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A Novel control converter for Power factor improvement and commutation torque ripple reduction of a BLDC motor

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Abstract:Suitable for low-cost, widely-applicable motor drives, this research offers new discoveries on torque ripples of phase commutation in a four-switch, three-phase inverter-based Brushless DC (BLDC) motor drive (FSTPI). Torque ripple and commutation time are calculated analytically for a variety of operating circumstances. In addition, the operating speed range restrictions due to DC-link voltage splitting are shown. Afterwards, an unique current management strategy that can function at varying speeds is developed in order to lessen the commutation torque ripple. The proposed method relies on the idea that, with the right duty-ratios at commutations, the current slopes of the rising and lowering phases may be equalized throughout the commutation intervals. The analysis and technique suggested and developed for reducing torque ripple are then put through their paces in a simulation to ensure their effectiveness.

Keywords: It's a brushless DC motor with a four-switch inverter and a ton of commutation torque.

Introduction

One trapezoidal inverse electromagnetic field Due to its minimal maintenance requirements, great efficiency, low noise levels, and responsiveness to input, brushless DC motors have gained widespread acceptance. In order to keep the torque output of BLDC motors constant, a rectangular stator current is supplied, as illustrated in Fig. 1. Torque ripple is

switches, a pair of complementary switches as shown in Fig. 2 to save costs for simple applications. A three-phase BLDC motor drive using six or four switch inverters, with their advantages and disadvantages. It is difficult for a four-switch inverter

really generated in reality due to things like stator inductance, cogging effect, and motor feeding [2, 3]. While using a six-switch inverter to power a brushless DC motor, Carlson noticed a correlation between the commutation torque ripple and the driving speed [4]. The four-switch, three-phase inverter (FSTPI) uses only four

to generate 120-degree conducting current profiles due to the design of the device. Three-phase brushless DC motors with four switches need a unique set of control strategies, thus familiarity is key.

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An approach is required. Many proposed remedies for the asymmetrical voltage issue focus on enhancing the system's performance during the conduction phase, whereas the commutation intervals are mostly ignored. In this work, we provide a new method for investigating commutation in FSTPI topology and conduct a thorough analytical

Brushless DC Motor Drive: FSTPI Reanalysis

The FSTPI-BLDC Motor Drive: A Discussion of Modeling Techniques

In Figure 2, we see a comprehensive block diagram of an FSTPI-based BLDC motor drive. Both the ad and b legs of the inverter, as well as the bus's main terminal, provide energy to the motor. The following equation may be used to explain the operation of a three-phase brushless DC motor:

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_s - M & 0 & 0 \\ 0 & L_s - M & 0 \\ 0 & 0 & L_s - M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (1)$$

and,

$$\begin{cases} v_a = v_{an} + v_{no} \\ v_b = v_{bn} + v_{no} \\ v_c = v_{cn} + v_{no} \end{cases} \qquad (2)$$

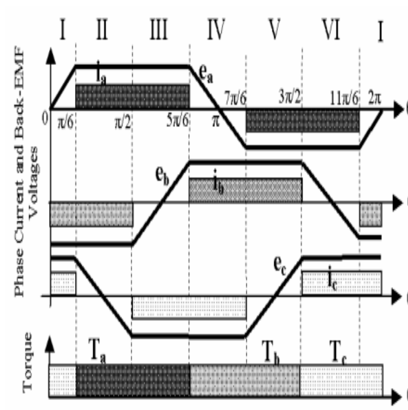
line terminal voltage (vxo), motor star point (vno), phase terminal voltage (vxn), phase current (ix), and phase back-EMF voltage (vxn), and resistance (R), inductance (Ls), and mutual inductance (M) [7]. A brushless DC motor's two primary working zones are the conduction zone and the commutation region. In the conducting region, current is always carried by two phases. Since the commutation zone is a transitional area between two conduction modes, all three phases (the rising, the dropping, and the non-commutating) are conducting.

