Dropping Commutation Torque Ripple & Fuzzy logic control for Brushless DC Motor Based on SEPIC Converter

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Abstract - Brushless dc motor still suffers from commutation torque ripple, which mainly depends on speed and transient line current in the commutation interval. This paper presents a novel circuit topology and a dc link voltage control strategy to keep incoming and outgoing phase currents changing at the same rate during commutation. A dc–dc single-ended primary inductor converter (SEPIC) and a switch selection circuit are employed in front of the inverter. The desired commutation voltage is accomplished by the SEPIC converter. The dc link voltage control strategy is carried out by the switch selection circuit to separate two procedures, adjusting the SEPIC converter and regulating speed. The cause of commutation ripple is analysed, and the way to obtain the desired dc link voltage is introduced in detail. Finally, simulation and experimental results show that, compared with the dc–dc converter, the proposed method can obtain the desired voltage much faster and minimize commutation torque ripple more efficiently at both high and low speeds and the closed loop control is achieved by Fuzzy logic control.

Index Terms — Brushless dc motor (BLDCM), commutation, dc link voltage control, single-ended primary inductor converter (SEPIC).

I. INTRODUCTION

The BRUSHLESS DC MOTOR (BLDCM) has been widely used in industrial fields that require high reliability and precise control due to its simple structure, high power density, and extended speeding range. The performance of such motors has been significantly improved due to the great development of power electronics, microelectronics, and magnetic performance of magnets, and motion control technology in recent years. However, commutation torque ripple, which usually occurs due to the loss of exact phase current control, has always been one major factor in preventing BLDCM from achieving high performance. So far, many studies have been performed to reduce commutation torque ripple. An original analytical study on commutation torque ripple is presented in, from which a conclusion has been drawn that relative torque ripple is independent of current and varies with speed. A similar analysis is presented in, and the strategy of changing the input voltage to reduce commutation torque ripple is proposed. Both papers are based on some necessary assumptions such as ideal trapezoidal back electromotive force (EMF), very small current hysteresis or pulse width modulation (PWM) cycle, and constant back EMF during commutation, and no implementation of voltage adjustment is demonstrated in them. It is proposed in that a single dc current sensor and a current deadbeat control scheme should be used to keep incoming and outgoing phase currents changing at the same rate during commutation, hence effectively suppressing commutation torque ripple at both high and low speeds. It is an effective method to introduce some special topology of a circuit to BLDCM drives to control its input voltage, as shown by some researchers presented in. In, a buck converter is used, and commutation torque ripple is then greatly reduced at low speed. In, a superlight Luo converter is placed at the entrance of the inverter to produce desired dc link voltage, and the structure is more competent under the high-speed work condition, compared with the method proposed in. A developed structure of the inverter is proposed in, which avoids the effect of the fly-wheeling process and acquires more exact estimated torque with sampling current. All of the above methods suffer from slow voltage adjustment, and therefore, they can only achieve satisfactory torque pulsation suppression in low- or high-speed regions. In this paper, a novel topology of a circuit is proposed, and an appropriate dc link voltage is used to drive phase currents to increase and decrease in the identical slope, resulting in the great reduction of pulsated commutation torque. To get the desired dc link voltage, a single-ended primary inductor converter (SEPIC) circuit is used to control the input of the inverter. The adjustment of dc voltage can be completed during non commutation conduction period and switched immediately at the beginning of commutation by the switch selection circuit. Simulation and experimental results show that, compared with common dc–dc converter, the proposed method, when applied in a steady state, can reduce commutation torque ripple both at high and low speeds with much faster dc voltage regulation.

II. ANALYSIS OF TORQUE DURING COMMUTATION INTERVAL

A typical block diagram of BLDCM drive system is shown in Fig. 1. The BLDCM has three stator windings and permanent magnets on the rotor. Due to the nonzero inductance of the stator phase windings, the actual phase currents, instead of the desired rectangular form, are in a trapezoidal form with a finite rise time. In fact, the different slopes of incoming and outgoing phases have a direct influence on the commutation torque, which can be illustrated using the following analysis. For this analysis, the commutation of the current from phase A to phase B is considered. This current transfer is done by switching off VT1 and switching on VT3, with VT2 remaining on. With only a very small period of PWM, the current through the winding of the motor between commutations is regarded to be constant and equal to Im. It implies that the initial values of iA = −iC = Im and iB = 0are known at the beginning of commutation. The equivalent circuit during commutation is shown in Fig. 3. According to Fig. 3, switch K1 is off and K2 is on at point 1 before commutation begins. During commutation, K1 is switched on. Because iA flows through the freewheeling diode VD4, K2 is switched on at point 2, and when the commutation is over, K1 is on and K2 is switched on at point 3 (suspended). K1 and K2 stand for the MOSFETs carrying on PWM modulation when turned on.

