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Torque ripple minimization in bldc motor using dc-dc sepic converter

***Abstract**. Torque ripple in Brushless dc motors is generally undesirable. Torque ripple causes increased acoustic noise and undesirable speed ripple preventing BLDC motor from achieving high performance. This article presents the method of reducing torque ripple in BLDC motor. This study presents an approach to reduce torque ripples by controlling the voltage while maintaining speed. To get the desired dc link voltage, a single-ended primary inductor converter (SEPIC) circuit is used to control the input of the commutation circuit.*

Streszczenie**. W artykule analizuje się możliwości minimalizacji zafalowań momentu napędowego w silniku bezszczotkowym. Zmniejszenie tętnień uzyskuje się przez sterowanie napięcia utrzymującego prędkość. W celu utrzymania pożądanego napięcia dc wykorzystano niesymetryczny przekształtnik typu DSEPIC. **Minimalizacja tętnień momentu w silniku bezszczotkowym przy wykorzystaniu przekształtnika dc typu SEPIC

Keywords: Brushless dc motor, commutation, single-ended primary inductor converter, torque ripples.
Słowa kluczowe: silnik bezszczotkowy, zafalowania momentu napędowego

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Introduction

Brushless dc motor offer many attractive features like low maintenance, fast response, high efficiency, high power density, good reliability and compact construction. As a result, the brushless dc motor is increasingly being used in military, industrial and commercial applications. Its market is rapidly expanding. But these motors still suffer from commutation torque ripple. The primary disadvantage of brushless dc motor is higher torque ripples compared with conventional machines. So far, many research studies have been performed to reduce commutation torque ripple [1-10].

An active topology to reduce the torque ripples in BLDC motor was investigated in [1]. This paper [1] discusses 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 commutation circuit. The implementation of higher degree polynomial acceleration profile for torque ripple reduction is presented in [2]. In this work [2], a novel digital PWM controller is proposed for the BLDC motor. This controller treats the BLDC motor as a digital system. The method to simply vary the input voltage to reduce commutation torque ripple is proposed in [3] for reducing current ripple after circuit analysis using the Laplace transformation. The circuit analysis involves acquiring the period of freewheeling region and the voltage value to be varied. A new torque control method for reducing the torque ripple of the BLDC motor with un-ideal back EMF waveforms is reported in [4].In [4] the duty cycle of the corresponding switches is pre-calculated in the torque controller about the actual back EMF waveforms in both normal conduction period and commutation period.

It is proposed in [5] 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. The study [5] presents a comprehensive analysis of the commutation torque ripple suppression method in brushless dc motor drives with only a single current sensor. Coupled inductor SEPIC converter can be used for reducing the ripple and helps to improve converter efficiency has been discussed in [6].The literature [7] describes an improved implementation of direct torque control (DTC) to the brushless DC drive. It adaptively adjusts the phase current waveform to maintain constant electromagnetic torque, so that commutation torque ripple is eliminated. A low-cost sensorless control scheme for BLDC motors is found in literature [8]. This leads to a significant reduction in the component count of the sensing circuit and also torque ripple is minimized. An analytical study [9], [10] is developed concerning the torque ripple due to phase commutation on brushless dc motors. All the above methods experience from slow voltage adjustment and therefore they can only achieve satisfactory torque ripple suppression.

In this study, the main desire is to reduce the torque ripples present in brushless dc motor. In this topology, a dc voltage control strategy is carried out by using a dc to dc SEPIC converter. The desired dc voltage is accomplished by using this converter which is used to control the input of the inverter. MATLAB/Simulink is used to perform simulation. Simulation results show that the proposed topology can significantly reduce torque ripples both at high and low speeds with different load conditions. This work is organized as follows. In section 2, conventional BLDC motor drive system is given. In Section 3, sepic converter for BLDC motor is discussed. In section 4, simulation results are provided to confirm the validity of the method. Finally, in section 5, conclusions are given.