In place regulations

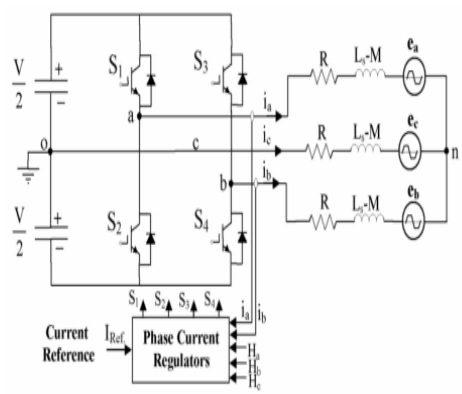
A four-switch BLDC motor drive requires more careful management of current than a six-switch drive. As can be observed in Fig. 1, phases a and b carry the current during modes II and V, while phase

investigation into the bounds of this method. After that, an FSTPI brushless dc motor drive is proposed to mitigate commutation-induced torque ripple. The drive's performance is improved in simulations after a unique approach was created to reduce torque ripple via iterative trial and error.

c is idle. It is possible that the current in phases a and b will be distorted by the back EMF voltage (ec) of phase c. Therefore, if is and if are separately controlled, there will be no current distortion in phases a and b, and the impact of voltage ec will be nullified. The FSTPI-BLDC motor drive's direct phase current (DPC) control system, seen in Fig. 2, makes use of two current sensors. If successful, the DPC control mechanism might be used to commutation as well as conduction. In cases when currents are relatively calm, this technique may be used to great success. Therefore, the current and torque are only slightly variable, within the hysteresis zone. But it has been demonstrated that DPC control cannot suppress commutation torque ripple under high-speed conditions [8]. Accordingly, choosing a trustworthy approach to management is crucial.



The ideal waveforms for driving a three-phase brushless DC motor are shown in Figure 1.

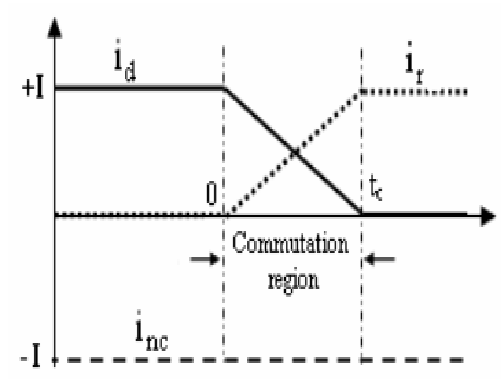


The FSTPI-BLDC motor drive system spins the rotors in a direct phase current control configuration, as shown in Fig. 2.

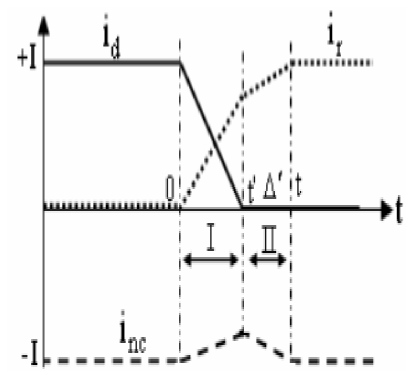
A Commutation Analysis of a Three-Phase Induction Permanent Magnet DC Motor

Phase Currents and Their Commutation Behaviors

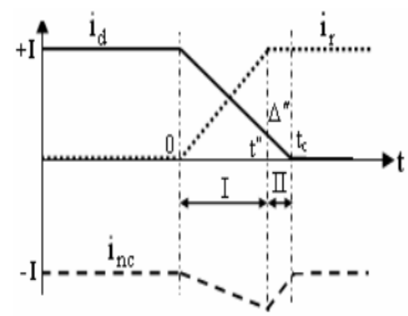
It has been shown that a BLDC motor drive with six switches provides more consistent phase commutations throughout all modes of operation than a four-switch inverter. Each setting has three potential outcomes determined by the motor speed: Case A, seen in Figure 3, is one in which the currents decreasing (id) and growing (ir) both vanish at the same time, with the latter reaching its maximum value (+I) (a). Case B is seen in Fig. 3, where the decaying current dissipates before the growing current reaches its maximum size (b). In Case C, as shown in Fig. 3, the rising current reaches (+I) before the falling current vanishes (c). The following analysis assumes that the stator resistance is zero and that the phase back-EMF voltages are constant throughout commutation. The commutation times, ripple values of the generated torque, and so on may all be calculated analytically under these circumstances.



(a) Case A evolution



(b) Case B evolution



(c) Case C evolution

Fig. 3 Current behaviors during commutation.

