THOMSON REUTERS ENDNOTE

[Sutar, 5(5): May, 2016] ISSN: 2277-9655
Impact Factor: 3.785

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

IMPLEMENTATION AND STUDY OF BLDC MOTOR DRIVE SYSTEM

Amol R. Sutar*, G. G. Bhide, J. J. Mane

Electronics Department, Electrical Department. FAMT Ratnagiri. India

DOI: 10.5281/zenodo.50975

ABSTRACT

The BLDC motor is an electronically commutated dc motor becoming very popular in many applications. There are various speed control methods used for BLDC motor. The performance of BLDC motor drives can be improved using sensored control techniques over sensorless technology. This paper presents Brushless Direct Current motor drive system and its sensored speed control technique with PWM. Advantages and limitations of sensorless techniques are reviewed and then, sensored speed control technique is introduced with their advantages, performance analysis, practical implementation and applications. Torque and speed behavior during clockwise and anticlockwise motion, use of hall sensors to detect rotor position, speed control technique using PWM method are discussed in detail. Detailed hardware design its implementation and experimental results covered. This paper also covers performance analysis of BLDC motor using experimental results.

KEYWORDS: back-EMF; sensored control; rotor position; Hall-effect sensors; PIC microcontroller, PWM.

INTRODUCTION

Brushless Direct Current (BLDC) motors are nowadays becoming popular in many applications such as Automotive, Aerospace, Medical, Industrial automation Equipment and Instrumentation due to its advantageous features over brushed dc motors and induction motors. BLDC motors have many advantages [1] [2] such as better speed versus torque characteristics, High dynamic response, high efficiency, long operating life, noiseless operation and higher speed ranges etc. BLDC motors do not use brushes for commutation; instead, they are electronically commutated like stepper motor. In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where size and weight are main constraint.

The BLDC motor drive voltage can be commutated by sensing the back EMF voltage on an un-driven motor terminal during one of the drive phases. Like brushed dc motor and induction motors, BLDC motor generates back emf during run condition. In off state of motor back emf across three phases is zero and increases with the speed of motor. The advantage of sensor less control is only the elimination of the Hall position sensors but there are several disadvantages [1] [2] of sensor less control:

1. The motor speed should be always greater than zero speed so as to generate sufficient back EMF to be sensed.
2. Sudden changes to the motor load and speed can result in loss of the spped control.
3. The BEMF voltage can be measured only when the motor speed is within a certain limited range of the ideal commutation rate for the applied voltage.
4. Commutation at rates faster than the ideal rate will result in a discontinuous motor response.
5. Sensor less program code of microcontroller for BLDC motor is more complex than sensored control method.

In addition BLDC motor speed control by sensing back emf needs extra voltage sensing and conditioning circuit to be interfaced with microcontroller. But in applications where the motor speed requirement is higher, load conditions remains same and low cost is a primary concern then sensorless control may be the better choice for the application.

To avoid above mentioned disadvantages BLDC motor is usually controlled using position sensors called Hall Effect sensors which comes with BLDC motor itself. BLDC motors have three Hall sensors fixed into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding is to be energized following the energizing sequence. Based on the physical position of the Hall sensors, there are two versions of output. The Hall sensors may be at 60° or 120° phase shift to each other. The motor manufacturer defines the commutation sequence, which should be followed when controlling the motor. In this paper, proposed the sensored speed control method and its implementation using PIC microcontroller for BLDC motors.

BLDC MOTOR

BLDC motor consists of permanent magnetic rotor and stator windings. Depending on stator winding BLDC motor may be single phase or three phase. Figure 1 shows internal structure of three phase BLDC motor and star connected three phase stator winding[1]. The numbers one to six on stator winding represents the commutation sequence. Each commutation sequence has one of the windings energized to positive power, the second winding is negative and the third is in a non-energized condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field.

