Proposed Commutation Method for Performance Improvement of Brushless DC Motor

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This study focused on efficiency improvement of BLDC motors via reduction of torque ripple, core loss, and permanent magnet loss. To achieve this objective, we proposed an improved 150° commutation method for three-phase permanent magnet brushless DC (BLDC) motors to improve the current waveform. Although the 120° commutation method is generally employed for a BLDC motor, the 150° commutation method is introduced in order to operate the BLDC with the same efficiency as a brushless AC (BLAC) motor. Moreover, an improved 150° commutation is proposed to reduce the phase current harmonics. The study investigates the attributes of different commutation methods analytically and experimentally in order to determine the optimal commutation method. The result of this study indicates that the improved 150° commutation method is optimum in terms of harmonic attributes, and reduced torque ripple, thereby improving the motor's efficiency.

***Index Terms*— Brushless motors, AC motors, Commutation, Coupled mode analysis, Finite element method**

I. Introduction

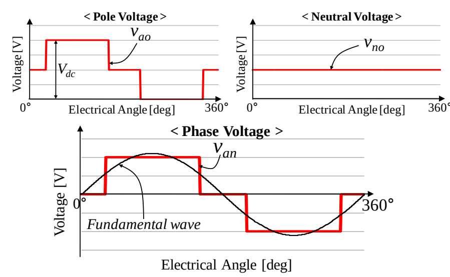
GENERALLY, BRUSHLESS DC (BLDC) motors use three low-cost Hall sensors to obtain information regarding the position of the rotor, and operate using a 120° commutation method. Furthermore, BLDC motors require an ideal trapezoidal back-EMF waveform owing to input current. However, it negatively affects the motor performance owing to the notch phenomenon of current. In addition, torque ripple, core loss, and permanent magnet loss may result from current harmonics. Therefore, to minimize this effect this study focused on a new commutation method to generate a sinusoidal current waveform [1]-[3]. This paper proposes an improved 150° commutation method to generate a sinusoidal current waveform; this method is compared with the 120° and 150° commutation method. The method is validated using an analytical method, a coupling analysis technique, and an experiment.

II. Comparison of Commutation Methods

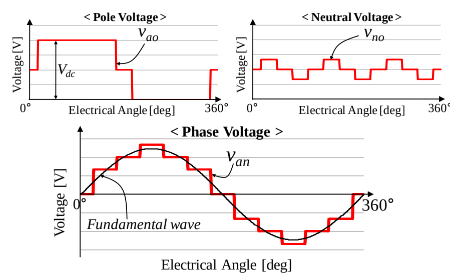
A. Pole, neutral, and phase voltages according to Commutation methods

Figure 1 shows the pole, neutral, and phase voltages of the general 120°, 150°, and improved 150° commutation methods, respectively. As shown in Fig. 1(b), although the 150° commutation method results in lower phase voltage harmonics than the 120° commutation method (Fig. 1(a)), the phase voltage harmonics for the 150° commutation method is still high [4]-[6].

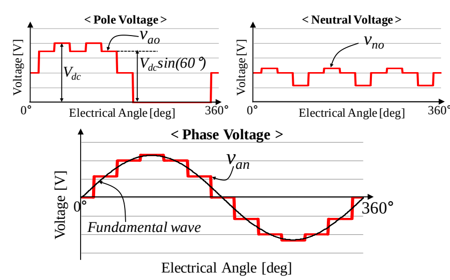
Therefore, this paper presents an improved 150° commutation method for reducing the harmonics as compared to the 150° commutation method. As shown in the Fig. 1(c), it is evident that the harmonics are significantly reduced as compared to the 120° commutation method. To realize the improved 150° commutation, a pole voltage of $V_{dc}\sin 60°$ should be applied in the 15°~45°, 75°~105°, and 135°~165° ranges of the general 150° commutation.



(a) 120° Commutation method



(b) 150° Commutation method

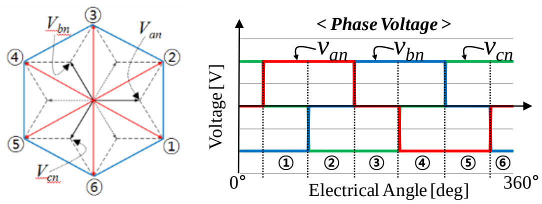


(c) Improved 150° Commutation method

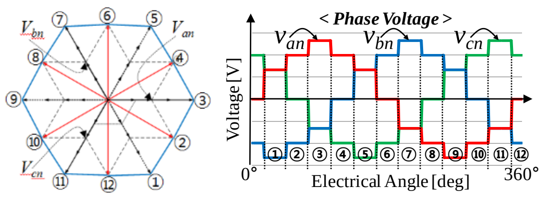
Fig. 1. Pole, neutral, and phase voltages of commutation methods

B. Consideration on Commutation method

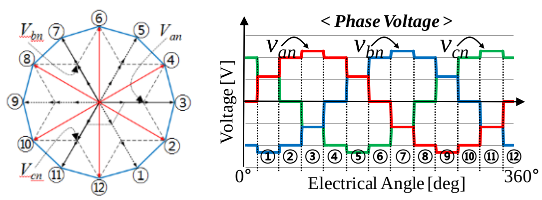
The voltage phasor diagram of the general 120° commutation is shown in Fig. 2(a). As shown in the figure, the 120° commutation method cannot have a sinusoidal phase voltage since the voltage phasor diagram is hexagonal in shape. Voltage phasor diagrams of the 150° commutation and improved 150° commutation are shown in Figs. 2(b) and 2(c). To generate the sinusoidal phase voltage, the shape of the voltage phasor diagram must be similar to a circle, such as that of the BLAC control. It can be seen from Fig. 2(c) that the voltage phasor diagram of the improved 150° commutation is similar to a circle.



