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Speed Control of BLDC motor for Electric Vehicle

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Abstract -**Brushless DC Motor overcomes many problems of the brushed DC Motor and has been widely applied in various fields. The development of BLDCM control system requires reliable operation, excellent performance of control algorithm, low cost and short development cycle. This paper proposes the speed control of BLDC motor for an electric vehicle. The flexibility of the drive system is increased using digital controller. The 3-phase inverter is implemented using Smart Power Module for feeding BLDC motor. The proposed system accepts Hall sensor signals from the motor and is programmed for desired speed. Experimental results verify the effective developed drive operation.**

Keywords: Brushless DC motor (BLDCM), Electric Vehicles (EVs), Hall sensors, Microcontroller.

I. INTRODUCTION

Electric motor technology involves machine constructions, materials, electronics, sensors and control technologies. A suitable converter and control techniques need to be developed for different kind of motors in order to generate a high performance drives. The important aspect of various converter designs is the converter efficiency and its dynamic response. Low power loss in converters is due to high efficiency. The 3rd harmonic and its corresponding multiples component are eliminated in the output due to this feature three phase power system is used in DC drive systems. Comparing 1-phase system with that of 3-phase, the ripple voltage is significantly less.

Now a days we are facing lot of different crisis caused by high oil prices and obsolete designs which have prompted the search for more efficient road vehicles, possibly based on environment friendly sources located in politically stable areas. This has led to the development of electric vehicles. [1].

Compared with a DC motor, the BLDC motor uses an electric commutator rather than a mechanical commutator, so it is more reliable than the DC motor. In a BLDC motor, rotor magnets generate the rotor's magnetic flux, so BLDC motors achieve higher efficiency [2]. It has become possible because of their superior performance in terms of high efficiency, fast response, and weight, precise and accurate control, high reliability, maintenance free operation, brushless construction and reduced size, Torque to motor size ratio is high, Thermal overload & under load protection is provided. [3, 5, 8]

Microcontroller has more advantages than microprocessors. These ICs are cost effective and can be used for any applications ranging from appliances to automobile engines to text or data processing equipment.

Because of their higher performance; they perform high-resolution control and minimize control loop delays . These efficient controls make it possible to reduce torque ripples and harmonics and to improve dynamic behavior in all speed ranges. The motor design has optimized due to lower vibrations and lower power losses such as harmonic losses in the rotor. Smooth waveforms allow an optimization of power elements and input filters. Overall, these improvements result in a reduction of system cost and better reliability. Switching electric machines from ordinary digital control to microcontroller significantly improves operating efficiency, saving energy while allowing the use of smaller, less expensive motors.

Since the advancement in battery technology has been relatively sluggish, compared with the power electronics area, the handicap of short range associated with EV still remains. With this technology limitation, the EV seems to be the viable alternative to the ICE automobile at the present. [7]

The aim of this project is to design microcontroller-based BLDC motor drives for electric vehicle. Based on several PWM switching schemes the performance of converter parameters will be tested and observed. Open loop and closed loop speed control of the system is done and the results are tabulated which verify the effective developed drive operation.

II. BLOCK DIAGRAM OF THE CONTROL SYSTEM

The block diagram of BLDC drive system is shown in Figure 1. It consists of a three phase inverter, position sensors, signal conditioner and a digital controller. The inverter along with the position sensor arrangement is functionally analogous to the commutator of a dc motor.

The commutation of a BLDC motor is controlled electronically. The stator windings should be energized in a sequence in order to rotate the motor. Rotor position should be known in order to switch the winding in sequence. A permanent magnet brushless dc motor incorporates some means of detecting the rotor position.

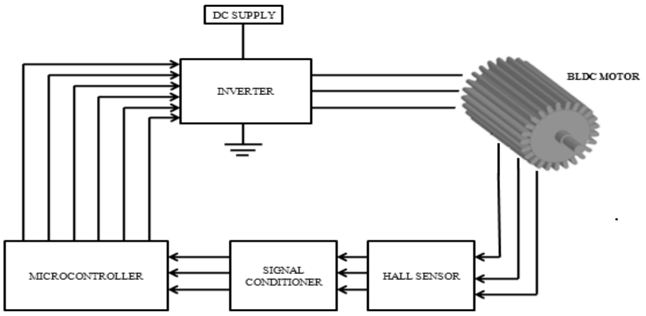

Fig 1: Block diagram of BLDC drive system

The BDLC motor detects the position of the rotor using Hall sensors. Three sensors are required for position information. With three sensors, six possible commutation sequences could be obtained. In the Hall sensor technique, three Hall sensors are placed inside the motor, spaced 120 degrees apart. Each Hall sensor provides either a High or Low output based on the polarity of magnetic pole close to it. Rotor position is determined by analyzing the outputs of all three Hall sensors. Based on the output from hall sensors, the voltages to the motor's three phases are switched.