Transmission Torque Waves: What to Expect For each mode of operation, the total torque may be expressed as:

$$T = \frac{2EI}{\omega} = T_n$$

The torque at intercom mutation points is also calculated as:

$$T = \frac{1}{\omega}(e_d i_d + e_r i_r + e_{nc} i_{nc})$$

Assuming the commutation voltages of the back-EMF are always the same:

$$T = \frac{1}{\omega}(E \cdot i_d + E \cdot i_r - E \cdot i_{nc}) = -\frac{2E \cdot i_{nc}}{\omega}$$

"Commute Time" Has Arrived

In this section, we will examine the current commutations that occur at positive current levels, which are modes II, IV, and VI. Modes I, III, and V all use the same line of thinking to justify commutation.

To Succeed Using an Improved Approach

As can be seen in Fig. 1, the commutation direction in mode II is from phase c to phase an, with id, ire, and inc (the non-commutated current) being the analogues of ice, is, and if, respectively. S1 and S4 are the conductors of this current. In order to get the current where it needs to go, the freewheeling diodes must be used first. Figure 4 depicts the circuit in its non-commuted state. (a). To illustrate the circuit configuration with S1 active, see Fig. 4. (b). There are three potential consequences that may be drawn from this: A, B, and C. Calculating the current derivatives is the first stage in this circuit analysis. You may write out the KVL equations for the sequence in Fig. 4 as (a) (b).

are written as:

$$\begin{cases} +\frac{V}{2} = R \cdot i_a + L\frac{di_a}{dt} + e_a + V_{no} \\ -\frac{V}{2} = R \cdot i_b + L\frac{di_b}{dt} + e_b + V_{no} \\ 0 = R \cdot i_c + L\frac{di_c}{dt} + e_c + V_{no} \end{cases}$$

Is L the same as all of M's Ls, then. Phase back-EMF voltage magnitudes are entered, resulting in:

$$V_{no} = -\frac{e_a + e_b + e_c}{3} = -\frac{E}{3}$$

Modern day derivatives are often expressed as:

$$\begin{cases} \frac{di_a}{dt} = \frac{3V - 4E}{6L} \\ \frac{di_b}{dt} = -\frac{3V - 8E}{6L} \\ \frac{di_c}{dt} = -\frac{4E}{6L} \end{cases}$$

The same method is used to determine the derivatives of the sequence shown in Fig. 4(c):

$$\begin{cases} \frac{di_a}{dt} = -\frac{3V + 4E}{6L} \\ \frac{di_b}{dt} = \frac{3V + 8E}{6L} \\ \frac{di_c}{dt} = -\frac{4E}{6L} \end{cases}$$

Depending on the motor speed, three results are possible:

Case A:

Since ice and is both converge to their final values at the same time, the slopes are equal. Here are all the things that must happen for instance A to occur in Eq. (5):

$$\frac{E}{V} = \frac{3}{8}$$

By setting the beginning of the commutation as the initial time, we may deduce is from Eq. (5) as follows:

$$i_a(t) = \frac{3V - 4E}{6L}t$$

It follows that tic, the commuting time, might be derived from

$$t_c = \frac{3LI}{2E}$$

During commutation, torque ripples are minimized.

By analyzing the commutation process of a four-switch inverter, we learn that commutation ripple is inevitable, necessitating the need for torque ripple suppression. In the low speed range (case C) of an FSTPI-BLDC motor drive, the commutation torque ripple may be mitigated or even avoided by using the direct phase current (DPC) control strategy during the commutation period. However, it has been proven that the DPC control strategy is not able to entirely eliminate the commutation torque ripple in the high speed range (instance B) [8]. As a result, we develop a novel form of control that use current slope equalization to maintain a steady state between two commutated currents. Below the current limit point V 4E =, torque ripple is removed using this approach.

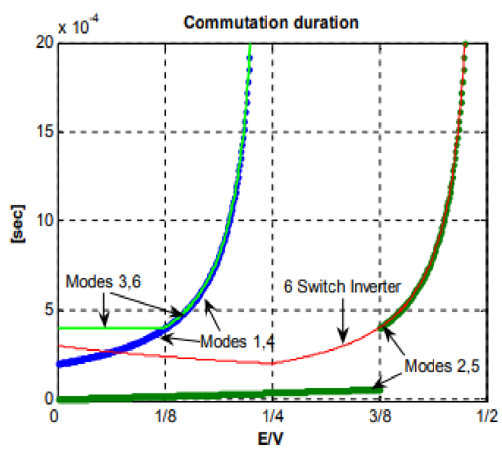


Figure 4: Average time spent commuting by method.