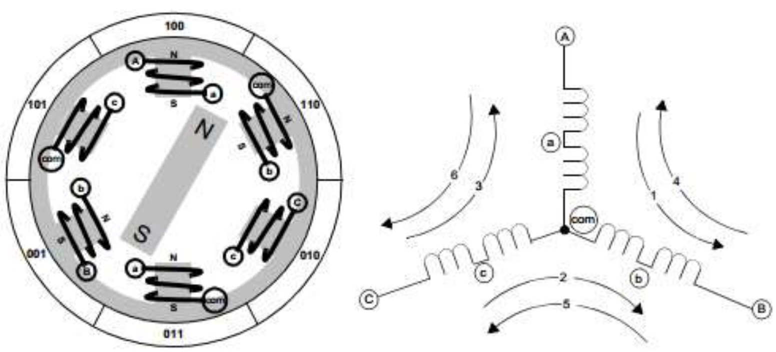

Fig.1 BLDC motor structure and stator winding

Commutation Sequence

Fig. 2 shows an example of phase voltage with respect to Hall sensor signals. As shown in these waveforms after every 60 electrical degrees of rotation, one of the Hall sensors changes the state. In one electrical cycle, the phase voltage and current switching occurs six times, each after every 60 electrical degrees. In BLDC motor, one electrical cycle may not correspond to a complete mechanical revolution of the rotor. The number of electrical cycles to be repeated to complete a mechanical rotation depends on number of the rotor pole pairs. For each rotor pole pair, one electrical cycle is completed. So, the number of electrical cycles per rotations is equal to the number of rotor pole pairs. For example in four poles BLDC motor four electrical cycles has to be completed for a mechanical revolution.

The commutation sequence numbered one to six at top of waveforms and respective hall sensor signals are shown in the fig.2.

The commutation sequence is generated based on the hall sensor output (rotor position) and required phase voltage. For continuous rotation phase sequence numbered 1 to 6 should be followed to energize respective phases based on hall sensor output.

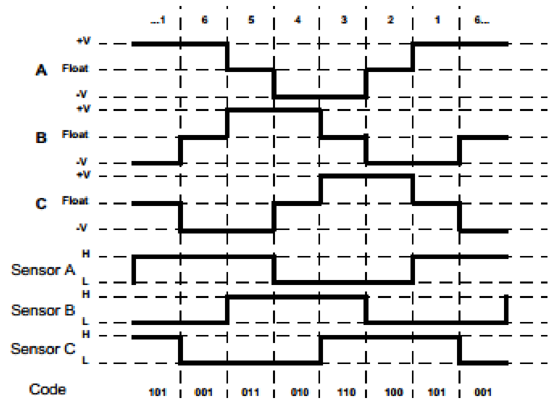

Fig. 2 phase voltage and sensor output waveforms.

For example consider phase sequence number 1, the hall sensors logic output is 101 i.e HC=1, HB = 0, HA = 1 where the MSB bit is sensor HC and the LSB bit is sensor HA. The north pole of permanent magnet rotor points to the sensor code that is output at that rotor position. To move the rotor from 101 position in forward direction phase A should be positive energized, phase B should be negative energized and phase C is kept floating. The magnetic field produced due to current flowing in phase A and B of stator winding is 90^0 out of phase to that of rotor poles magnetic field. Due to this peak torque produced which drag the rotor to align with magnetic field of stator winding where hall sensors output code is 100 as illustrated in fig.1.

Table 1 and Table 2 shows the six step sequence in which the power switches of three phase inverter should be switched on and off based on the Hall sensor inputs HA, HB and HC. Table 1 shows hall sensor output code and respective PWM codes for clockwise rotation of the motor and Table 2 is for counter clockwise motor rotation. This is an example of Hall sensor signals having a 60 degree phase shift with respect to each other. Resultant hex code can be used where driver output is in phase with input while inverted hex code (last column) can be used where driver output is complementary.

Table 1. PWM sequence for rotating motor in clockwise direction.

No.	Hall Sensor			Active PWM						HEX Code	Inverted HEX Code
	HC	HB	HA	PWMC’	PWMC	PWMB’	PWMB	PWMA’	PWMA		
1	0	0	1	1	0	0	0	0	1	0x21	0xde
2	0	1	0	0	0	0	1	1	0	0x06	0xf9
3	0	1	1	1	0	0	1	0	0	0x24	0xdb
4	1	0	0	0	1	1	0	0	0	0x18	0xe7
5	1	0	1	0	0	1	0	0	1	0x09	0xf6
6	1	1	0	0	1	0	0	1	0	0x12	0xed

Table 2. PWM sequence for rotating motor in counter-clockwise direction.