Conventional BLDC motor drive system

BLDC motor is an electronically commutated motor. Since the stator of BLDC motor is fed from a dc supply, a commutation circuit along with PWM controller is mandatory. It requires a six switch commutation circuit as shown in Fig.1. The electronic commutator receives the switching logical pulse from the hall sensors. These motors are conventionally excited with bipolar currents.

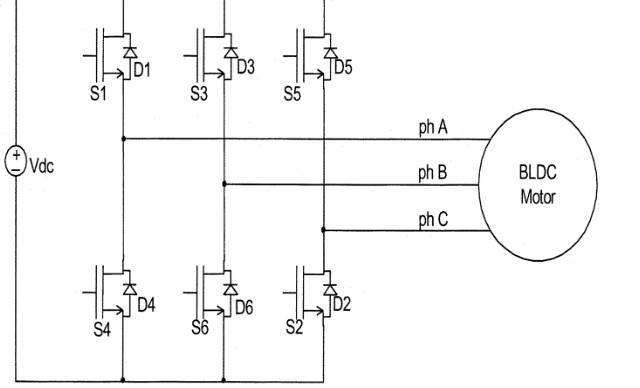


Fig.1. Basic configuration of conventional six switch fed BLDC motor drive

SEPIC Converter

A SEPIC is a type of non-isolated dc-dc converter that can convert a dc voltage to another equal, lower or higher stable dc voltage level at its output. “Single-ended” means that only one switch in the converter controls energy exchange between its components. Overall, a SEPIC function is general to a buck-boost converter, but has the additional advantages of having its output voltage polarity non-inverted with respect to its input voltage, having a true shutdown mode – i.e. when switch S turns off, the converter’s output voltage reduces to 0V, and having isolation between the input and output.

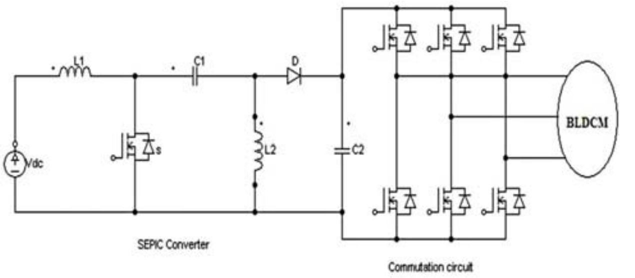


Fig.2. Proposed dc to dc SEPIC converter coupled with BLDC motor drive

The capacitive isolation prevents unwanted current flowing from the input to output. The output voltage of the sepic converter is controlled by varying duty cycle of the switch. Typically ‘S’ is an electrically controlled switch, such as a power metal oxide semiconductor field effect transistor (MOSFET), power bipolar junction transistor (BJT) or insulated-gate bipolar transistor (IGBT).Its switching actions are controlled by a pulse-width modulation.

SEPIC converter fed BLDC motor

A new topology of brushless dc motor control using a dc-dc SEPIC converter is proposed resulting in the great reduction of torque ripples. The dc voltage control strategy is carried out by using the SEPIC converter. An appropriate dc voltage is used to control the current which results in a great reduction of torque ripples. Fig.3 shows the block diagram of the proposed system. The block diagram of the proposed system mainly consists of dc voltage source, SEPIC converter and the brushless dc motor. The dc input voltage is given to the SEPIC converter. The SEPIC converter is used to control the input of the inverter module i.e., commutation circuit.

