotor

The no-load rotor core loss curve is obtained by the finite element calculation of BDFM with hybrid rotor in Fig. 3. According to the Fig.3, the value of rotor core loss is 172.2W.

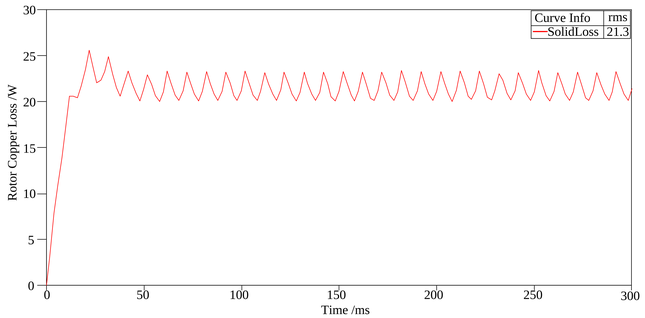


Fig.5 Rotor copper loss of BDFM with hybrid rotor

The cage bars current and rotor copper loss of BDFM with hybrid rotor is obtained by finite element method respectively in Fig. 4, Fig. 5. The calculation value of rotor copper loss is 24.7W by formula (1), and the simulation value of rotor copper loss is 21.3W.

Conclusion

- This paper has presented equivalent circuit and analytical equation for calculating rotor copper loss in brushless doubly fed machine with hybrid rotor.
- The time-stepping finite element model of rotor core loss and copper loss for the BDFM with hybrid rotor is established and analyzed.
- The rotor copper loss and core loss is respectively 21.3W, 172.2W. Moreover, the rotor copper loss is 24.7W by equivalent circuit of hybrid rotor cage bar.

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