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COMMUTATION TORQUE RIPPLE REDUCTION USING FUZZY LOGIC CONTROLLER IN SENSORLESS BRUSHLESS DC MOTOR

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ABSTRACT

Brushless Direct Current (BLDC) motors are widely used due to high reliability, simple frame, straight forward control, and low friction. BLDC motor has the advantage of high speed adjusting performance and power density. Speaking of the motor drive, the most important part is commutation control. On the other hand, they show a high torque ripple characteristics caused by nonideal commutation currents. This limits their application area especially for the low-voltage applications.

In order to minimize torque ripple for the entire speed range, a comprehensive analysis of commutation torque ripple was made according to phase advancing(PA) commutation control method. This approach is based on the terminal voltage sensing and converting the voltages into d-q reference frame and the commutation signals are generated by comparing it with reference values. The gating signals are obtained by switching sequence of BLDC motor and it is done using fuzzy logic controller(FLC).The design analysis and simulation of the proposed system is done using MATLAB version 2013a and the hardware for the reduction in torque ripple in bldc motor fuzzy logic controller are shown and proved.

KEYWORDS- Brushless DC motor, torque ripple, Phase advancing method, fuzzy logic controller

INTRODUCTION

BRUSHLESS DC MOTOR (BLDCM) has been widely used in fields that require high reliability and precise control, due to its simple structure, high power density, high efficiency, high starting torque, long operating life and extended speeding range. BLDC motors are used in industries such as automotive, aerospace, consumer, industrial automation and instrumentation.

As the name implies, BLDC motors do not use brushes for commutation, because BLDC motors are electronically commutated motor. BLDC motors have many advantages over brushed DC motors and induction motors.

In [1] commutation torque ripples according to three most common commutation control methods are analyzed and compared. Uses three commutation control methods for full speed range operation. Conventional six-step and phase- advancing (PA) methods are adopted below the base speed, and the phase-advancing with overlapping (PAO) method is used for over the base speed to obtain higher speed operation with low torque ripple.

A hysteresis and deadbeat current control have been proposed to minimize the commutation torque ripple in [3]. Both methods use inner current control loops to regulate commutation current. In order to keep incoming and outgoing phase currents changing at the same rate during commutation, the duty cycle is regulated at low speed and the deadbeat current control is adopted at high speed. In [2] an overlapping technique, which extends the phase conduction period over 120 electrical degree, was adopted to reduce the torque spike by exciting a new conducting phase in advance.

The direct torque control (DTC) scheme is suggested in [6]. The proposed DTC, however, needs arithmetic calculations for the extracting torque and flux compensation term that can add further computational overload to low cost CPUs. The duty ratio compensating torque fluctuation in PWM ON PWM method was discussed in [7]. This type of duty control, however, needs real-time measurements and calculation of phase current, angular position, and speed. In [5], a buck converter was used with a new modulation pattern to reduce the commutation torque ripple, but the bandwidth of the buck converter was not considered, so this structure can only handle torque pulsation at the low speed.

A super-lift Luo topology and SEPIC converter were employed in [9] and [8], respectively. But these structures need complex control or additional power switches

PROPOSED SYSTEM –TORQUE RIPPLE REDUCTION IN BLDC MOTOR USING FUZZY LOGIC CONTROLLER

System Configuration

For sensorless BLDC drive which is complex, multivariable and nonlinear, even if the plant model is well-known, there may be parameter variation problems. Figure 1 shows the circuit diagram of sensorless BLDC motor drive system. A conventional star connected inverter drives the bldc motor. DC power is supplied by rectifying the 3 phase ac supply. Control configuration shown is composed of a single-speed loop. Speed control output is directly fed to the PWM module as the duty ratio D, i.e., D ∈[0,1].The commutation detection block enables sensorless operation of the motor, comparing the measured back EMF with half dc-link voltage. The PWM duty is updated six times during an electrical period and maintained constant during a mode.

