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Reducing Torque Ripple of BLDC Motor by Varying Input Voltage

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***Abstract*—This paper presents the method of reducing torque ripple of Blushless Direct Current(BLDC) motor. In the BLDC motor, the torque ripple is decided by the back-EMF and current waveform. If the back-EMF is constant, the torque ripple depends on the current ripple during commutation period. The current in commutation period is acquired by circuit analysis and then the torque ripple simply can be reduced by varying input voltage to flow the current continuously. And suggested method is confirmed by dynamic simulation with parameters of 500W BLDC motor.**

I. INTRODUCTION

The Blushless Direct Current(BLDC) motor has of high torque, compact size, and high efficiency. Therefore, the BLDC motor is widely used from computers, household and industrial products, and automobiles. However, the BLDC motor has a disadvantage that is high cost compared with DC motor because it is necessary to use an inverter and controller to remove brush of DC motor[1],[3].

The ideal BLDC motor has a trapezoidal back-EMF and the constant source voltage is inputted. And then the current made by source voltage instantly rise to steady state. Therefore, the torque is produced without torque ripple. However, the current characteristic of the actual BLDC motor is different from the ideal case, because current is influenced by the inductance and it can not rise or fall to the stead state directly as Fig. 1. Also, the current ripple is produced by difference between the rising and falling current in the freewheeling region and rising current continuously increases because of rising time that is longer than the commutation time in high speed. Therefore, the current ripple is produced by influence of the inductance and the torque ripple is affected by current ripple directly[2].

In this paper, the method of reducing torque ripple is proposed by varying the source voltage to flow the current continuously after analyzing circuit for acquiring the current.

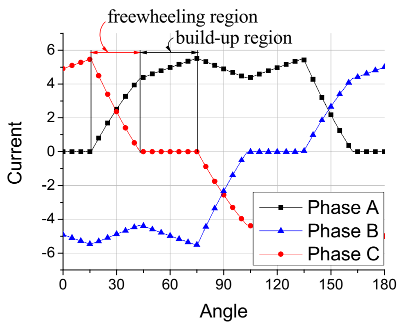
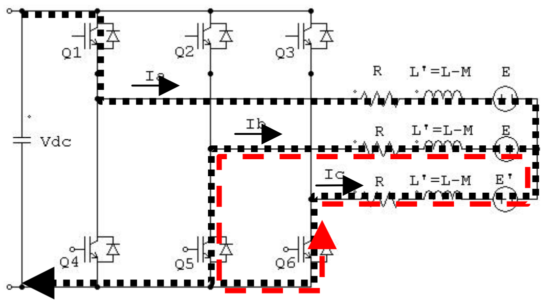
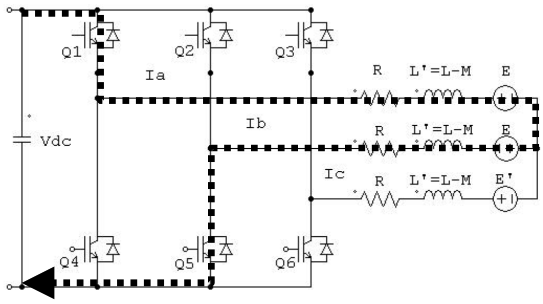


Fig. 1. Actual current waveform in BLDC motor.



(a)

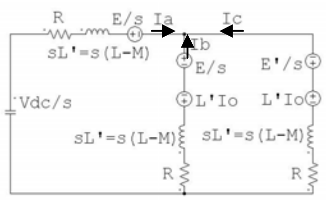


(b)

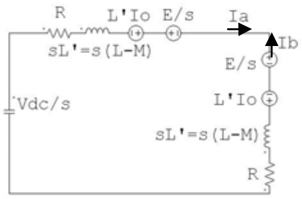
Fig. 2. Current flow when commutation is occurred from phase C to A. (a) is the current flow in the freewheeling region, (b) is the current flow in the build-up region.

II. CIRCUIT ANALYSIS

The current flow when commutation is occurred from phase C to A is represented by Fig. 2. and the current in the phase B flows continuously. In the freewheeling region, Q1, Q5 and the diode of Q6 is turned on, so the current of phase A, B, C is conducted until the current of phase C reaches zero. And if the current of phase C reaches zero, the current only flow through phase A and B and it is build-up region.