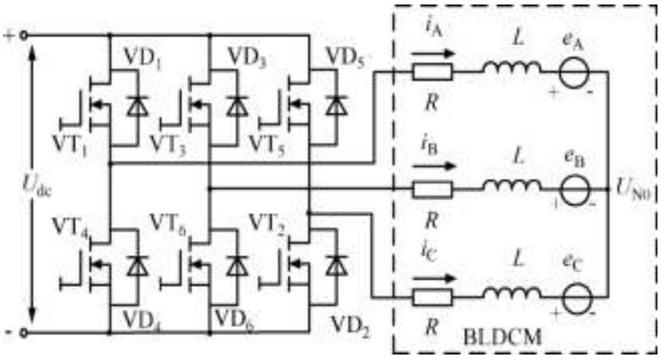

Fig. 1. Block diagram of the BLDCM drive system.

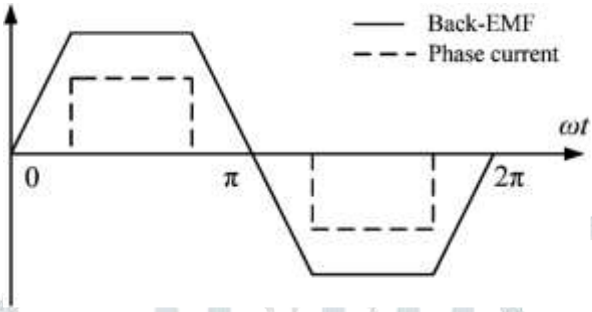

Fig. 2. Ideal current and back EMF waveforms in BLDCM (single phase).

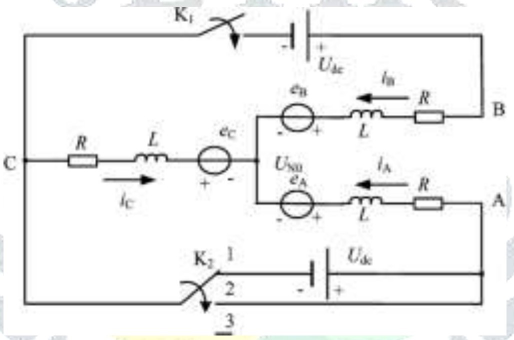

Fig 3. Equivalent citcuit diagram of the BLDC Motor.

This system, the switch time of the MOSFET VT1 − VT6($t$on, $t$off) is about 80 ns, and the reverse recovery time of the diode ($t$rr) is about 20 ns. When compared with the commutation interval, the switch action of the diode and the MOSFET can be neglected.

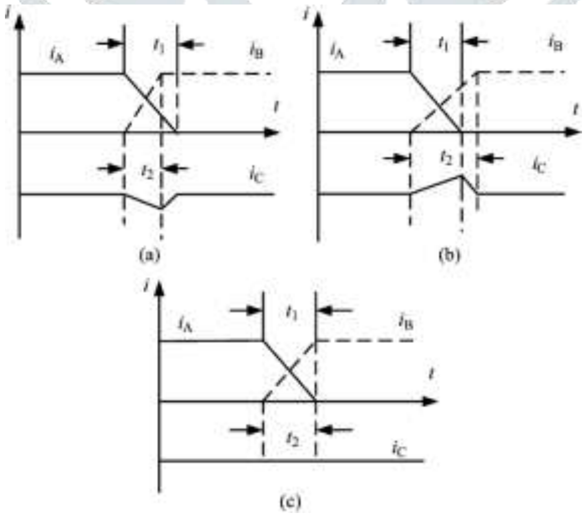

Fig. 4. Current behaviours during commutation.

The slopes of the currents during commutation depend on the dc link voltage Udc and the maximum value of back EMF Em. Em is proportional to speed and considered constant during commutation. Udc is generally invariable due to uncontrollable rectification. Consequently, Udc =4Em cannot always be satisfied during speed adjustment, which leads to significant torque pulsation. The torque ripple during commutation is proportional to |Udc − 4Em|, and the closer Udc is to 4Em at the commutation interval, the little the torque ripple becomes. In this paper, a new circuit topology is proposed, which can reduce commutation torque pulsation by keeping Udc close to 4Em during commutation.

