Comparative Analysis on Axial Flux Machine with Halbach/Vertical Magnetized PM for Wind Power Generator by Flux Leakage Computation

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Abstract — This paper deals with the comparison and characteristic analysis of axial flux machine with Halbach and vertically magnetized permanent magnet (PM) rotor applying both analytical method and finite element method (FEM). Due to its structural features, 3-dimentional analysis is employed, and the comparative analysis is performed according to the magnetization patterns and the analysis methods.

I. INTRODUCTION

Due to higher power density than conventional radial flux machines, so axial flux machines are widely employed to various industrial applications, for instance, a low speed wind power generator[1]-[3]. For the characteristic analysis of the electrical machines, finite element method(FEM) is widely applied due to its high reliability. However, differently from other types applying 2D FEM, axial flux machines must employ 3D FEM with very long analysis time owing to their structural features. As an another choice, plenty of researches on analytical method have been performed to reduce the analysis time, but its research results for the axial flux machines are not sufficient. In fact, their reliability is less than FEM, but it is very big burden to consider every case for their initial design by only 3D FEM. Therefore, the analytical method cannot be ignored in that it can dramatically reduce the time. The main aim of this paper is not to mention which method is superior, but to take advantages from both methods by reducing analysis time and offering accurate analysis result by both methods. Besides, among various options of magnetization patterns, this paper employs Halbach and vertical types, and their comparative analysis is also performed for the application of small scaled wind power generators [4]-[5].

II. CHARACTERISTIC ANALYSIS ACCORDING TO MAGNETIZATION PATTERNS AND ANALYSIS METHODS

A. Analysis Model

The analysis models according to the magnetization

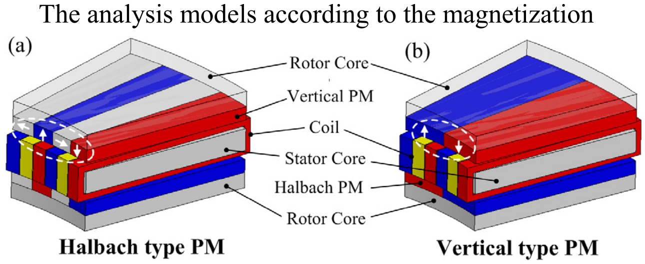

Fig. 1. Analysis Model : (a) Halbach type, (b) Vertical type.

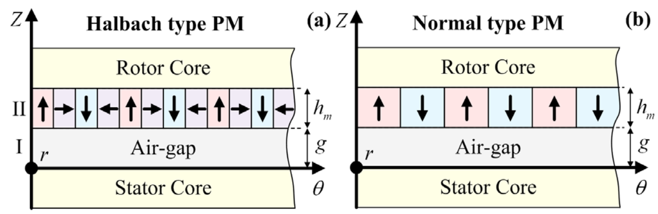

Fig. 2. Simplified analysis model for analytical method.

TABLE I. DESIGN SPECIFICATIONS

Specification	Value	Specification	Value
Rated Power	500[W]	Speed	300[rpm]
Frequency	100[Hz]	Pole Number	40
Outer Radius	143[mm]	Inner Radius	90[mm]
Stator Thickness	12[mm]	Mechanical Airgap	1[mm]
PM Thickness	7[mm]	Rotor Core Thickness	8[mm]
PM Remance	1.27[T]	Turns per Phase	1200[turn]

patterns of permanent magnet (PM) are shown in Fig. 1. For the reduction of cogging torque, which is very essential for wind power generators, the stator core is slotless type, and three phase coils are wound in the core as ring-wound and distribution type. Here, the analysis model can be simplified for the static characteristic analysis by the analytical method as shown in Fig.2, and the simplified model consists of 4 regions, which are rotor core, PM, air-gap and stator core region. In this paper, although the analysis model is double side type, the static characteristic analysis in this paper only considers single side in that the back-EMF value are exactly two times when the stator core is not saturated. The other design specifications are presented in Table I. Prior to the analysis, Fig.3 shows the flux density by one pole of vertical type PM in air-gap from inner PM radius to outer PM radius. As indicated in the figure, the amount of flux density is different according to the positions due to flux leakage. For the accurate characteristic analysis, the flux leakage should

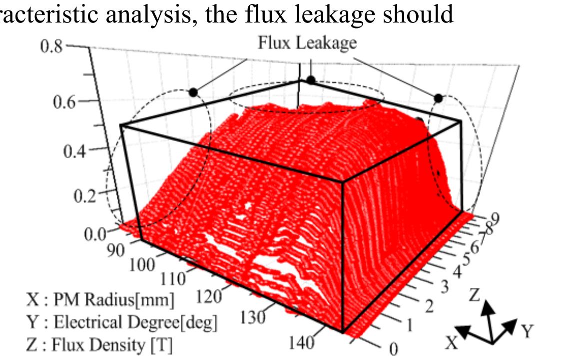

Fig. 3. Flux density by one pole of vertical type PM (3D FEM).