No.	Hall Sensor			Active PWM						HEX Code	Inverted HEX Code
	HC	HB	HA	PWMC'	PWMC	PWMB'	PWMB	PWMA'	PWMA		
1	0	0	1	0	1	0	0	1	0	0x12	0xed
2	0	1	0	0	0	1	0	0	1	0x09	0xf6
3	0	1	1	0	1	1	0	0	0	0x18	0xe7
4	1	0	0	1	0	0	1	0	0	0x24	0xdb
5	1	0	1	0	0	0	1	1	0	0x06	0xf9
6	1	1	0	1	0	0	0	0	1	0x21	0xde

BLDC MOTOR DRIVE SYSTEM:

Typical three phase BLDC motor drive system is similar to three phase induction motor drive system as shown in fig. 3. DC voltage source may be a battery, fuel-cell stack, diode rectifier and capacitor. DC source gives 5V, 12V and 24V output for operation of controller, driver and the main inverter circuit respectively. Three phase inverter circuit consists of six switches connected in three legs. PIC Microcontroller 18f452 has High Performance RISC architecture, with in built four 16 bit timers, eight channel-10 bit configurable analog to digital controller, 10 bit PWM generator, capture/compare module and many other advanced features. These advanced features make it useful in all types of control system applications. Microcontroller is used to generate PWM pulses to control on/off time of switching devices in a proper sequence based on hall sensor feedback signal. Driver circuit is used to amplify PWM signal and to provide isolation between microcontroller and inverter circuit. A display device such as LCD display is used to display speed and duty ratio of PWM signals and provides interaction between user and the system.

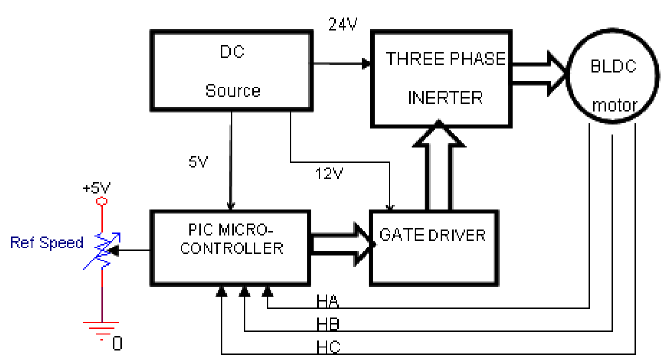

Fig.3. BLDC Motor Control System block diagram.

LEDs are also used to indicate status such as ON/OFF, forward direction, reverse direction etc. Here PIC microcontroller 18f452 used to generate PWM pulses at PORTD using its internal TIMER0. The potentiometer, connected to one of the analog-to-digital converter channel in PIC microcontroller, is used to set reference speed. Based on this reference input voltage, the PWM duty cycle is calculated. PWM output of PIC microcontroller is applied to the respective gate terminals of inverter switches through gate drive circuit. The hall sensor feedback signal is applied to the PORTE of microcontroller to sense the rotor position.

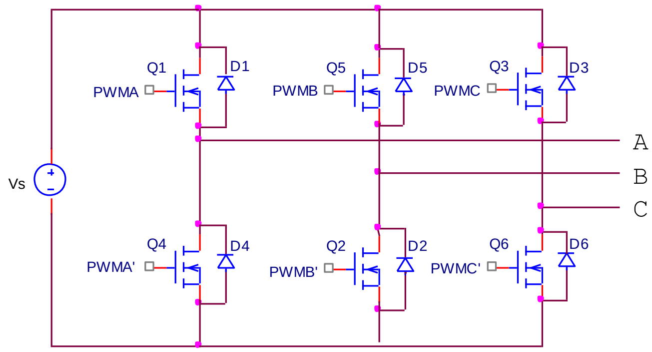

Fig. 4. Three phase Inverter Bridge

The three phase inverter to drive the BLDC motor is shown in the Fig. 4. Q1 to Q6 are the power switches controlled by the PIC18F452 micro-controller. Based on the motor voltage and current ratings, these switches can be MOSFETs, or IGBTs, or simple bipolar transistors. The BLDC motor is connected at the output terminals A, B, C. If the signals marked by PWMx are switched ON or OFF according to the sequence, the motor will run at the rated speed, provided DC bus voltage is equal to the motor rated voltage, plus any losses across the switches.