III. PROPOSED CONTROL STRATEGY FOR BLDCM

As mentioned above, an adjustable dc link voltage is required to maintain *U*dc = 4*E*m to avoid the commutation torque pulsation. In this paper, a SEPIC converter with a switchover MOSFET is used to implement the dc link voltage adjustment, as can be seen in Fig. 5

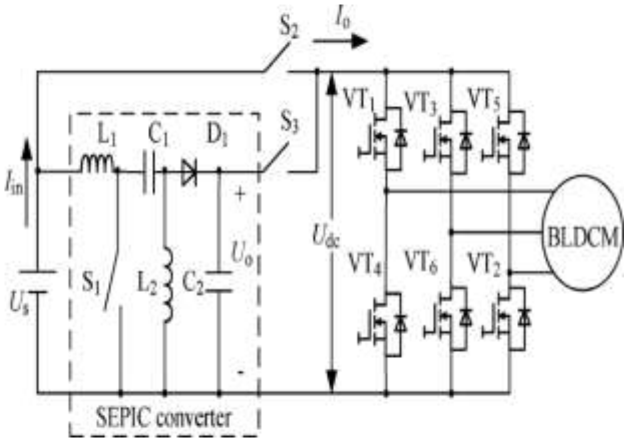

Fig. 5. Configuration of BLDCM driving system with a SEPIC converter.

In Fig. 5, S1, S2, and S3 are all power MOSFETs. By operating S1 appropriately, the energy storage components (i.e., *L*1, *L*2, *C*1, and *C*2) of the SEPIC converter can be adjusted to get the desired output voltage S2 and S3 are switchover power MOSFETs used for choosing between the inputs of inverter *U*s and the output voltage of the SEPIC converter *U*o, which can be calculated. When the iron losses are not taken into account, *E*m is proportional to speed, i.e.,

*E*m = *K*eΩ

Where

*K*e is the back EMF coefficient.

The duty ratio of S1 corresponding to the desired dc link voltage can be estimated by measuring the motor speed. The adjusting process of the SEPIC converter needs about 40 ms, which is a much longer time compared with the commutation interval, which is generally about tens or hundreds of microseconds of BLDCM. To achieve an immediate change of the input voltage of inverter, S2 and S3 are required to be complementary to each other. At the beginning of every commutation, S2 is switched off, and S3 is on. The SEPIC converter stops adjusting, and the output voltage remains constant. Once commutation is over, S2 is switched on and S3 is off.

The SEPIC converter begins regulating again, and its output voltage will reach the expected value before the next commutation. It should be noted that theoretically, the SEPIC converter can finish adjusting during 1/6 electrical cycle with enough energy storage, even if the speed is very high in the steady state. However, as far as the speed step is concerned, the converter generally fails to respond fast enough due to its significant inertia. As a result, when the speed varies significantly, the system needs some time to get the steady state.

The actual speed of the motor and reference speed is compared and the error speed is given to the Fuzzy logic controller. The Fuzzy logic controller will reduce the speed error and the BLDC motor will run at constant speed with respect to the variation of load. This will improve the efficiency of the motor.

IV. SIMULATION AND EXPERIMENTAL RESULTS

To verify the feasibility of the proposed strategy, simulations and experiments are carried out.

It can be calculated that torque ripple decreases from about 48.1% to 19.2% at 1000 r/min, and from about 57.3% to 19.5% at 2500 r/min. input voltage of the inverter during commutation, torque pulsation is significantly reduced. From the closed loop control the motor is runs at constant speed irrespective of the motor load.

The figure shows the SEPIC converter output voltage, Hall sensor output signals, PWM pulses to the inverter, Inverter output voltage, current waveform of the motor, speed and torque characteristics of the Brush less DC motor based on the SEPIC converter.