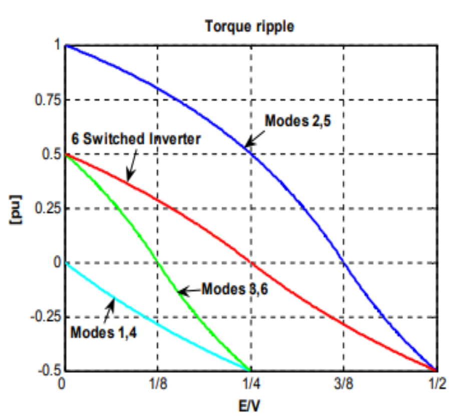


Figure 5shows a comparison of the torque ripple amplitudes across the different modes of operation.

Lower Torque Ripple in Mode II

In Case B, the current limit may be set to E / V 0.5 =, allowing for the use of current control or torque ripple reduction between the values 3/8 E / V 0.5 and E / V 0.5. Modes I, III, IV, and VI have an upper bound of V 4E =, however the region 3/8 E / V 0.5 is more than this. This renders the current control's II and V modes utterly useless.If we examine Fig. 7(a) and Esq. (6). By turning on S4, the currents may reach slope equality by decreasing the slope of is. The solid line represents the is current with the modulation overlaid on top. In Fig. 7 we can see the circuit layout with S1 turned off (b). The KVL equations that apply during commuting hours may be written as:

$$\begin{cases} S \cdot \frac{V}{2} = R \cdot i_a + L\frac{di_a}{dt} + e_a + V_{no} \\ -\frac{V}{2} = R \cdot i_b + L\frac{di_b}{dt} + e_b + V_{no} \\ 0 = R \cdot i_c + L\frac{di_c}{dt} + e_c + V_{no} \end{cases}$$

The voltage at the motor's first rpm may also be determined using

$$V_{no} = (S-1)\cdot\frac{V}{6} - \frac{E}{3}$$

S1 is both on (S 1 = +) and off (S 1 =) during the duration of the whole transition. Determine the normal inclines of commutated currents using the following method:

$$\frac{d\bar{i}_a}{dt} = \frac{1}{6L}[4D \cdot V - V - 4E]$$

$$\frac{d\bar{i}_c}{dt} = \frac{1}{6L}[-2D.V + 2V - 4E]$$

When the slopes of the currents is and ice are equalized, we get 0 E / V 3/ 8 from Eq. (21). D2,Low will be non-negative and between 0 and 1 if the expression 1/ 8 E / V 3/ 8. It is further shown that, with S4 active, slope matching between currents is and ice is attainable in the range 0 E / V 1/ 8. As such, the duty cycle may be calculated in this case by

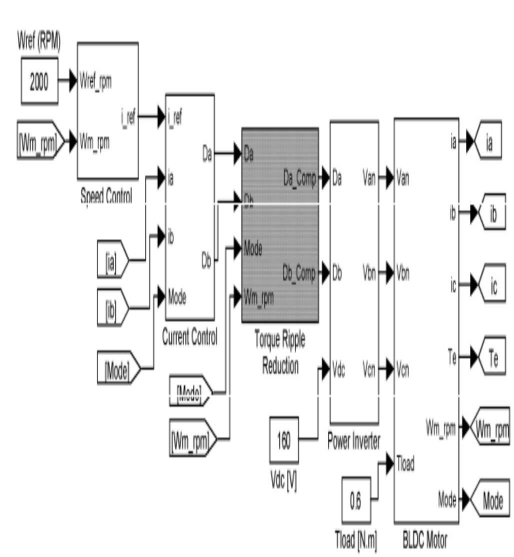
$$D_{2,Low\_2} = \frac{3}{4} + \frac{2E}{V}$$

