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Research paper



A Study on Field Current Ripple Reduction of Wound Field Synchronous Motor for EVs

[1]Jun-Kyu Kang, [2]Hong-Sik Lim, [*3]Ki-Chan Kim

[1,2,3]Dept. of Electrical Engineering, Hanbat National University, Daejeon, 305-719, South Korea
**Corresponding author Email: [*]kckim@hanbat.ac.kr*

Abstract

Background/Objectives: Since the WFSM controls the field current by applying DC current to the field winding, it has the advantage that the magnetic flux of the rotor can be controlled. However, if the rotor of the WFSM rotates, the field current ripple occurs and it has an unfavorable influence on the motor control
Methods/Statistical analysis: For the basic model, the maximum output is 80 kW. The WFSM compares the results of the motor performance test with the data values of the FEM simulation to analyze the causes of the current ripple. In addition, basic model and the design model applied the skew method is compared and analyzed by the finite element analysis method simulation.
Findings: Looking at the waveform of the actually measured test data of WFSM, it is found that the field current ripple of 6 harmonic components per cycle with electrical angle occurs. This field current ripple affects the inverter current for driving the motor. As the electric motor rotates, the magnetic resistance in the air gap changes, which changes the inductance. The number of slot open each per rotor pole of the basic model is six. The inductance changes six times, and field current ripple of six harmonic components occurs based on this change. This was clarified through test and the FEM simulation. In order to reduce the six harmonics ripple of field currents, FEM analysis was performed by applying the skew method to the rotor. Each waveform is synthesized with phase difference in this skew method and the field current ripple of the 6th harmonic component decreases.
Improvements/Applications: The skew method is used to analyze field current ripple through FEM analysis and characteristics are derived.

Keywords: *Electromagnetic characteristic analysis, Finite element method, Skew method, Wound Rotor Synchronous Motor, Field current ripple*

1. Introduction

As the recent ownership of cars increases, air pollution problems are getting worse due to emit gas from fossil fuels. In order to solve these problems, research on environmentally friendly electric vehicles is actively underway. It has been developed into an electric motor system driven by electric energy from an internal combustion engine system in which existing fossil fuel is a driving source[1,2]. In particular, an Interior Permanent Magnet Synchronous Motor is mostly used as an electric motor for driving an electric vehicle. IPMSMs using rare earth magnets have high power density and high efficiency characteristics[3,4]. However, as the price of rare earth magnets rises steadily, researches on non-rare earth motors are being actively pursued. As a result, prior studies of Synchronous Reluctance Motor spoke type synchronous motor using ferrite magnet, synchronous motor of winding type, etc. are underway[5].A wound field synchronous motor has lower power density and lower efficiency characteristics than IPMSM, but among non-rare earth type electric motors. It has better power density and better controllability than other electric motors. It has high-speed operation characteristics. In addition, since the rotor of the coil type synchronous motor is not circular, it is designed with the structure of Salient Pole, so it can be reduced weight compared to IPMSM, and the material cost can be reduced. Also, since IPMSM can't control rotor flux, output at high speed operation is reduced[6,7].On the other hand, WFSM can control the current by applying DC current to the winding field wound on the rotor, so the output is high and the operating range is expanded during high speed operation. The WFSM applies DC current to the field winding to generate rotor flux. Therefore, the magnetic flux of the rotor can be controlled by controlling the field current. However, ripple is made in the DC current of the field as the rotor rotates. Field current ripple has a bad influence on motor control[8].Therefore, field current ripple affect torque ripple and motor control. Therefore in order to secure the ripple and control reliability of the motor, it is necessary to design the design that reduces the ripple of the field current[9,10].

In this paper, it was conducted to reduce the field current ripple of WFSM. We analyze the cause of the ripple of the field current by comparing the ripple of the field current generated during the test of the WFSM motor with the results obtained through the FEM simulation. In addition, basic model and design model applying the skew method is compared and analyzed by the finite element analysis method simulation.

2. Analysis Model of WFSM

2.1. 2D Model FEM Simulation

Figure 1 shows 2D finite element analysis model of the WFSM basic model. As shown in Figure 1, the rotor winding is wound. Table 1 shows the design specifications of the WFSM basic model. As shown in the table, the maximum output power of the WFSM is 80 [kW], with 8 poles and 48 slots selected. As shown

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in table1, the rated operating speed and maximum operating speed are selected as 3000 [rpm] and 12000 [rpm], respectively. The winding specification and size of the electric motor were selected in consideration of the thermal performance of the electric motor. The shape of the stator and rotor was optimally designed for high efficiency and high power factor.