(a) 120° Commutation method



(b) 150° Commutation method



(c) Improved 150° Commutation method

Fig. 2. Voltage phasor diagram of commutation method

III. Analysis Results

In order to prove the efficacy of the improved 150° commutation method proposed in this study, each commutation method attribute was analyzed; BLDC control circuit was established and the co-simulation with the finite element method (FEM) was carried out.

The control logic and circuit for co-simulation are shown in Fig. 3. Table I shows the analysis results of the co-simulation; the improved 150° commutation method stands out in terms of torque ripple and efficiency.

IV. Experiment Results

Figures 4 shows the experimental equipment, the experimental current waveform of 120°, 150°, and the improved 150° commutation methods respectively. As shown in Fig. 4 the improved 150° commutation method exhibits more sinusoidal current waveforms. Moreover, the fact that the improved 150° commutation method consumed the least current to yield 2 Nm at 1,325 rpm, reflects the efficiency improvement.

The total harmonic distortion (THD) analysis of each method is as shown in Table II. Table II shows that the current harmonics of the proposed commutation method reduced five times compared to that of the 120° commutation method, and two times compared to that of the 150° commutation method. Therefore, the improved 150° commutation method reduces the current harmonics, thereby reducing the torque ripple and improving the efficiency significantly.

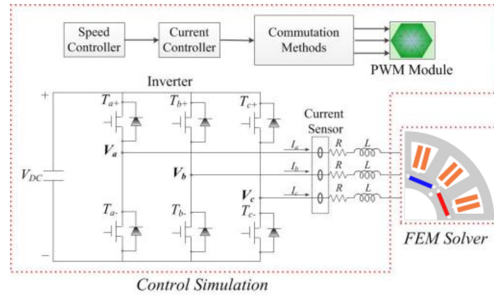


Fig. 3. Control logic and circuit for co-simulation

TABLE I
Results of Co-Simulation

DC-link36V @1,325rpm	120° Comm.	150 ° Comm.	Improved 150 ° Comm.	Unit
Current/Torque	5.06	4.23	4.08	A/Nm
Torque Ripple	24.1	13.6	12.03	%
Efficiency	92.1	94.81	95.09	%

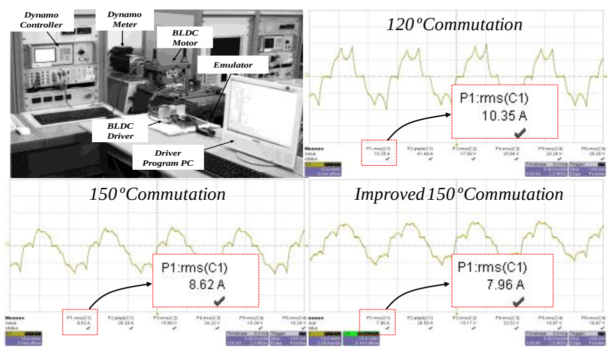


Fig. 4. Experiment current waveform

TABLE II
Results of Current Experiment

@ 2Nm	120deg Comm.	150deg Comm.	Improved 150deg Comm.	Unit
Current	10.35	8.62	7.96	A_{rms}
Current/Torque	5.27	4.31	3.98	A/Nm
THD	0.287	0.112	0.055	-

V. References

[1] Jaenam Bae; Seung-Joo Kim; Sung-Chul Go; Hyung-Woo Lee; Yon-Do Chun; Cheol-Jick Ree; Ju Lee;, "Novel Configuration of the Magnetizing Fixture for a Brushless Permanent-Magnet Motor", Magnetics, IEEE Transactions on,Vol 45 , 2009, pp, 2807 – 2810.

[2] Hyung-Woo Lee; Ki-Doek Lee; Won-Ho Kim; Ik-Sang Jang; Mi-Jung Kim; Jae-Jun Lee; Ju Lee;, "Parameter Design of IPMSM With Concentrated Winding Considering Partial Magnetic Saturation", Magnetics, IEEE Transactions on, Vol 47, 2011, pp. 3653 – 3656.

[3] S. J. Park, et al., "A new approach for minimum-torque-ripple maximum-efficiency control of BLDC motor," IEEE Transactions on Industrial Electronics, vol. 47, pp. 109-114, Feb 2000.

[4] T. J. E. Miller, "Brushless Permanent-Magnet and Reluctance Motor Drives," Oxford Science Publications, 1989.

[5] H. Lu, et al., "A new torque control method for torque ripple minimization of BLDC motors with un-ideal back EMF," Power Electronics, IEEE Transactions on, vol. 23, pp. 950-958, 2008.

[6] K-L. W. Shinn-Ming Sue, Jhih-Sian Syu and Kuo-Cheng Lee, "A Phase Advanced Commutation Scheme for IPM-BLDC Motor Drives," ICIEA, p. 2010~2013, 2009.