Back-EMF Optimization of Constant-Frequency Double-Rotor Generator for Minimizing Harmonics

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Abstract —The optimal design of constant-frequency double-rotor (CFDR) generator for minimizing harmonics is proposed in this paper. Three parameters, pole arc factor, slot opening width and slope angle of permanent magnet, are optimized to reduce total harmonic distortion (THD) of the back-EMF waveform in CFDR generator. 2-D finite element analysis (FEA) is employed to calculate the magnetic field distribution and the back-EMF waveform. The FEA results show that the optimal parameters may be chosen for the CFDR generator to minimize the harmonics of back-EMF.

I. INTRODUCTION

Nowadays, there are mainly two kinds of variable speed constant frequency wind power generation system. One is the doubly-fed induction generator (DFIG) system; the other is the PM direct-drive power generation system. For the former, a gearbox is needed between the wind turbine and the generator, which reduces the reliability of the system. For the latter, bulky generator and full-power converter lead to high costs. Therefore, a novel constant-frequency double-rotor (CFDR) generation system is proposed [1] [2].

The CFDR generator of the variable speed constant frequency generation system is directly connected to grid and only part-size converter is needed. As a PM synchronous machine, CFDR generator acquires better dynamical performance than DFIG, especially when the gird is under abnormal conditions, such as grid fault ride-through and grid voltage unbalanced situation. However, the PM machines have the disadvantage on harmonics of the electric motive force (EMF), which will cause poor power quality as the CFDR generator connected with the grid.

In this paper, optimal design of a CFDR generator for minimizing harmonics in back-EMF is proposed. Firstly, the structure of the CFDR generator and the equation for calculating the back-EMF are introduced, then the finite element model (FEA) of the CFDR generator is proposed and three optimization methods for reducing THD in back-EMF of the generator are analyzed.

II. MACHINE TOPOLOGY AND PRINCIPLE

Fig. 1 shows the cross-section of the CFDR generator. It is shown that the CFDR generator mainly contains three parts: wound stator, inner wound rotor and outer PM rotor. The armature windings on the stator are directly connected to the grid, while the windings on the rotor are connected with the partsize back to back converter. The harmonic components in stator back-EMF will arouse total harmonic distortion (THD) in the phase current. Then the minimized THD in stator back-EMF is favored for the CFDR generator.

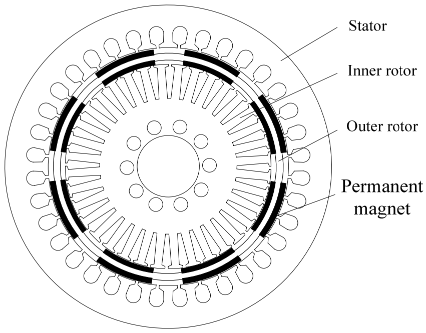

Fig. 1. Cross-section of CFDR generator

The flux linkage versus rotor angle can be obtained from the FEA. From the flux linkage, the induced back EMF can be obtained by:

$$e = \frac{d\psi}{dt} = \frac{d\psi}{d\theta}\omega_r \quad (1)$$

where e is the back EMF, ψ is the flux linkage through the closed conductor, θ is the rotor angle and ω_r is the angular velocity of rotor.

III. FINITE ELEMENT ANALYSIS

The accuracy of FEA largely depends on the level of mesh discretization. For high accuracy calculation, high level of mesh discretization for the CFDR generator is adopted, as shown in Fig. 2.

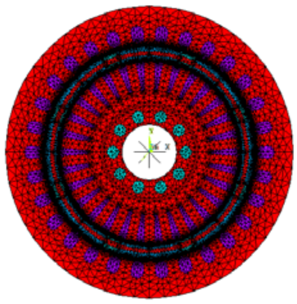

Fig. 2. Mesh discretization of CFDR generator

For simplification, the end-effect of the machine is neglected and then 2D FEA model of the CFDR generator is established. Fig. 3 shows the PM flux distributions of the CFDR generator. The more details will be given in the full paper.