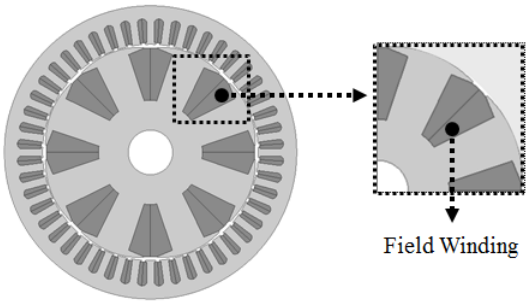


Figure 1: 2D FEM analysis model of WFSM basic model

Table 1: Design specifications of WFSM basic model

division		Model Specifications	Unit
maximum output		80	kW
Speed (Rated / Max)		3,000 / 12,000	Rpm
Battery voltage		270	V_{dc}
Number of poles / number of slots		8/ 48	-
Stator	Outer diameter	200	ϕ
	Inner Diameter	136.2	ϕ
	Lamination length	190	Mm
Rotor	Outer diameter	135	ϕ
	Inner Diameter	46	ϕ
	Lamination length	190	Mm
	Air gap	0.6	mm

2.2. WFSM Problem Analysis Using Measured Data

2.2.1 Measurement Data of the Produced WFSM

Figure 2 shows the experimental setup of WFSM. It consists of WFSM as shown in the figure 2, inverter for motor control and power analyzer. The WFSM is driven by controlling the armature current, the armature current phase angle and the field current through the inverter.

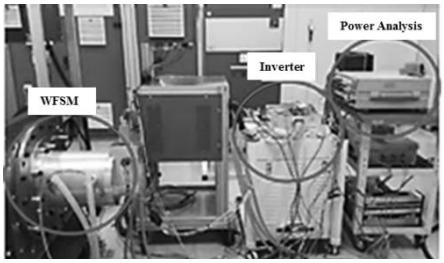


Figure 2: Test configuration of WFSM

Figure 3 shows the waveform of the actual test data of WFSM. Figure.3 shows the armature U phase current, electrical degree and field current at 3,500 rpm. As shown in the figure, it can be seen that the field current ripple of 6 harmonics per one electrical degree has occurred. The peak to peak is about 0.9A. This current ripple affects the current control of the inverter.

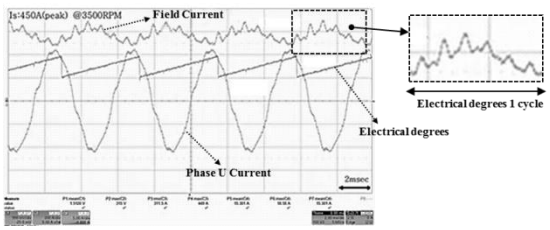


Figure 3: Test data waveform of WFSM

2.2.2 Field Current Ripple Analysis of WFSM

The reluctance in the air gap changes as the motor rotates. As a result, inductance is changed. The 6 harmonic of the field current is generated by the slot open number per rotor pole as shown in Figure.4.As a result, ripples of six harmonic components occur in the field current for each electrical cycle.

Figure.5 shows the field current waveforms in the FEM simulation. The field current waveforms in steady state are shown. As shown in the figure.5, the field current ripple of 6 harmonics occurs in one cycle of electric and the peak to peak is about 0.8A.Compared result of FEM simulation and motor test, the problem that occurred in actual measurement was the same. This problem is reduced through the design changes of the WFSM in the simulation. In this paper, FEM analysis is being carried out by applying the skew method to the rotor in the direction of security design.

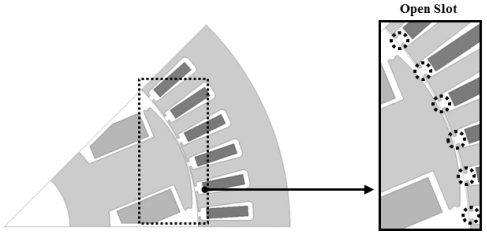


Figure 4: Slot open for each rotor open in WFSM

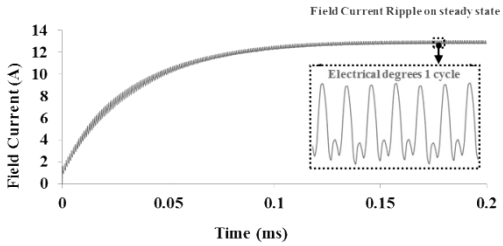


Figure 5: Waveform of FEM simulation analysis result

3. Introduction of WFSM skews model and comparison of FEM analysis results

3.1. Winding and EMF Phasor Diagram

Figure.6 (a) shows the rotor shape of the WFSM basic model. In the model of Figure.6 (b), the skew method is applied by separating the axial length of the rotor into three stages. As shown in Figure.6 (b), selected counterclockwise and clockwise skew angle variables. Therefore, the sizes of the two variables are the same. The skew angle of the entire rotor varied from 0deg to 7.5deg applied skewing the rotor. As a result of the FEM simulation analysis, the ripple reduction of the field current is most effective when the machine angle is 5 °.Therefore, the machine angles are + 2.5deg, 0deg, -2.5deg.