SPEED CONTROL USING PWM

PWM method is very advantageous in motor control applications. The speed of the motor can be varied smoothly from zero to rated speed, the starting current of motor as well as torque can be kept within limit these, also, if the DC bus voltage is much higher than the motor rated voltage, the motor can be controlled by limiting the percentage of PWM duty cycle corresponding to that of the motor rated voltage. The Pulse Width Modulated (PWM) signals should have much higher frequency than the motor frequency. When the duty cycle of PWM is varied within the sequences, the average voltage supplied to the stator reduces, thus reducing the speed. ADC module and TIMER0 of PIC microcontroller is used for PWM signal generation. ADC module generates 10bit data with respect to analog voltage at channel 0. This analog voltage corresponds to reference speed. ADC module is configured as left justified so that the content of eight bit ADRSEL can be used for duty cycle adjustment as it is, without need of modification. Here TIMER0 is configured in eight bit mode, so it can vary PWM duty ratio and speed in 256 levels which is sufficient at higher PWM frequency to vary the speed smoothly. In eight bit mode timer rolls over after count = 255 and set its flag. Suppose PWM frequency is set to 10KHz. To obtain a PWM frequency of 10 kHz timer must be running at 256 times that rate, or 2.56MHz. Assuming minimum prescaler value of timer is 1:2. It needs an input frequency of 5.12MHz. The input to Timer is FOSC/4. This requires a crystal frequency (F_{OSC}) of 20.48 MHz. That is an odd frequency, and 20 MHz is close enough, so we can use 20 MHz resulting in a PWM frequency of around 9.77 kHz. If prescalar is bypassed reduces required crystal frequency to half i.e. 10MHz and 11.0592MHz is close enough, resulting in a PWM frequency around 10.8kHz. At 11.0592 MHz clock rate, control latency may be caused by the loop time, but it spreads evenly in all ON and OFF time and not so much significant. For low-cost, low-resolution speed requirements, the Hall signals can be used to measure the speed feed-back. A timer other than Timer0 from the PIC18F452 can be used to count between two Hall transitions. With this count, the actual speed of the motor can be calculated.

I. Proteus Simulation

The simulation is performed using Proteus software to observe hall sensor signals and PWM signals. Use of Proteus software reduces programming time greatly.

ISSN: 2277-9655
Impact Factor: 3.785

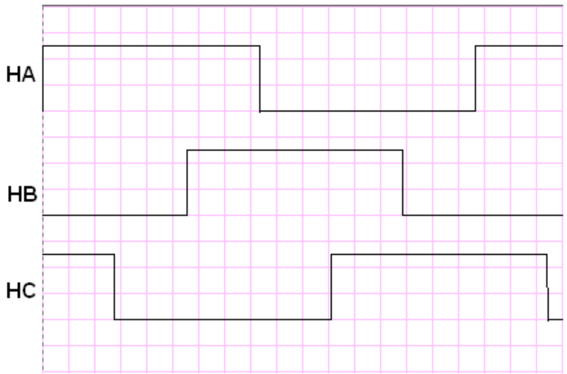

Fig. 5.Hall sensor signals(Scale:2V/div)

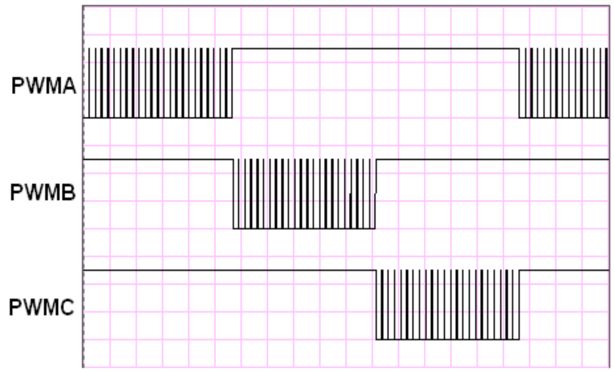

Fig. 6. PWM output signals. (Scale:2V/div)

