A Study on Comparison of Quasi 3D Modeling and 3D FEA of AFPMG for Large Scale Offshore Wind Turbine

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The aim of this paper is to calculate the overall characteristics of axial flux permanent magnet generator (AFPMG) by using a general analytical model. The flux densities in the air gap where axial and circumferential magnetic field are obtained using a correction functions. At each calculated section, FE models were built to validate the analytical model. The results show that the analytical predictions agree well with the FEA results. Finally, the analytical results are verified by experimental results.

***Index Terms*— Axial flux permanent magnet motor (AFPMG), three-dimensional finite element analysis (3D FEA), Qushi 3D, large scale offshore wind turbine, analytical model.**

I. Introduction

In the case of radial flux permanent magnet generators (RFPMGs), two-dimensional finite element analysis (2D FEA) has been mainly used as an advantage such as shortening of analysis time and simplicity of modeling. 2D FEA is possible to analyze geometric and physical quantities in the vertical direction of the cross section. However, axial flux permanent magnet generator (AFPMGs) has a structure with different dimensions in the vertical direction of the cross section, which has difficulty in applying the conditions necessary for two-dimensional analysis. Therefore, three-dimensional finite element analysis (3D FEA) is generally used to analyze the characteristics of AFPMG [1]. However, 3D FEA is usually too time consuming, especially the analysis of AFPMG for the large scale wind turbine is almost impossible because the model is very large size. To solve the problem, the magnetic equivalent circuit and quasi 3D are applied to the design of AFPMG [2]. However, the quasi 3D results are different compared with FEA results because the magnetic flux density is not uniform due to the leakage reactance component at the inner diameter and outer diameter of the generator and the unbalance of air gap due to the axial force of the stator core and rotor permanent magnet. This paper presents quasi 3D with the correction function for design of AFPMG of large scale offshore wind turbine. The results show that the analytical predictions agree well with the 3D FEA results. Finally, the results of analytical model are verified by experimental results.

II. Description of AFPMG

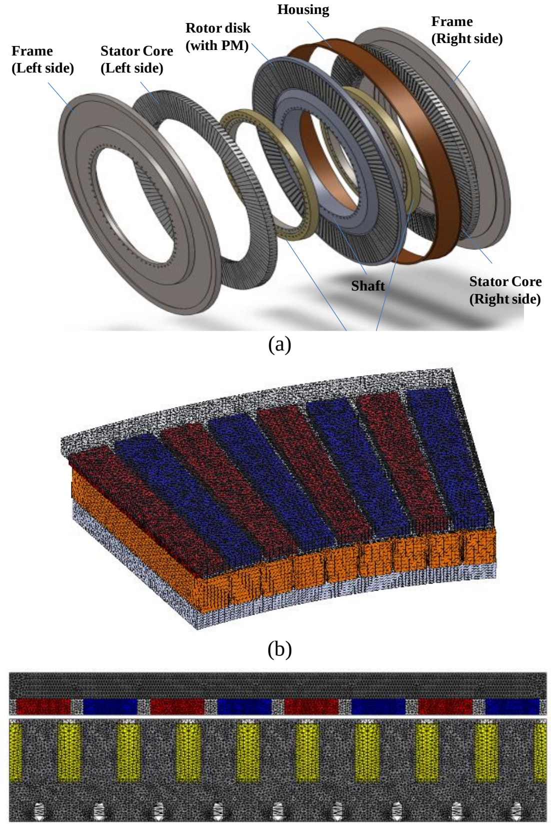
Fig.1 (a) shows the construction of AFPMG. The specifications of the AFPMG are shown in Table I.

3D Quasi of AFPMG

A. Correction function considering edge effect

To model the radial dependence of the magnetic field, the correction function can be written as

$$G(r) = \frac{1}{\pi}\left[\tan^{-1}\left(\frac{2(r-R_i)\tan(\beta\pi/2)}{(R_o^2-R_i^2)}\right) - \tan^{-1}\left(\frac{2(r-R_o)t\,\mathrm{an}(\beta\pi/2}{(R_o^2-R_i^2)}\right)\right] \quad (1)$$



(c)

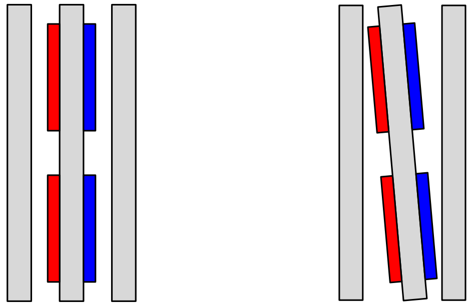
Fig. 1. FEA model of AFPMG. (a) Construction. (b) 3D model. (c) Quasi-3D model.

