Demagnetization Characteristic Analysis in accordance with Freewheeling Current in BLDC Motor

Jong-Hun Park, Hyung-Kyu Kim, and Jin Hur, *Senior Member, IEEE*

School of Electrical Eng., University of Ulsan, 102 Street Dae-hak, Nam-gu, Ulsan 680-749, Korea, jinhur@ulsan.ac.kr

In this study, we analyzed that the freewheeling current is affected by variations of the rotating speed in permanent magnet brushless dc motor through the finite-element method, and then, we analyzed magnetic field distribution depending on change of freewheeling current. As a result, we confirmed that demagnetization gets worse by growing slope of freewheeling current.

***Index Terms*—Brushless motor, Demagnetization, Magnetic analysis, Switching circuit, Permanent magnet motors.**

I. Introduction

PERMANENT MAGNET (PM) BRUSHLESS DC MOTOR (BLDCM) has been used in many industries such as electric vehicles, hybrid electric vehicles, cranes. In such industries, devices of high reliability are needed because of inevitability of damage for humans. Especially, PM BLDCM can bring bad influence such as noise, vibration in case that demagnetization of PM is generated by imbalance of magnetic flux density [1], [2].

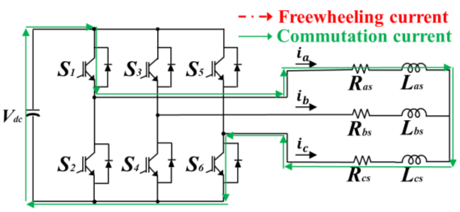
Demagnetization of PM BLDCM is influenced by magnetic field generated by freewheeling current (FC) that is appeared when inverter switches turn on or off. Then, the FC is relatively changed in case that speed of BLDCM is changed in constant torque region [3]. So, when it's stopped being lifted and it's lifted again like a crane, devices which are needed speed control in the section of constant torque that can retain power regular even if speed is changing are easier to affect demagnetization of BLDCM. Therefore, demagnetization research for high reliability is surely needed in the devices requiring a speed control in constant torque region.

Preferentially, we conducted finite elements method (FEM) so as to check change in FC in accordance with speed. Then, FC derived from the FEM analysis can be explained by change in period when speed is changed. Namely, when torque and current are constant, period of FC is changed by change in speed. And then, we presented algorithm for analyzing changes in magnetic field and demagnetization according to change in FC. This algorithm is based on system matrix that is constructed by combining the two-dimensional governing equation and voltage equation of the PM BLDCM. Change in the FC does not almost affect demagnetization in normal state. But, in case that overcurrent flows, PM BLDCM is negatively influenced like demagnetization of PM because of change of magnetic field. Finally, in states of normal and overcurrent, we analyzed demagnetization phenomenon in accordance with magnetic field analysis.

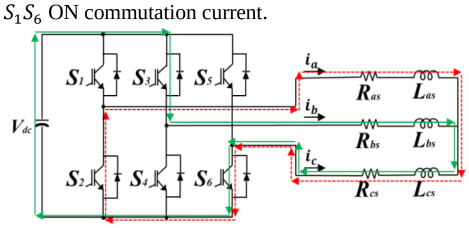
I. The Freewheeling Current

The FC, when the BLDC motor is commutated through inverter switch turning on or off, is called current that remain although commutation turns off by time constant. As shown in Fig. 1 (b), the dotted line is FC, which is generally influenced by time constant as (1). Thus, in that the resister and inductance are constant in the motor, it can be considered that the FC is constant; however, the FC can be changed when the speed of the BLDC motor is changes in constant torque region.

$$i(t) = I_0 e^{-\frac{t}{\tau}}, \quad \tau = \frac{L}{R} \tag{1}$$



(a) Switch S_1S_6 ON commutation current.



(b) SW S_3S_6 ON commutation current and FC.

Fig. 1. Commutation state from S_1S_6 *to* S_3S_6 in BLDC motor.

Where I_0 is the initial current of the inductor, τ is the time constant, L is the inductance, and R is the phase resistance. R_{as}, R_{bs}, and R_{cs} are the winding resistances. L_{as}, L_{bs}, and L_{cs} are the phase inductances of the PM BLDC motor.

Table 1 and Fig. 2 are respectively data according to speed and A-phase current waveform. In table 1, we set constant torque in order to flows the same current although change of speed. In Fig. 2, when section of FC is compared, we can check different FC. For this reason, when current of constant size is supplied, we can be interpreted in varying the period as changing speed. In current of constant size and waveform, if the current is changed, the FC varies. In other words, period changed by speed make size of FC different by changing energy stored in inductance.

TABLE I
FEM Analysis and Calculation According To Motor's Speed

	FEM analysis data				Calculation date	
Speed (rpm)	Torque (Nm)	Input Voltage (V)	BEMF (V_{rms})	Current (A_{rms})	Frequency (Hz)	Inductance (mH)
2000	1	16.6	9.70	7.6	33.33	4.3
3000	1	24.2	14.4	7.6	50.00	4.1
4000	1	31.6	19.2	7.6	66.66	4.0

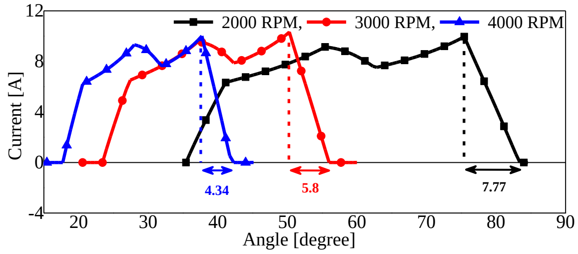


Fig. 2. Current arcorrding to motor's speed.