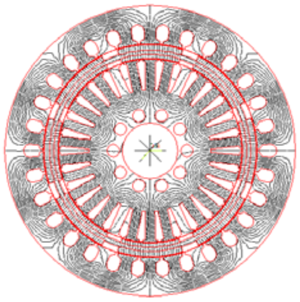

Fig. 3. PM flux distributions

IV. OPTIMIZATION METHODS

A. Optimization of PM Arc Factor

The PM arc factor represents the ratio of the PM arc to the pole pitch [3]. Fig. 4 shows the variation of THD with respect to the PM arc factor. It is shown that the PM arc factor is an important factor in reducing the THD of back-EMF. The optimal PM arc factor may be 0.62 for inner layer PM and 0.68 for outer layer PM as shown in Fig. 4.

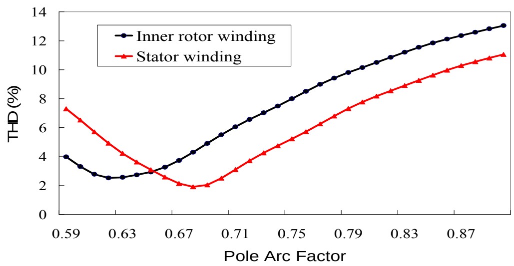

Fig. 4. The variation of THD with pole arc factor

B. Optimization of Slot Opening Width

Slot opening width is also another factor in reducing the THD of back-EMF. Fig. 5 shows the THD of the back-EMF versus the opening width of the inner and stator slot as initial state with optimal PM arc factor is considered. it shows that 3.2mm for inner rotor and 2.4mm for stator is optimal where smaller THD is acquired.

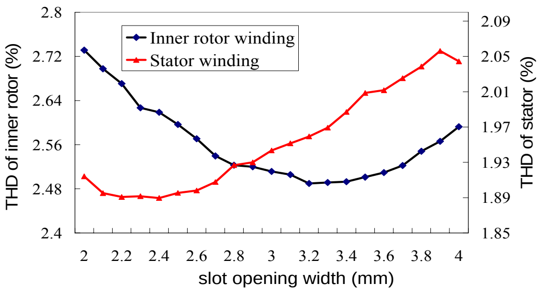

Fig. 5. The variation of THD with slot opening width

C. Optimization of PM Shape

PM shape is another factor in reducing the THD of back-EMF. Considering the difficulty in changing the PM shape, only the outer PM slope height and slope length are considered for optimization, as shown in Fig. 6.

Fig. 7 shows the variation of THD according to the PM shape. It is shown that the THD of stator back-EMF is the lowest as the ratio of PM slope length with PM arc length c is 1/12 and PM slope hight d is 0.5mm.

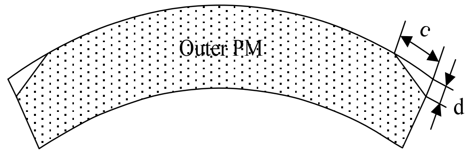

Fig. 6. Outer PM shape

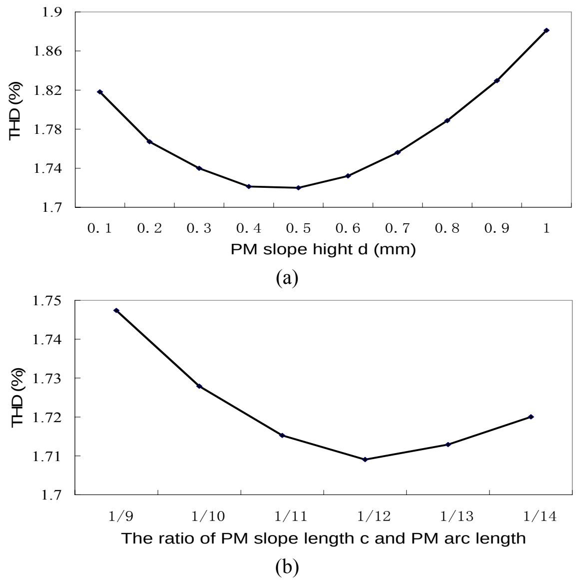

Fig. 7. The variation of THD with PM shape. (a) PM slope hight d, (b) The ratio of PM slope length c and PM arc length

V. CONCLUSIONS

In this paper, the optimization of the CFDR generator is proposed. The optimization of three parameters includes PM arc factor, slot opening width and PM shape are discussed. The 2D FEA is used to analyze the performance of the different parameters. The results show that the PM arc factor will do great effects on the THD than other two parameters. Obviously, the optimal design for CFDR generator can be reached by selecting appropriate parameters.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

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