Simulation

In this subsection, we utilize simulation to test how well our new strategy for reducing torque ripple works. In Fig. In Figure 12, we can see a Simulink representation of a four-switch brushless DC motor driving system. The reference current is supplied by the speed control module. Duty cycles (Ad and Db) for the power switches are generated and phase currents are controlled by direct phase current (DPC) control in the current control block. Figure depicts the suggested duty cycles for the commutation intervals of the torque ripple reduction block. 11. In order to run, the BLDC motor needs exact phase voltages, which are produced by the power inverter block. Equation () is used in the BLDC motor circuit. is often used for determining phase currents (1). Some of the features of BLDC motors are shown in Table 1. The calculated performance is at a rate of 2000 revs per min. The torque ripple with and without the suggested approach is shown in Figure 13 for comparison. The resulting current ripple is rather substantial, at 2.5 [A] (about 40%). Our unique method brings that percentage down to less than 7%.

Rated BLDC Motor Parameters Table 1

P_{rated}	1 [hp]	ω_{rated}	3500 [RPM]
R	0.75 [Ω]	L_s-M	3.05 [mH]
K_t	0.21 [N.m/A]	K_e	0.107 [V/(rad/sec)]
I_{rated}	10 [A]	$V_{DC\text{-}Bus}$	160 [V]
Z_p	2	J	8.2e-5 [Kgm^2]



A functional block diagram of the FSTPI-BLDC motor drive's novel commutation torque ripple reduction technique is shown in Figure 6

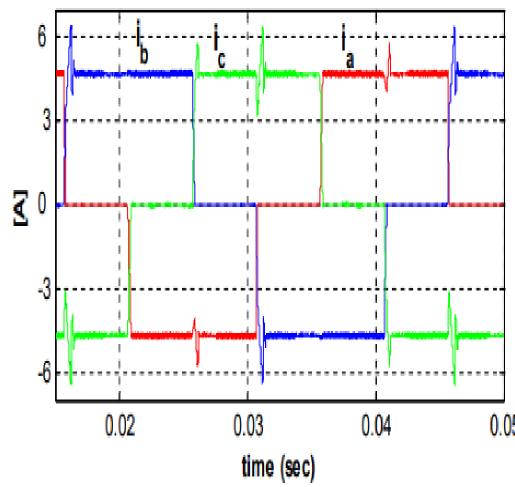
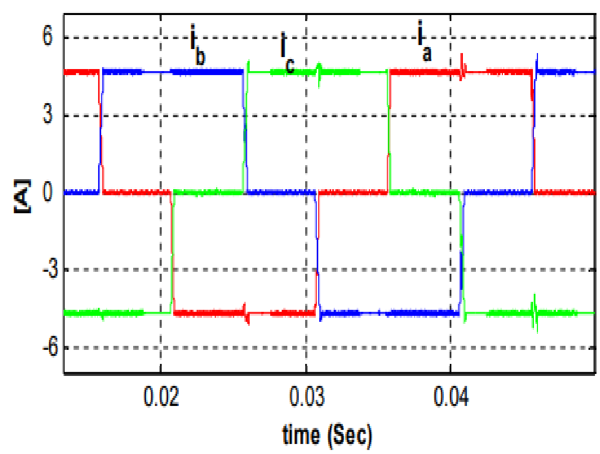
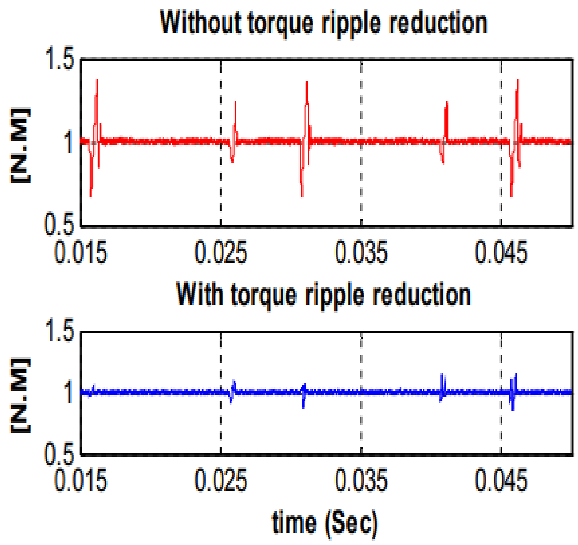


Fig 7In (a), without using the torque ripple reduction



Torque ripple reduction and its effect on the BLDC motor's phase current waveforms are shown in Fig. 8