The reference hall sensor signals are 120^0 phase shifted from each other. So those signals can be generated using three phase supply module, Op-amp comparator and diode combination. The generated signals are equivalent to the Hall sensor signals as shown in fig. 5. These signals are applied to the PORTE of microcontroller. The microcontroller is programmed to generate six PWM switching signals based on these hall sensor signals. The PWM output signals PWMA, PWMB, PWMC corresponding to the reference hall sensor signals are shown in the fig.6. PWM signals of lower switches are not shown in this figure, but are similar to upper switches and occur when respective hall sensor signal switches to low level.

HARDWAE RESULTS

The hardware setup is shown the fig.7. The PWM signals generated by microcontroller as illustrated in fig.6 are used to control the speed of BLDC motor. BLDC motor specifications are shown table 3.

Table 3. BLDC Motor Specifications

Sr. No	Parameter	Value
1	Rated voltage	24V
2	Rated current	1.8A
3	Rated speed	3000rpm
4	Rated power	37W
5	Impedance	R= 0.632Ω, L = 0.3mH
6	Number of poles	4
7	Frequency	50hz

Test is carried out in open loop with manual control. By varying pot resistance the analog voltage at channel 0 get varied. ADC module converts this analog voltage in to equivalent 10 bit digital data. The range of output of ADC is limited 0 to 255, by connecting a resistance in series with pot. Hardware results are taken for both full load and no load. At no load motor runs at full speed more than rated one with very small current 0.19A. When load is connected, the motor current increases with increase in load. Motor speed is found to vary smoothly from zero to rated speed with increase in PWM duty cycle. The motor hall sensor signals are obtained as shown in the fig.8.

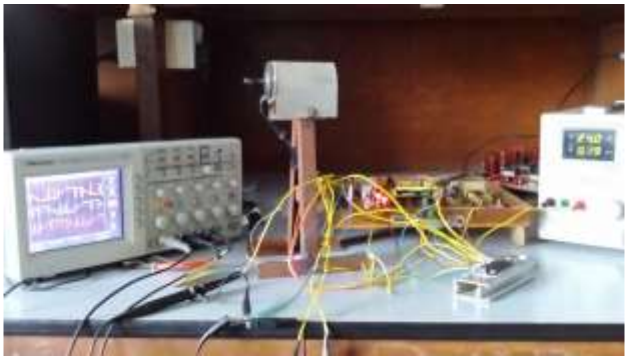

Fig.7. Hardware setup

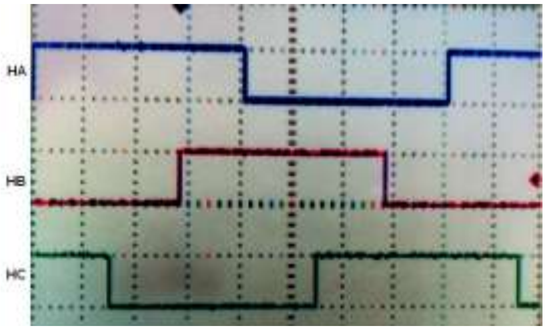

Fig.8. Motor Hall sensor signals. (Scale:5V/div)

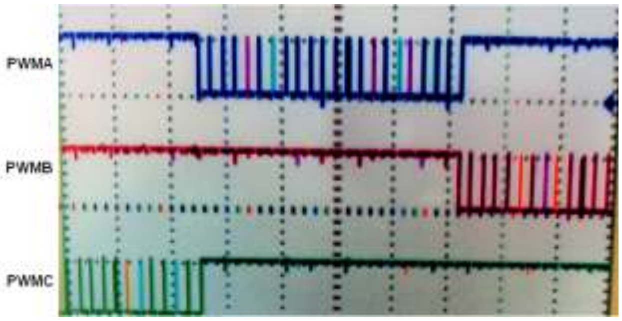

Fig.9. PWM output signals. (Scale:5V/div)