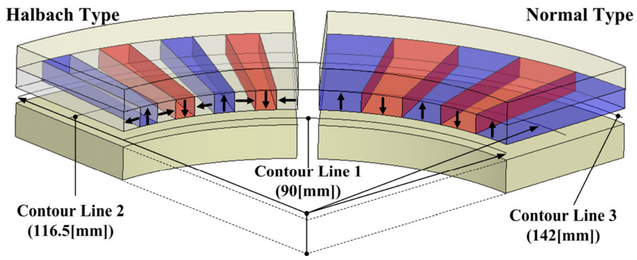

Fig. 4. Contour lines for leakage flux characteristic analysis.

be dealt with, and Fig.4 shows contour lines to confirm the consideration of flux leakage. Here, the radius of contour line 1, 2 and 3 are respectively 90[mm], 116.5[mm] and 142[mm], while the inner and outer radius of PM are 90[mm] and 143[mm]. In those lines, the normal component and tangential component of flux density are analyzed.

B. Electromagnetic Field Analysis

With the simplified analysis model and several reasonable assumptions, the governing equations and flux density in each region are derived based on Maxwell's equations for the application of the analytical method. Furthermore, unknown coefficients of the flux density equations are obtained by applying boundary conditions. In particular, since the leakage flux in inner radius and outer radius is very essential factor for accurate analysis, this paper will introduce the compensation factor for its consideration. The analysis results of flux density in the contour lines by both analytical method and 3D FEM are presented in Fig.5. Here, the flux density in contour line 2 is the highest, and the flux density in contour line 1 is vice versa in that the flux leakage more emerges in inner radius and outer radius. The more specific analysis results according to magnetization patterns will be presented in later full paper. Based on the obtained flux density, this paper derived the back-emf as well according to the magnetization patterns as shown in Fig.5(a). Since the transient analysis by only 3D FEM takes very long analysis time, this process is very significant for the time reduction. From the results, it is noticed that both results are well corresponded, and it must be very useful if the suggested analytical method is employed for initial designs, and FEM is applied to the specific designs for accurate analysis.

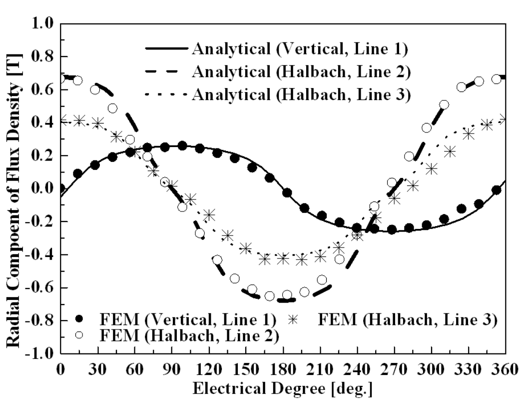

Fig. 5. Radial component of Flux density according to contour lines.

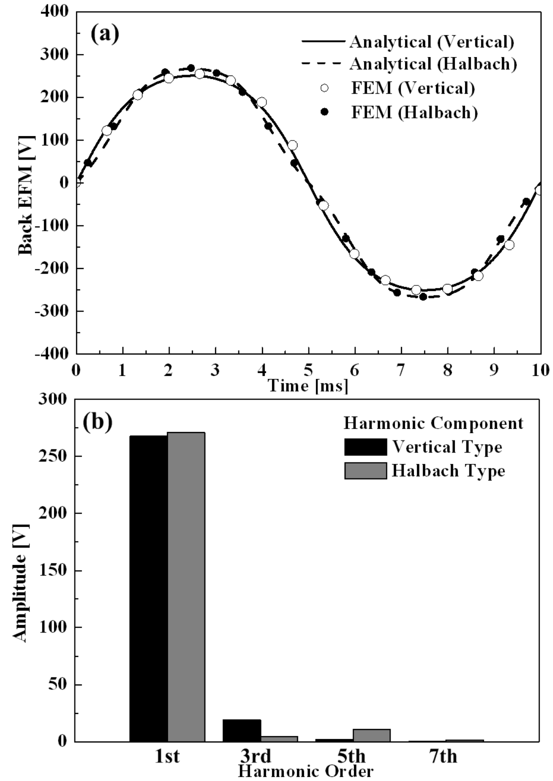

Fig. 6. (a) Back-emf comparison, (b) FFT results of back-emf.

III. CONCLUSION

For the comparison for the magnetization patters, Fig. 6(b) presents the FFT (Fast Fourier Transform) results of back-EFM according to magnetization patterns. Here, the vertical type has higher 3rd harmonic component and less 5th harmonic component than Halbach type. This paper determined the vertical type to manufacture in that the 3rd harmonic component less affects on electromagnetic torque ripple. The model is now being constructed, and its experiment will be performed soon. In later full paper, the experimental set and results will have been presented.

IV. REFERENCES

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