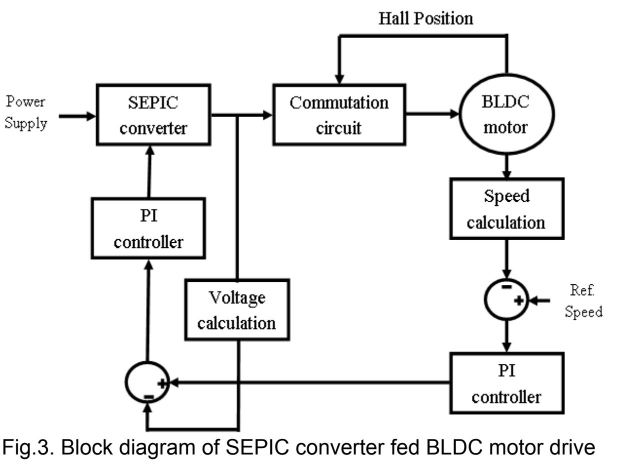


Fig.3. Block diagram of SEPIC converter fed BLDC motor drive

The desired commutation voltage is accomplished with the help of the SEPIC converter. This helps to control the current and proportionately the torque ripple is minimized in the BLDC motor. In this topology, SEPIC converter employs one switch which performs dc to dc conversion. The switch ‘S’ is a power MOSFET. By operating switch ‘S’ appropriately, the energy storage in components i.e., L_1, L_2, C_1, C_2 of a SEPIC converter can be adjusted to get the desired output. The rotor position sensor mounted on the motor shaft provides a position feedback. It monitors the shaft position and sends signals to drive the commutation circuit. In response of these signals, the commutation circuit allows the flow of current to stator phase windings in a controlled sequence so that motor produces desired torque and speed. The effectiveness of the topology for torque ripple minimization is analyzed through simulations.

Simulation and validation

In order to validate the performance of the brushless dc motor with proposed dc to dc SEPIC converter, a simulation model is developed. The simulation is performed with MATLAB simulink. The parameters of the BLDC motor used for simulation are listed in Table 1.

Table 1. Motor parameters

Motor characteristics	Values(units)
Terminal resistance	0.323 Ω
Terminal inductance	0.389 mH
Voltage constant	6.99 V/ k rpm
Electrical time constant	1.205 m-secs
Mechanical time constant	10.293 m-secs
Rotor Inertia J_m	$0.142e^{-3}$ Kg.m^2
No load speed	3434 rpm
No load current	1.24 A
Rated Power	123 W
Number of poles	8
Number of phases	3

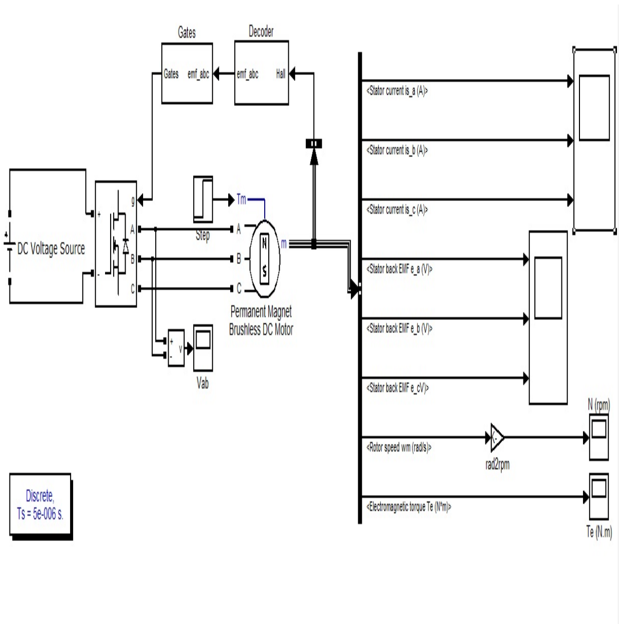


Fig.4. MATLAB simulation of conventional six switch fed BLDC motor drive

MATLAB simulation of conventional six switch fed BLDC motor drive

The simulation was performed with conventional six switch fed BLDC motor. In order to get 120º square wave phase currents, two switches are turned on at a time. The hall sensors mounted on the motor shaft gives the information about the position of the rotor. The parameters stator back emf, stator current, speed and torque waveforms were observed.