The rotor was rotated by the same angle to the left and right when skew was applied. Therefore, the gap magnetic flux emitted from the teeth of the rotor has a phase difference in the armature. In such skew method, because the magnetic flux interlinkage is phase difference appears, the respective waveforms are synthesized. Therefore, since the magnetic resistance changes and the inductance changes, the field current ripple of the six harmonic components decreases.

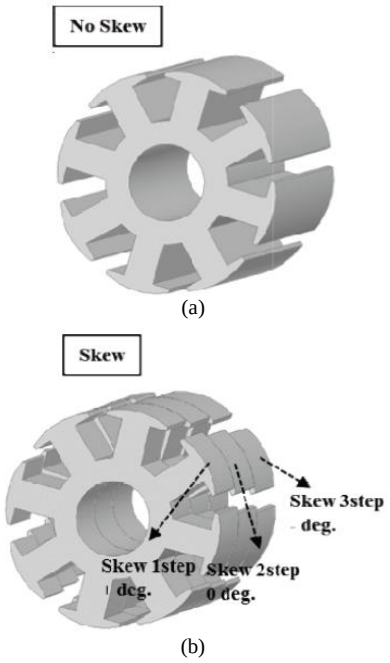


Figure 6:.WFSM rotor (a) WFSM basic model rotor, (b) rotor with three-stage skew applied

Figure 7 shows the waveform of the field current before and after applying skew method when a field current of 13 [A] is applied at no-load and rated operation. The dotted line is the waveform of the field current synthesized from the three waveforms in figure 7.As shown in figure 7, it can be seen that the field current ripple decreases when the skew is applied. At no load operation, ripple before application of skew is 0.26 [%], ripple after skew application is 0.05 [%], therefore the ripple of the field current decreased by 80.8 [%] and at rated operation, the ripple before skew application is 7.6% and the ripple after skew is 4.7%, so the field current ripple is reduced by 38.2%.

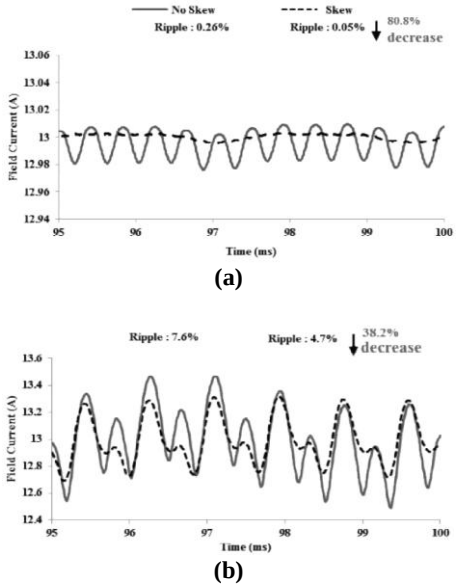


Figure 7: Comparison of waveforms before and after skew application (a)rated operation (b)no-load operation

Torque ripple and field current ripple are decreased during skew applications. The torque ripple before skew application is 12.9% and the torque ripple after skew is 8.9%, so the torque ripple is reduced by 31.0%.Therefore, when the skew is applied, the field current ripple of the six harmonic components decreases, so the reliability of the motor control can be secured as compared with before applying the skew and the torque ripple is also reduced so the vibration and noise reduced

4. Conclusion

In this paper, we have studied the method of reducing the field current ripple of WFSM in design. Finite element simulation analysis was performed by applying skew technique to the WFSM basic model. Since the rotor rotates leftward and rightward at the same angle when the skew is divided in three stages, the airgap flux from the teeth of the rotor bridges the interlinkage with phase difference to the armature. In order to be changed magnetic reluctance and inductance, the field current ripple of the sixth harmonic decreased. At no load operation, ripple before application of skew is 0.26 [%], ripple after skew application is 0.05 [%], therefore the ripple of the field current decreased by 80.8 [%] and at rated operation, the ripple before skew application is 7.6% and the ripple after skew is 4.7%, so the field current ripple is reduced by 38.2%.Therefore, there is an advantage that skew-applied field current ripple is reduced. Since the ripple before applying the skew is 7.6% and the ripple after the application of the skew is 4.7 %when the rated field current of 13 A is applied, the ripple of the field current is 38.2 % Diminished. Therefore, there is an advantage that field current ripple applied skew is reduced.

Therefore, when the skew is applied, there is an advantage of reducing ripple of the field current.

Acknowledgment

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