The Torque Ripple Minimization Technique for a Low Cost Brushless DC Motor Drive

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ABSTRACT
The torque produced in a brushless DC motor with trapezoidal back electromotive force (BEMF) is constant under ideal conditions. Some of these ripples result from the natural structure of the motor, while some are related to the motor design parameters. This paper introduces a torque ripple minimization technique for BLDC motor drive that is operated with a small DC link capacitor along with a fuzzy controller. It uses a single switch control strategy, resembles buck converter during operation at any switching state. The model of the proposed drive is done Matlab/Simulink to verify the effectiveness of the proposed scheme.

KEYWORDS: Brushless DC motor drive (BLDC), back electromotive force (BEMF)

INTRODUCTION

Brushless DC (BLDC) motors are becoming popular in industrial applications and home appliances. These motors offer many advantages such as high reliability, high efficiency in comparison to the other motor types such as induction and brushed DC motors. Both the BLDC and PMS are designed with high power densities for space craft applications [10]. For reducing commutation torque ripple in a position sensorless brushless DC (BLDC) motor drive (PWM) is designed to define the duty ratio from commutation interval in order to suppress the torque ripple [1].

The method to attenuate torque ripple with un-ideal back electromotive force (EMF) waveform is designed so that the time of pulses used to control corresponding switches, calculated in normal and commutation period [4]. The voltages is varied to VSI, in order to reduce torque ripple in the variable DC link [7].

A simple adaptive internal model based uncertainty control in BLDC drive is designed for the estimation of uncertainty function which provides efficient solution for torque ripple minimization [8].

The four-switch inverter based control with SVPWM is designed so that the six-step PWM current and voltage control scheme can be calculated within the reduced time [9]. A technique to reduce torque ripple by estimating and compensating the feed forward control technique is reported in [5].

Torque ripple suppression by combining commutation control and optimizing the duty ratio of the active controller is reported in [6]. Online estimation of unbalanced stator resistances of a permanent-magnet synchronous motor is reported in [2].

A simple buck converter based mathematical model is presented to accurately calculate the torque produced by the BLDC motor at constant speed [3].

The complexity in the buck model is reduced when compared to the comprehensive model of BLDC motor drive without a DC link capacitor is reported in [11]. The actively controlled and switched capacitors on the DC link are used to reduce the effects of torque ripple in the low cost brushless DC motor drive system [1].

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link capacitor to compensate for the inherent torque ripple in BLDC motors that are driven by matrix converters based system previously and proved to be a success [12].

BLDC which works with a direct power conversion technique that employs a minimum DC link capacitor to reduce the source ripple reduction which introduces the torque ripple due to power variations. Moreover by controlling an active capacitor switching scheme, a fuzzy control scheme is introduced to control the speed of the motor by integrating a novel control scheme to eliminate the power ripples by maintaining the speed of the motor is proposed in this paper.

II Block Diagram and Its Operation:

![Fig. 1: A typical BLDC motor drive.](image1)

In BLDC motors the electronic commutation of stator windings is based on rotor position with respect to the stator winding. Brushless DC motors are traditionally driven by Pulse Width Modulated Voltage Source Inverters (PWMVSI). However it has certain disadvantages like need of additional filter elements at input and output, the poor quality of output waveforms, harmonics depends on stability of DC link voltage and so on. A typical BLDC motor drive with rotor position feedback is illustrated in the Fig.1. The motor drive comprises a diode rectifier, a large electrolytic capacitor and a converter fed with rotor position information.

![Fig. 2: Proposed technique for torque ripple compensation.](image2)

In the proposed BLDC motor drive, a switching algorithm, which is based on single switch control while keeping the other switch in on state for the entire switching interval, is employed.

Switches of the phase legs A, B, and C of the inverter are represented by $A_{1}$, $A_{2}$, $B_{1}$, $B_{2}$, $C_{1}$ and $C_{2}$ where subscripts 1 and 2 denote the upper and the lower switch of each phase leg of the inverter, respectively.

During region 1 of $C_{DC}$ is charged through the antiparallel freewheeling diode associated with $S_{DC}$. However, there is no natural discharging path for the capacitor, and the discharge can be controlled by the gate signal applied to $S_{DC}$.