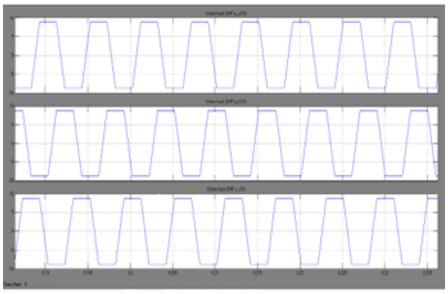


Fig.5. Stator back emf

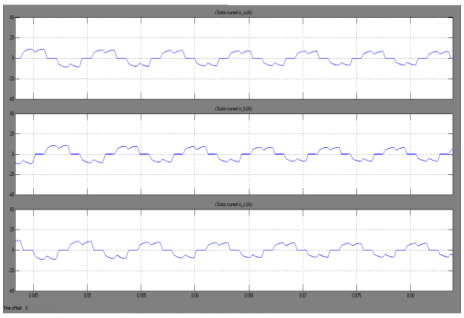


Fig.6. Stator current

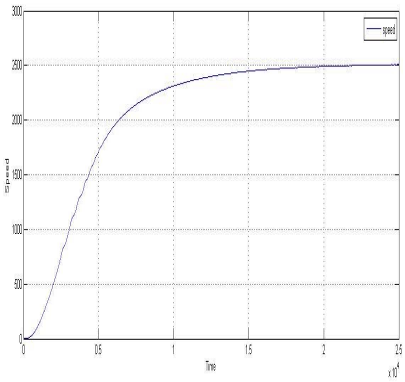


Fig.7. Speed

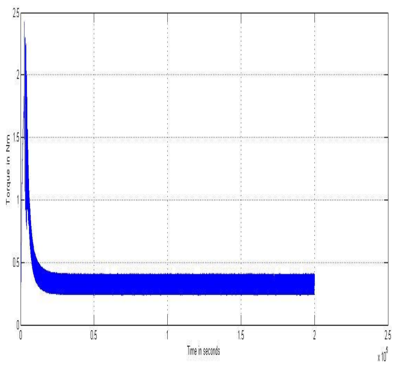


Fig.8. Torque

MATLAB simulation of sepic converter fed BLDC motor drive

Fig.9 shows the simulation model of the BLDC motor drive with dc to dc SEPIC converter in closed loop. In BLDC motor, the position of the rotor is sensed by using hall sensors. These signals are decoded by commutation logic to provide the firing signals on each of the three phases. The commutation logic unit gets the information about the position of rotor and decides which switching devices are to be turned on and off. The error speed is amplified by using a PI controller. The Pulse Width Modulation (PWM) technique is applied to the switch in SEPIC converter. In this work, the PI controller is designed to correct errors between measured speed values and desired speed in the system. A two-stage controller consists of an inner loop and an outer loop designed for the closed loop drive system. Outer loop is PI speed controller and inner loop is PI voltage controller. The simulation is performed for different speed and load conditions.