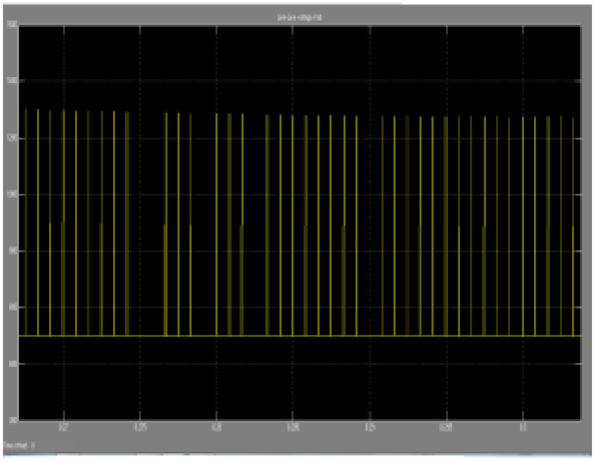

Fig.6 SEPIC converter output voltage

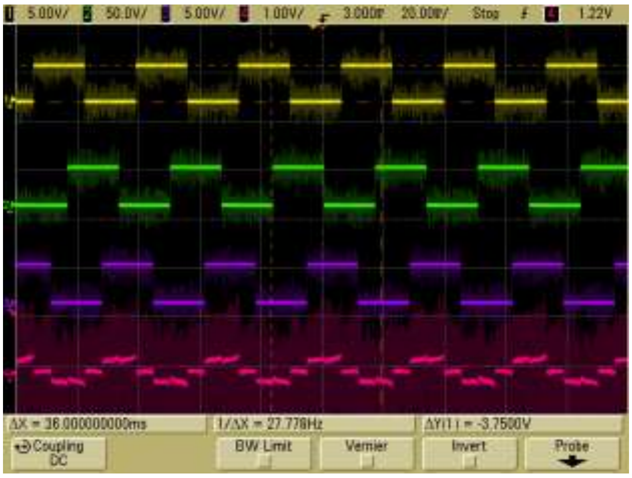

Fig.7 Hall sensor output signals and phase current

Fig.8 Line to line voltage from the inverter

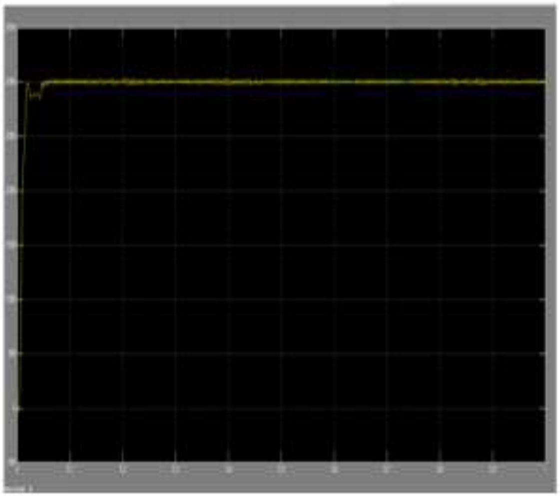

Fig. 9 Motor speed waveform using Fuzzy logic controller

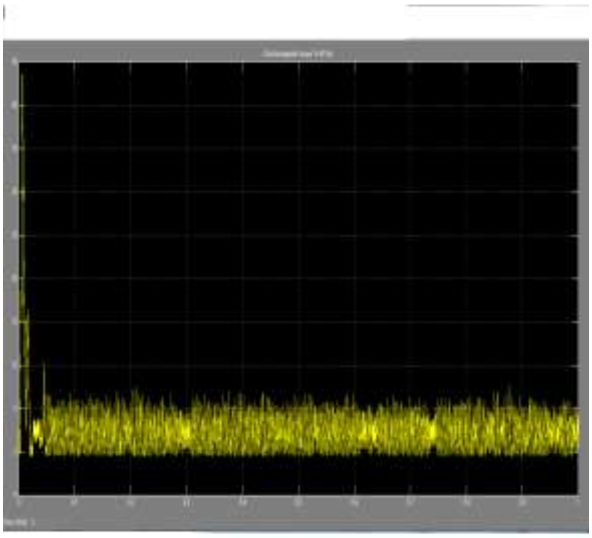

Fig.10 Torque waveform before SEPIC Converter

Fig.11proto type modal

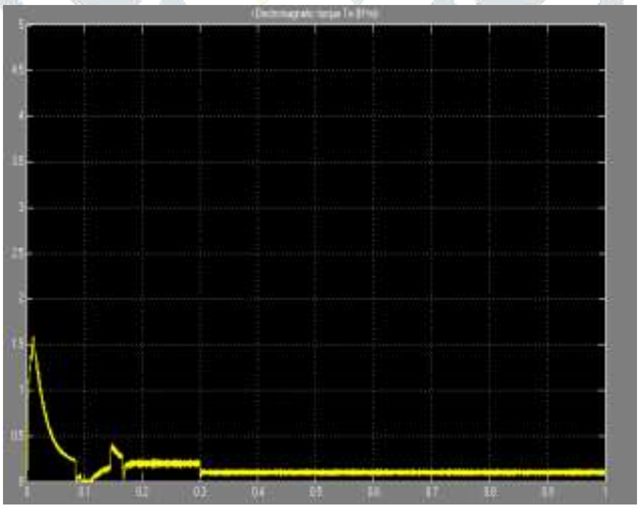

Fig.12 Torque waveform after SEPIC Converter

V. CONCLUSION

A new circuit topology and control strategy has been proposed to suppress commutation torque ripple of BLDCM in this paper. A SEPIC converter is placed at the input of the inverter, and the desired dc link voltage can be achieved by appropriate voltage switch control. The switch control separates the two procedures, adjustment of SEPIC converter, and regulation of speed so that torque can respond immediately during transient commutation and robustness can be improved. Furthermore, no exact value of the commutation interval *T* is required, and the proposed method can reduce commutation torque ripple effectively within a wide speed range and the closed loop control is achieved using Fuzzy logic controller. Finally, the simulated and measured results show an improved performance of the proposed method.

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