II. Magnetic Field Distribution and Demagnetization Analysis according to Freewheeling Current

Fig. 3 show algorithm for analyzing magnetic field and demagnetization in accordance with FC. The algorithm is based on system matrix that is constructed by combining the two-dimensional governing equation of the PM BLDCM for magnetic vector potential and voltage equation for freewheeling current and commutation current. In the light of the FC section, current of 6-switch inverter is modeled. Thereby modeling current and overcurrent can be applied by gradually increasing the current.

Fig. 4 shows three kinds of flux path and flux density analyzed by FEM. FC categorized into three. Furthermore periods of FC increased by 0.5 [ms]. Namely, when FC is changed, magnetic field distribution is analyzed how to change. In Fig. 4, flux density of phase B differs from the FC. This flux line can disregard in normal state. However, it can be severely affected by demagnetization phenomenon, when overcurrent and distortion of current waveform are generated. For these reasons, the flux path of phase B flows much more in the opposite direction to flux path of the PM. It means that flux path generated by FC demagnetized much more the flux path of PM.

Demagnetization phenomenon is mainly intensified once overcurrent flows. Fig. 5 show demagnetization phenomenon through slope change of the FC in normal and overcurrent states. As a result, the more FC is small; the demagnetization phenomenon of overcurrent state grows big.

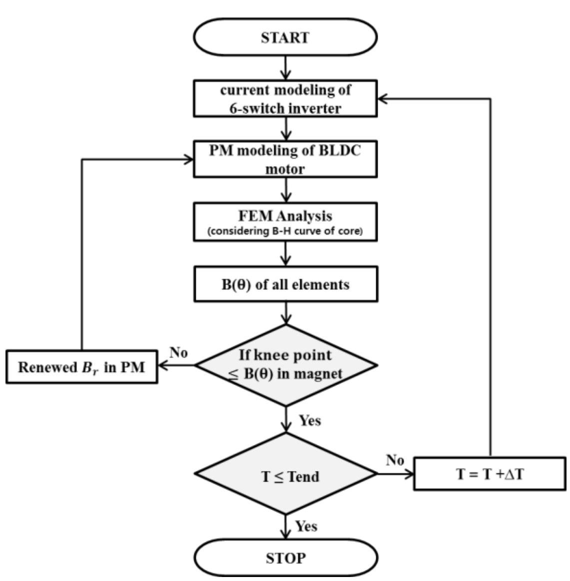


Fig. 3. Algorithm of magnetic field and demagnetization using system matrix.

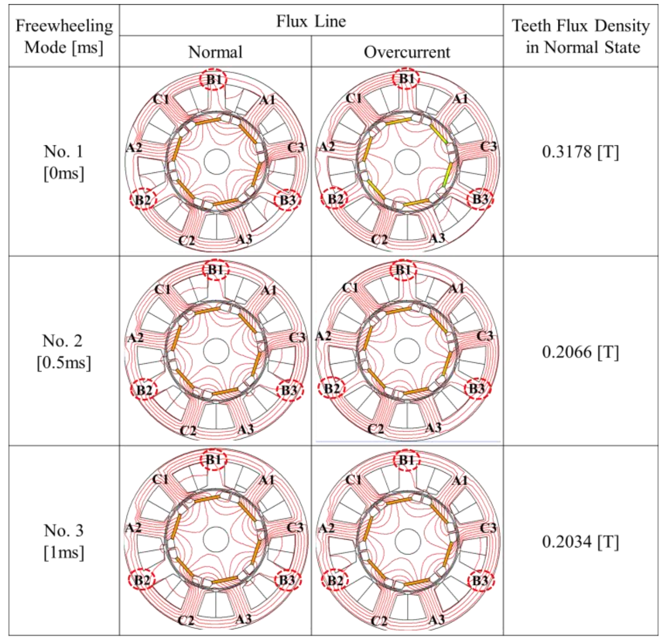


Fig. 4. Magnetic field characteristic according to FC.

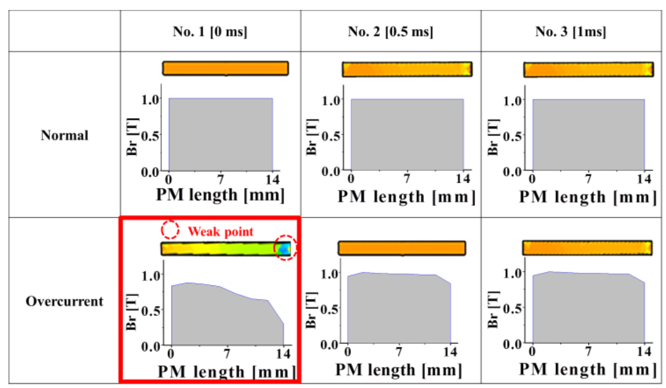


Fig5. Comparison of demagnetization in the PM.

Aknowledgment

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Knowledge Economy (No. 20122010100130)

References

[1] L. Yoon-Seok, K. Kyung-Tae, and Jin Hur, "Finite-element analysis of the demagnetization of IPM-Type BLDC Motor with Stator Turn Fault," *IEEE Trans. Magn.*, vol. 50, no. 2, Feb. 2014.

[2] J. Wang, W. Wang, K. Atallah, and D. Howe, "Demagnetization assessment for Three-Phase tubular Brushless Permanent-Magnet Machines," *IEEE Trans. Magn.*, vol. 44, No. 9, Sep.2008.

[3] D. Lin, P. Zhou, and Z. J. Cendes, "In-Depth Study of the Torque Constant for Permanent-Magnet Machines," *IEEE Trans. Magn.*, vol. 45, no. 12, DEC. 2009.