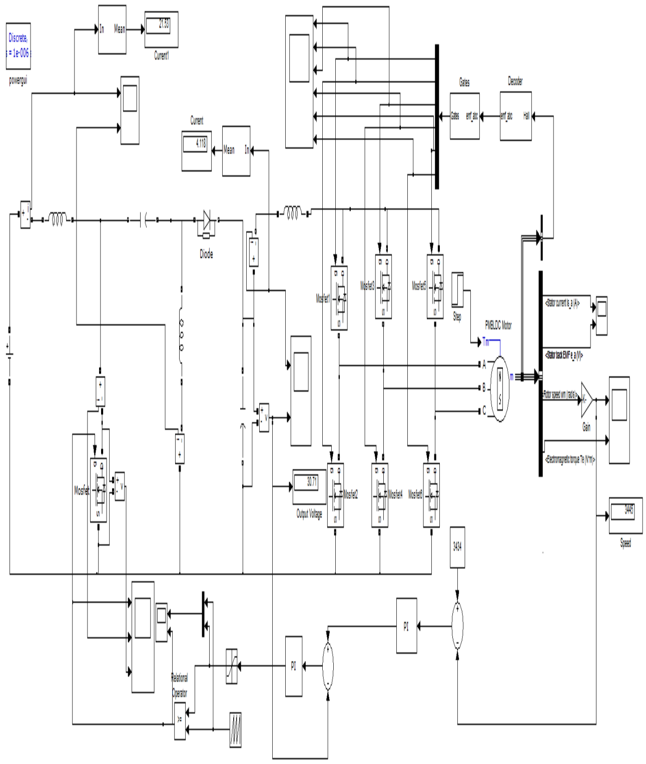


Fig.9.MATLAB simulation of SEPIC converter fed closed loop model of BLDC motor drive

Table 2 shows the specifications of the sepic converter designed for BLDC motor.

Table 2. Sepic converter specifications

Parameters	Values
Input Voltage	12 volts
Output voltage voltage	24 volts
Inductor L_1.L_2	10 μH
Capacitor C_1, C_2	10 μF

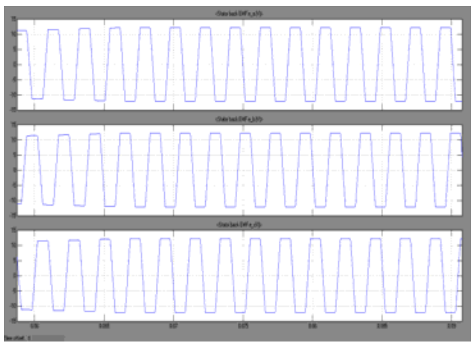


Fig.10. Stator back emf

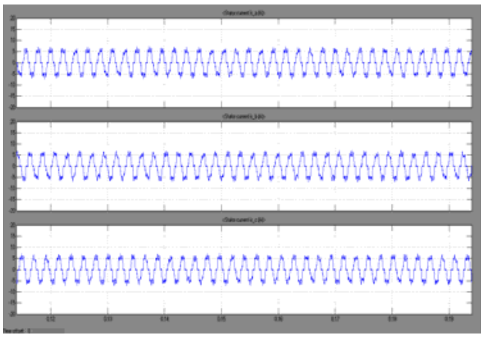
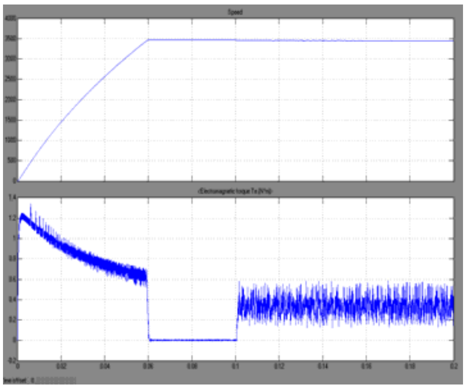
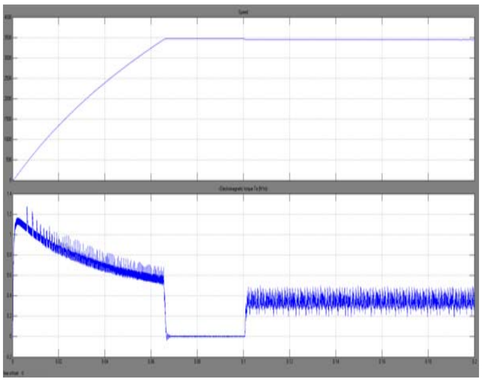