The energy stored in $C_{DC}$ should be sufficient to keep $i_{m}(t)$ at $I_{ref}$ during region 2 to eliminate the torque ripple. The controller is developed in such a way that the gate signal applied to $S_{DC}$ is derived based on $E$ and $v_{in}(t)$, while controlling the other switches in the inverter.
Consider the operation of the motor drive in step 2 of the switching algorithm during which switch $B_1$ is controlled while switch $C_2$ is left on. Phase A remains in off state. Fig. 2 illustrates the current paths when the switch $B_1$ is on and off, respectively. The operation of the motor drive during all other steps of the switching algorithm can be represented by the same buck converter model. Generally, the back emf waveform is trapezoidal for all BLDC motor drives which can be slightly distorted by harmonics in order to overcome that the ideal trapezoidal back emf is assumed.

To validate the proposed model and analysis, a Prototype BLDC motor controller was implemented in Matlab Simulink. The simulation model is analyzed with the power converter without a dc link capacitor, and with a low value DC link capacitor and a large value DC link capacitor which is referred with the basic PWM structure based on the position of the hall sensors a hysteresis controller based PWM control is provided, in which any two arms are controlled and triggered by the inverter.

In contrast to the traditional PWM structures a new modified PWM with a single arm control is been designed as the proposed scheme which is also to be validated with the same system along with the PI controller and a fuzzy logic control system, the design prototype of the system is listed below in the table.

The test system of a BLDC drive consist a Front end ac-dc converter followed by a small value capacitor and a three phase VSI incorporated with a hall sensor. Based on the hall sensors feedback the PWM signal is applied to the VSI and the control of the signals are based on the change in the position, the speed of the motor is controlled through the applied pwm.

![Hall sensor and switching signals.](image)

**Experimental Results:**

Compared to the large DC voltage ripple is satisfactorily reduced in the lower value DC capacitor, more over the ripples at the fuzzy and the PI controller are more compromising and they are almost equal to the larger value capacitor employed. With the extra triggering control at the PWM states helps in a major ripple reduction with a lesser cost compared to the conventional capacitor based systems.

**A IM Comparison:**

The compared form the without capacitor case the small capacitor and the pi controlled case and large capacitor case have reduced current ripples in the arms, among them the current ripples at the arms with the fuzzy controller havea smoother current transition which reduces higher current ripples and mostly suitable for drives with reduced dc link sizes.
Fig. 4: Effect of the capacitor in the BLDC drive.

Fig. 5: Effect of the capacitor in BLDC motor under various conditions.

Fig. 6: Im variations in BLDC motor.
From the above graphs it is clear that the system without and lesser capacitors would exhibit a higher current ripple compared to the larger value capacitor. In contrast to the higher value capacitors the graphs with switch PI and fuzzy shows a better reduction compared to the previous cases a same value of capacitor is used as the small value test i.e. (470 uf) compared to (2200 uf).

With the additional switch control and the closed loop speed control scheme reduces the current ripples and makes the system much reliable at the lower cost.

**B Torque Comparison:**

In Cases with the fuzzy controller has a lesser ripple value since the control system provides a better control over the torque values that smoothen the torque and maintains at the particular value with reduced ripples, which in turn can be used for speed and torque control application.

**C Speed Comparison:**

The steady state speed response of the motor drive under various configurations shows the variations of the speed is high under lower capacitor values and without dc link capacitors, more over fuzzy takes a time to settle but the speed ripples are lesser compared to all other modes.
Fig. 9: The variations of the torque ripples under steady state control mode.

Fig. 10: Speed comparison of various modes of the controller.

Conclusion:

The concept of synthesizing a 3 Ø BLDC motor drive from 1 Ø voltage source without any intermediate energy storage elements is presented. The switching sequence which is essential for the operation of the drive, has been tested extensively for trapezoidal back EMF brushless DC machine models with different machine parameters and load conditions to verify the theoretical performance of the proposed drive system. The speed and torque ripples are inherent with the method due to the zero crossing points of the input power supply in speed and current control modes, respectively. The simulation results obtained from the developed Matlab/Simulink model indicates that the performance of the drive system would be an attractive alternative for low cost motor drives, ideally to the places where torque ripple is not a concern.

REFERENCES