TABLE I
Specifications of AFPMG

Item	Unit	Value
Rated power	MW	2.5
Rated voltage	V	690
Rated current	A	2270
Rated torque	kNm	1588
Rated speed	rpm	16
Efficiency	%	94
Power factor		0.92

B. Correction function considering unbalance airgap

There are two cases of airgap as shown Fig. 2. Fig. 2 (a) shows ideal airgap condition.



(a) (b)

Fig. 2. Ideal and unbalance airgap conditions. (a) Ideal condition. (b) Unbalance condition.

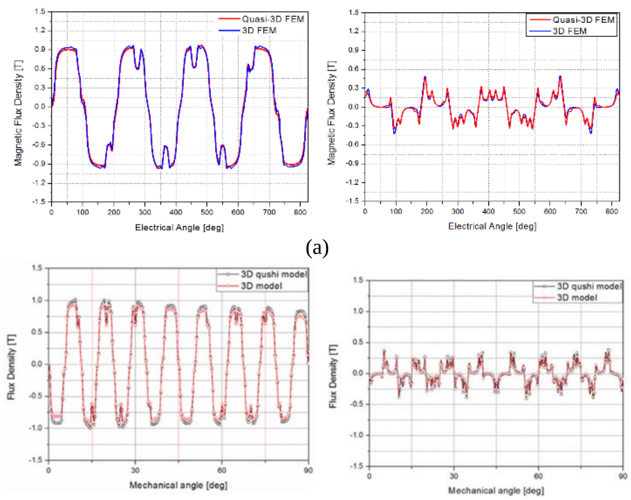


Fig. 3. Airgap flux density of axial direction and rotational direction. (a) Ideal condition. (b) Unbalance condition.

Fig (b) shows unbalance airgap condition. Under the unbalance airgap condition, the airgap length can be defined as

$$g_{case1}(\theta) = g + \Delta g \cos(\theta) \quad (2)$$

Where, g is base airgap, Δg is the misalignment condition factor.

III. SIMULATION RESULT

A. Ideal airgap condition

Fig. 3 (a) shows airgap flux density of axial direction and rotational direction under the ideal condition. The figures show that the analytical model is in a very good agreement with the FEA model.

B. Unbalance airgap condition

The axial and circumferential components of one side rotor disk with 45% eccentricity under no load condition are shown in Figures 3 (b). It can be seen that the axial and circumferential components of the flux density between the FE model and analytical method do not agree well due to the interaction between the circumferential and axial flux density, but the error still remains in a reasonable range. Overall, the proposed method in this paper is an effective way to investigate the eccentric influence of AFPMG.

Fig. 4. Experimental test.

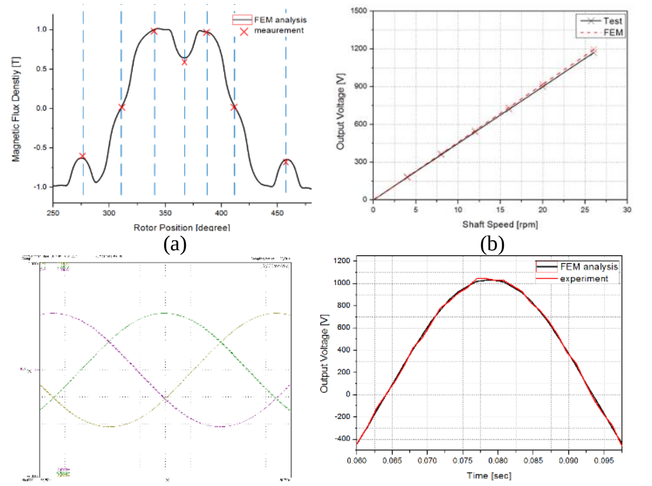


Fig. 5. Comparison of simulation and experimental results. (a) Airgap flux density. (b) Output voltage according to speed. (c) Experimental output voltage at rated speed. (d) Output voltage of FEA and experimental.

IV. EXPERIMENTAL RESULT

The experimental set up are presented in Fig. 4. The AFPMG is rotated by a geared induction motor. The airgap flux density and back EMF is measured by the gauss meter and oscilloscope. Fig. 5 shows comparison of FEA and experimental results. Although the FEA results shows a slight error compared to the experimental results, it is still acceptable. Finally, the experimental validation has been carried out to verify the accuracy of the simulation results obtained by the proposed method.

V. CONCLUSION

This paper presents quasi 3D with the correction function for design of AFPMG of large scale offshore wind turbine. To improve the accuracy of the analytical modeling, the correction function is defined considering the edge effect and unbalance airgap. Finally, the experimental validation has been carried out to verify the accuracy of the simulation results obtained by the proposed method.

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