The PWM signals corresponding to the upper switches in inverter (fig.4) are shown in the fig.9. The hall sensor signals and PWM signals are similar to the one observed in Proteus simulation. The driver circuit inverts these PWM signals, which are then applied to MOSFET gate. Thus 0 levels in PWM signal indicates ON state of MOSFET and 1 level indicates OFF state. The output voltage of inverter is found trapezoidal in nature as shown in the fig.10. The output voltages of three phase inverter are 120^0 phase shifted from each other. BLDC motor can be also controlled by sensing back emf of the motor.

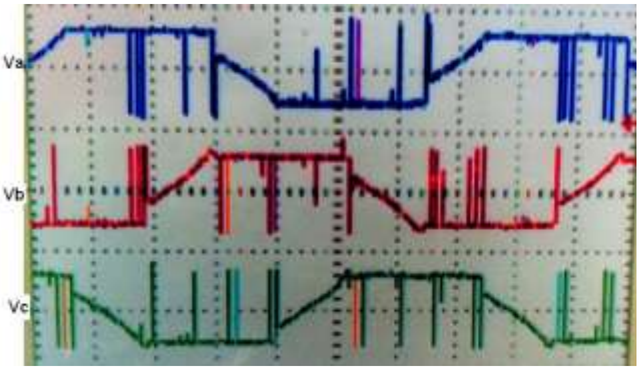

Fig.10. Motor input voltage. (Scale:20V/div)

The output voltage of inverter is found trapezoidal in nature as shown in the fig.10. The output voltages of three phase inverter are 120^0 phase shifted from each other. BLDC motor can be also controlled by sensing back emf of the motor.

CONCLUSION

BLDC motors have several advantages over brushed DC motors and induction motors. It provides highly efficient and noiseless operation. With these advantages, BLDC motors can be used in all applications wherever brushed dc motor and induction motor used. The sensored PWM control scheme proposed for BLDC motor to vary the speed of motor worked well as expected. It provides wide speed control range with high torque. Test results are verified for both CW to CCW direction. The significant advantages of the proposed work are: simple hardware circuit, reliability of the control algorithm, excellent speed control with and without load conditions. The sensored control algorithm is very simple to implement using PIC microcontroller. The designed and implemented prototype model may be implemented even for higher rated motors.

REFERENCES

[1] P. Yedamale, Microchip Technology Inc., “Brushless DC (BLDC) motor fundamentals”, 2003, AN885.
[2] Ward Brown, Microchip Technology Inc., “Brushless DC Motor Control Made Easy”, 2002, AN857
[3] V. U, S. Pola, and K. P. Vittal, “Simulation of four quadrant operation & speed control of BLDC motor on MATLAB/SIMULINK,” in *Proc.IEEE Region 10 Conference*, 2008, pp. 1–6.
[4] C.-W. Hung, C. T. Lin, C. W. Liu, and J.-Y. Yen, “A variable-sampling controller for brushless DC motor drives with low-resolution position sensors,” IEEE Trans. Ind. Electronics, vol. 54, no. 5, pp. 2846–2852, Oct. 2007.
[5] Microchip, PIC18F4520 Data Sheet, High Performance PIC Microcontrollers
[6] Nesimi Ertugrul, Paul P. Acarnley, “Indirect Rotor Position Sensing in Real Time for Brushless Permanent Magnet Motor Drives”, IEEE Transaction on Power Electronics, Vol. 13, No. 4, pp. 608-616, July 1998
[7] Fernando Rodriguez, Ali Emadi, “A Novel Digital Control Technique for Brushless DC Motor Drives”, IEEE Transaction on Industrial Electronics, Vol. 54, No., 5, pp. 2365-2373, Oct. 2007
[8] Anand Sathyan, Nikola Milivojevic, Young-Joo Lee, Mahesh Krishnamurthy, Ali Emadi, “An FPGA-Based Novel Digital PWM Control Scheme for BLDC Motor Drives”, IEEE Transaction on Industrial Electronics, Vol. 56, No., 8, pp. 3040-3049, August 2009