(a)



(b)

Fig. 3. Equivalent circuit of Fig. 2. with Laplace conversion. (a) is the current flow in the freewheeling region, (b) is the current flow in the build-up region.

The BLDC motor is driven by repeating the process of Fig.

2. And Fig. 3. represents the equivalent circuit with Laplace conversion.

In freewheeling region, current of phase A, B, C is calculated as (1), (2), (3).

$$I_a = \frac{2V_{dc} - 3E - E'}{3R}\left(1 - e^{-\frac{R}{L'}t}\right) \tag{1}$$

$$I_b = -\left(I_0 e^{-\frac{R}{L'}t} + \frac{V_{dc} - 3E - E'}{3R}\left(1 - e^{-\frac{R}{L'}t}\right)\right) \tag{2}$$

$$I_c = I_0 e^{-\frac{R}{L'}t} - \frac{V_{dc} + \frac{2}{3}E'}{3R}\left(1 - e^{-\frac{R}{L'}t}\right) \tag{3}$$

In build-up region, current of phase A, B is calculated as (4), and current of phase C is zero.

$$I_a = -I_b = \frac{V_{dc}}{2R} - \frac{E}{R} - \frac{V_{dc} - 2RI_0 - 2E}{2R} e^{-\frac{R}{L'}t} \tag{4}$$

In freewheeling region, the current of phase B must be constant to obtain the required torque. If it is considered that the initial current of phase B has made constant torque, the voltage to make constant current can be estimated such as (5).

$$V_{dc\_free} = 3RI_0 + 3E + 3E' \tag{5}$$

When the current of phase C reach to zero, the freewheeling is finished. Therefore, the time of freewheeling period can be estimated such as (6).

$$t_{free} = -\frac{L'}{R}\ln\left(\frac{3V_{dc} + 2E'}{9RI_0 + 3V_{dc} + 2E'}\right) \tag{6}$$

In build-up region, the voltage to make constant current can be calculated such as (7).

$$V_{dc\_build} = 2\left(RI_0 + E\right) \tag{7}$$

III. Simulation

TABLE I
PARAMETERS OF 500W BLDC MOTOR

	Parameter	Value	Unit
1	Phase resistance	0.9889	[Ω]
2	Self-inductance	0.0054	[mH]
3	Mutual inductance	-0.0013	[mH]
4	Pole number	4	
5	Rated speed	6660	[rpm]

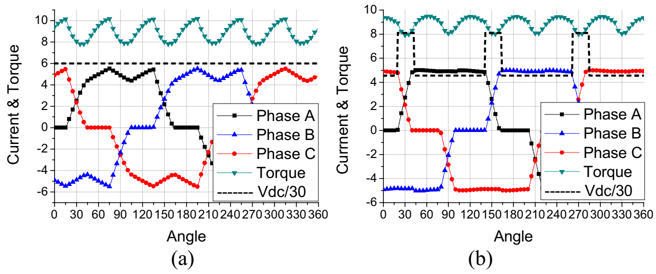


Fig. 4. Current and torque waveform. (a) is the current and torque waveform with constant source voltage, (b) is the current and torque waveform with varying source voltage.

Table I. represents parameters of 500W BLDC motor. The source voltage in freewheeling and build-up region is determined by using (5), (6), (7). And I_0 is initial current or required current to take the wanted torque, E is average back-EMF in the build-up region and E' is back-EMF when the freewheeling region is started.

Fig. 4 represents the current and torque ripple waveform with constant and varying source voltage.

When the constant voltage source is utilized, the torque ripple is 27.8%. In the varying voltage source, the torque ripple is 17.9%.

IV. Conclusions

This paper presents the method of reducing torque ripple of the BLDC motor using the circuit analysis, and torque ripple is reduced by 10% in the dynamic simulation. In the case of simulated motor, the back-EMF waveform is sinusoidal, so torque ripple is not reduced conspicuously. However, if the simulation is performed by the motor with the square wave back-EMF, it is expected that the torque ripple is reduced definitely because the torque ripple that caused by back-EMF is not produced. The full paper will contain the simulation with a motor that has square wave back-EMF.

References

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