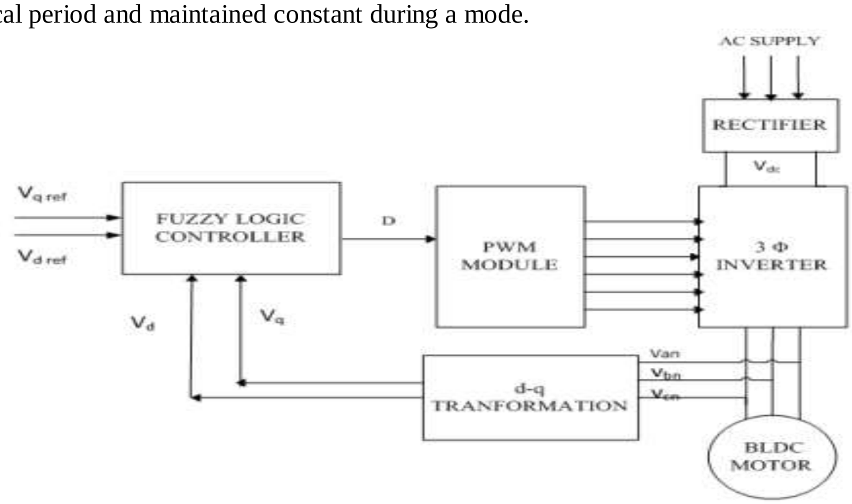

Fig. 1 Block diagram of sensorless Brushless DC motor drives system using Fuzzy Logic controller

The ripple contents of stator current, electromagnetic torque and rotor speed are minimized with FLC method. . The advantages of Fuzzy Logic Controller is that it does not require any mathematical model and only based on the linguistic rules. In a 3 phase star connected motor with non-sinusoidal air flux distribution the d-q transformation used is a simpler method and shows the similar d-q-0 of line to line transformation.

During start-up and other severe motoring operations, the motor draws large currents, produce voltage dips, oscillatory torques and can even generate harmonics in the power system. It is therefore important to be able to model the asynchronous machine in order to predict these phenomena. Various models have been developed and the q- d axis model for the study of transient behavior has been well tested and proven to be reliable and accurate.

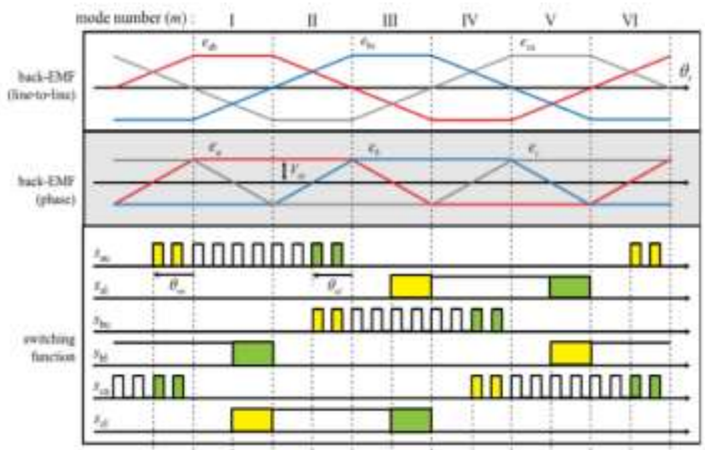

Fig. 2 Voltage waveforms according to the commutation control method i) line- to – lie back emf , ii) phase back emf, iii) switching function

The measured phase back EMF waveforms in natural a-b-c reference frame are transformed to the d-q-0 reference frame by using the equations.

$$\begin{bmatrix} e_d \\ e_q \\ e_o \end{bmatrix} = [C] \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

$$C = \frac{2}{3} \begin{bmatrix} \cos(\theta_e + \Phi) & \cos\left(\theta_e + \Phi - \frac{2\pi}{3}\right) & \cos\left(\theta_e + \Phi + \frac{2\pi}{3}\right) \\ \sin\theta_e & \sin\left(\theta_e + \Phi - \frac{2\pi}{3}\right) & \sin\left(\theta_e + \Phi + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

where $\theta_e = \omega_e t$, ω_e is an electrical angular frequency and ϕ is an angular displacement between the stator current and rotor flux linkage and is generally equal to zero, and C is the transformation matrix of three phase to synchronously rotating d-q-0 reference frame.

B. Phase advancing method for commutation control: inverter topology and firing scheme

The CPA method uses the common three-phase, voltage-fed inverter (VFI) topology shown in Fig. 3 shows the motor model used for simulation.