Fig.11. Stator current



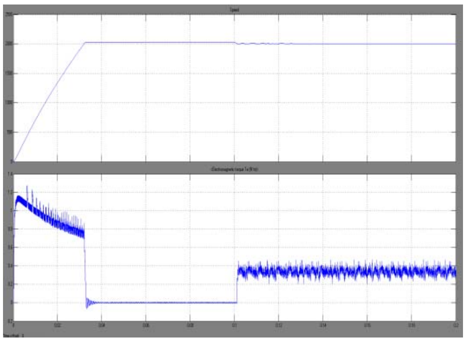
(a) without dc to dc SEPIC converter



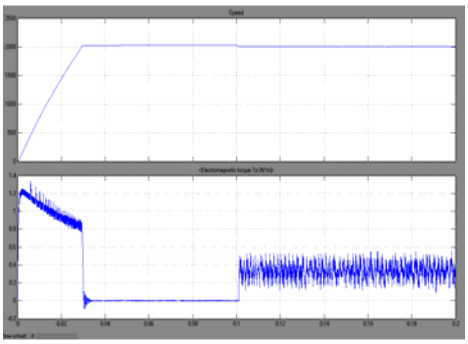
(b) with dc to dc SEPIC converter

Fig.12. Speed and torque waveforms for rated speed of 3434rpm with 100% load

Fig.12 shows the simulation results obtained for rated speed with full load conditions. From Fig.12, it can be seen that the closed loop system brings the speed to the normal value and is maintained constant with significant reduction in torque ripple.



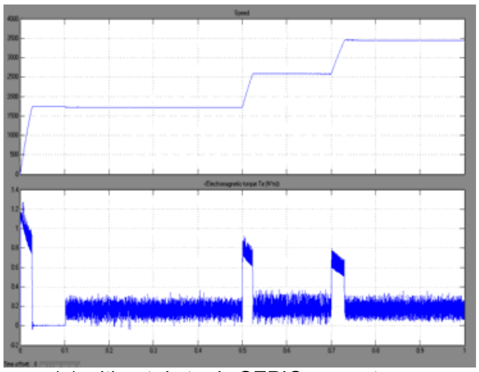
(a) without dc to dc SEPIC converter



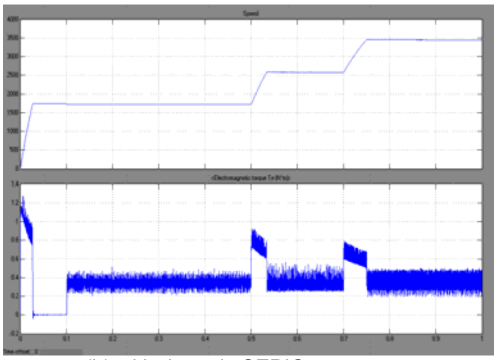
(b) with dc to dc SEPIC converter

Fig.13. Speed and torque waveforms for reference speed of 2000rpm with 50% load

From Fig.13 it is obvious that for reference speed of 2000rpm with 50% load the speed response is appreciable. The torque ripples are well reduced.



(a) without dc to dc SEPIC converter



(b) with dc to dc SEPIC converter

Fig.14. Speed and torque waveforms for different reference speed with 100% load

Fig.14 shows the performance comparison for different values of reference speed with full condition. The results obtained are found to be satisfactory.

Table 3. Summary of results

Load torque in %	speed in rpm	Torque ripple in %	
		without SEPIC converter	with SEPIC converter
100	3434	24.65	12.5
50	2000	22.5	9.21
75	1000	21.45	8.61

Table 3 summarizes the simulation results, specifying the torque ripple associated with each commanded speed. These results indicate that the proposed technique is very effective at the commutation torque ripple suppression over the entire motor speed range. The results reveal that SEPIC converter fed BLDC motor drive give better performance in terms of lesser torque ripple.

Conclusion

In this paper, a torque ripple minimization method has been proposed for brushless dc motor using a dc-dc SEPIC converter. The dc-dc SEPIC converter is placed at the input of the commutation circuit, and the desired dc voltage is achieved through closed loop controllers. And also this system provides the regulation of speed so that torque can respond immediately. The proposed method can reduce the torque ripples effectively within a wide speed range. The simulated results show an improved performance of the proposed method.

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