Developed electromagnetic torque in various modes is shown in Fig. 9

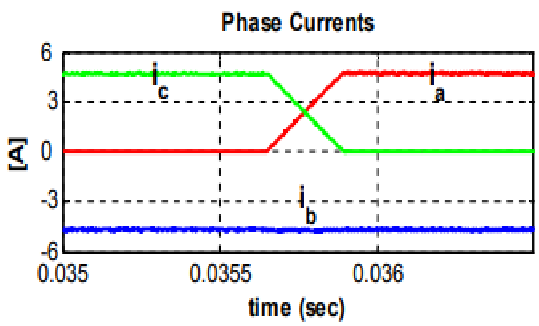


Figure 10: Current commutation during mode II without torque ripple mitigation.

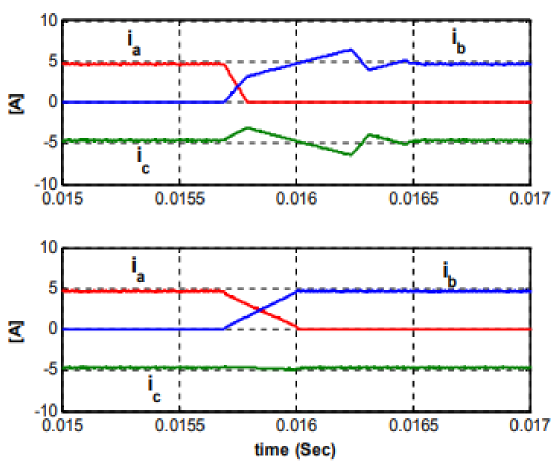


Figure 11: Current commutation during mode IV.

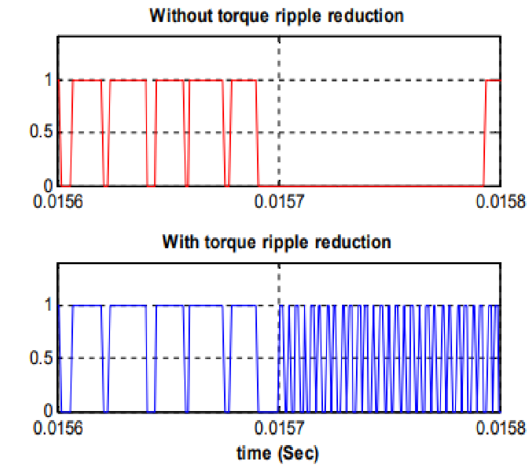
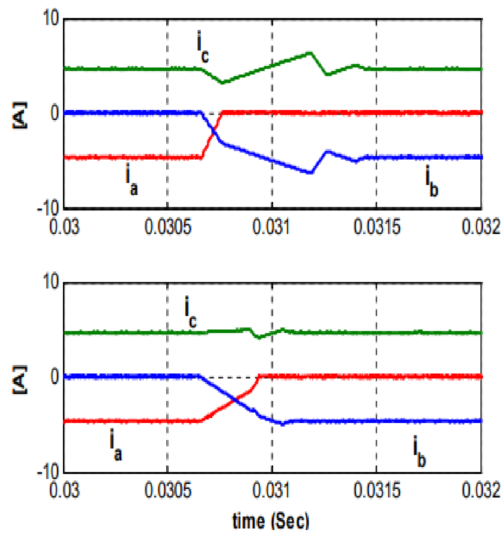


Figure 12: A instruction to switch was sent to S1 while in mode IV.



Commutation of the current in Mode VI is seen in Figure 13.

Conclusion

This study examines the commutation torque ripple produced by a four-switch brushless DC motor drive. Analytic formulae for the commutation intervals and the commutation torque ripple are found for each mode. According to the results obtained, phase commutation has different features in different operating modes. There is data suggesting that the limit point for current control is just half that of a six-switch inverter. This means that rectangular phase currents can only be altered at a pace that is half of the typical rate. Since the current control limit point V 4E = is below the speed range in question, a novel way of eliminating torque ripple has been developed. In fact, it depends on the commutation interval's slope equalizing the descending and ascending currents. We have shown the effectiveness of the proposed method through simulation. The recommended method may be applied to the FSTPI-BLDC motor drive with little effort and money.

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