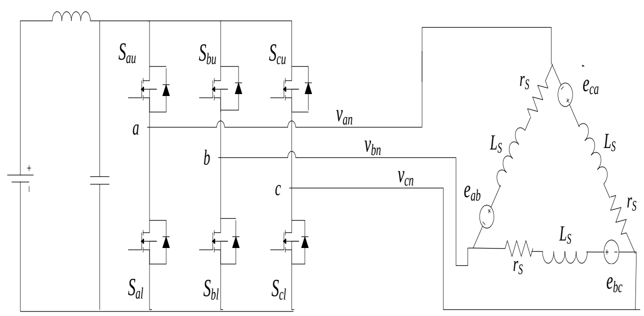

Fig.3 Common voltage-fed inverter topology and motor model

The bypass diodes of the common VFI make this configuration inherently capable of regeneration. This capability is desirable in the case of controlled regenerative braking, but it also has two undesirable consequences.

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If a fault develops in the dc supply, the motor will feed current into the fault so long as the permanent magnets continue to rotate. In addition, if the motor is operating at high speed, a loss of transistor firing signals will result in uncontrolled regenerative braking until the motor slows to the speed where the back emf magnitude drops below the level of the dc supply voltage. Guarding against the consequences of such failures would require additional components

Above base speed, the back emf exceeds the dc supply voltage and the firing must be advanced (i.e., a phase is energized during the transition portion of the back emf where the available dc supply voltage can drive current into the motor). In the vicinity of base speed, operation is a mixture of phase advance and current regulation. At a speed only slightly greater than base speed, the current regulation becomes ineffective and all the control is accomplished by phase advance. In this work we consider only speeds at which all control is achieved through phase advance.

The phase B and C back emfs have the same shape but are delayed from phase A by 120^o and 240^o, respectively. The firing of phase B and C transistors is analogous but with the appropriate delays applied. The switching frequency during pure phase advance is at the fundamental electrical frequency consistent with motor speed. Pulse width modulation is not necessary.

Transistor Q1 is fired θ_a degrees ahead of the instant that the phase A back emf, e_{an}, reaches its positive maximum. θ_a is called the "advance angle." Transistor Q4 is fired θ_a degrees ahead of the instant that e_{an} reaches its most negative value. Although that can be varied from 0 to 60^o,it is found that the limiting range is from -60 to +120^o.An advance angle near 30^o, the exact value being parameter and speed dependent, results in zero average power. An advance less than this value results in regenerative braking and a greater value results in motoring operation.

HARDWARE

The hardware block diagram for the proposed system is shown in figure 4. The main parts of the hardware block diagram include

- Power Supply Unit
- Diode Rectifier
- Six Switch Inverter
- PIC Microcontroller 16f877A
- Driver Circuit
- Load

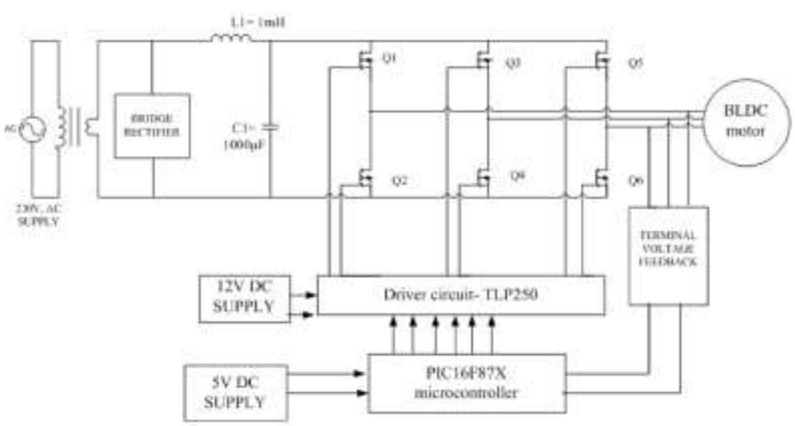

Figure 4: Hardware Block diagram of proposed system

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HARDWARE RESULTS AND DISCUSSION

INTRODUCTION

This chapter deals with hardware results of the proposed system. The performance of Reduction of Commutation Torque Ripples in BLDC Motor is tested using the software package MATLAB. Simulation and hardware studies were conducted to evaluate the performance of the BLDC motor under various speed conditions.

SNAPSHOT OF HARDWARE SETUP

The snapshot of entire hardware setup is shown in the Figure 9.

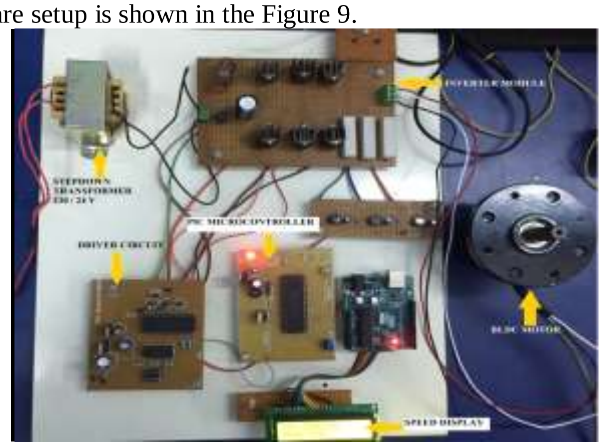

Figure 9 Hardware setup

The circuit has Diode rectifier, smoothening capacitor, Driver circuit, BLDC motor and PIC microcontroller to regulate the torque.

HARDWARE RESULTS

Inverter output

The inverter output waveform is shown in figure 10. This is the pulse measured between phase A and Phase B which is feed to the BLDC motor.

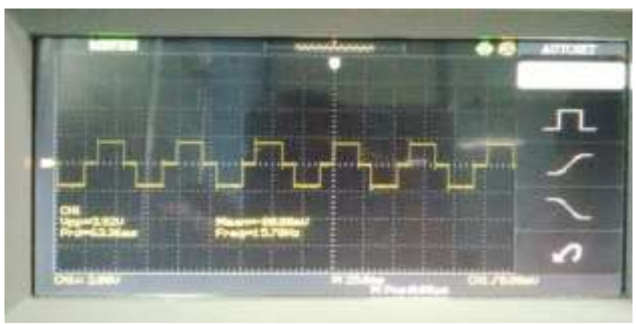

Figure 10 Inverter Output Waveform

Current waveform for various speed ranges

Current waveform for two speed ranges are shown in figure 11 and figure 12.Speed can be observed from the LCD display.

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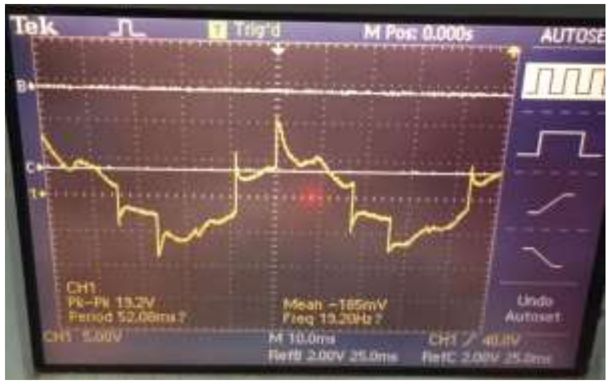

Figure 11 Output current waveform at lower motor speed

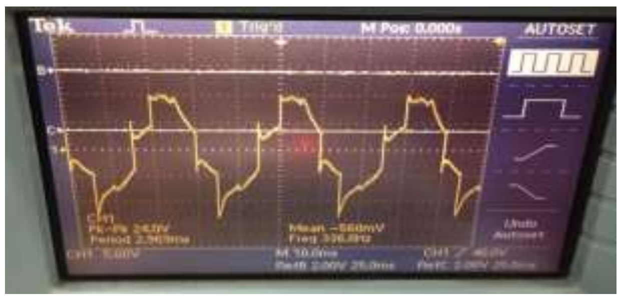

Figure 12 Output current waveform for higher motor speed

In the lower speed ranges, Current ripple is high. But as the motor achieves speed the feedback circuit and the fuzzy logic controller implemented in the microcontroller will tune the motor for less torque ripples.

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