The advantage of Hall sensor-based commutation is that the control algorithm is simple and easy to understand. Hall sensor-based commutation can also be used to run the motor at very low speeds.

BLDC motor control is to have only one current at a time. Because of which current sensor is not advised to be placed on each phase of the motor; one sensor placed in the line inverter input is sufficient to control the current of each phase. Insulated systems are not required when sensor is on the ground line.

The torque and speed of motors is managed by microcontroller. A sufficient amount of processing power is required to solve the algorithms needed to generate Pulse Width Modulated (PWM) outputs for motor.

By simply varying the voltage across the motor, one can control the speed of the motor. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal. The three-phase BLDC speed control is done by using both open loop and closed loop configurations. Open-loop control is used to control the speed of the motor by directly controlling the duty cycle of the PWM signal that directs the motor-drive circuitry. The duty cycle of the PWM signal controls the ON time of the power switches in the half bridges of the motor-drive circuit and this in turn controls the average voltage supplied across the motor windings. Closed loop control regulates the speed of the motor by directly controlling the duty cycle of the PWM signals that direct the motor-drive circuitry. The major difference between the two control systems is that the open-loop control considers only the speed control input to update the PWM duty cycle, whereas, the closed-loop control considers both speed-input control and actual motor speed (feedback to controller) for updating the PWM duty cycle and, in turn, the motor speed. A PID controller is a closed-loop control implementation that is widely used and is most commonly used as a feedback controller.

The actual motor speed is calculated by tracking the time period between successive Hall events, which represents a part of the mechanical cycle of the motor. In a 3-phase BLDC motor control, one electrical cycle has six Hall states and, depending on the number of poles pairs in the motor, the electrical angle measured between successive Hall state changes can be translated to a respective mechanical angle.

III. EXPERIMENTAL SET UP & ITS RESULTS

The proposed scheme is first simulated and then implemented in the laboratory. The simulations are carried out using MATLAB 7.13. The control scheme is implemented by DSC (dsPIC30F4011). Software program is written in C language. Programming is done using MPLAB Integrated Development Environment (IDE) tool. For execution of C code MPLAB C30 compiler is used.

The BLDC motor specifications are as shown in Table 1.

Table 1: BLDC motor specification

Type of motor	BLDC MOTOR
Stator voltage	48v
Power rating	250watts
Speed	3500rpm
No. of poles	46
No. of turns	8
Degree	60^{o}

FSBB20CH60F smart power module is used. It is an advanced SPM which is designed to provide very compact and high performance ac motor drives. The SPM combines optimized circuit protection and a drive that are matched to the IGBT's switching characteristics. The three Phase IGBT

Inverter Bridge includes control ICs for gate driving and protection. The Voltage rating is 600V & Current rating is 20A. Figure 2 shows three phase IGBT based inverter circuit.

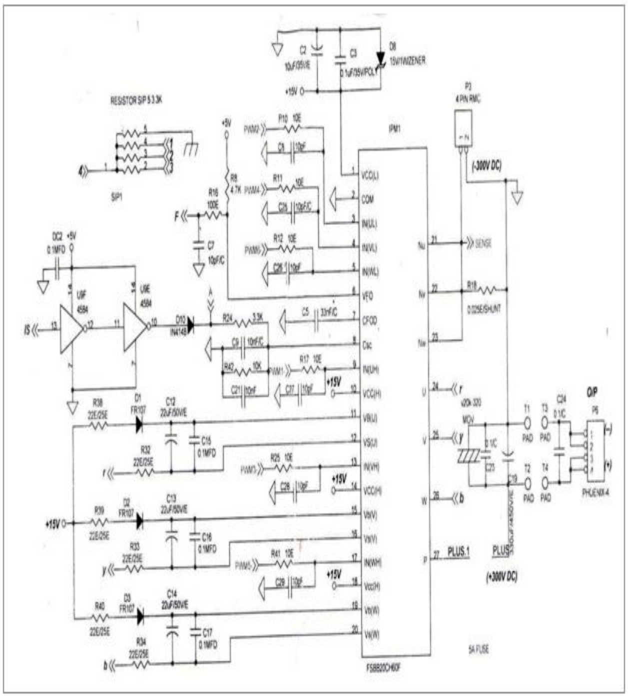

Fig 2: Three phase IGBT based inverter circuit

As the motor draws more current during starting hence for protection safety fuse is used. In the circuit, for best protection 5A fuse is used. Motor draws more current during starting & during fluctuation in the load.

The control circuit consists of a controller & a gate drive circuit for the generation of pulses of required frequency which is 10 KHz. The internal timer is used as a clock to determine the timing & counter is used for counting the pulses from the proximity sensor. A software program is written which decides the frequency of pulse to be applied to gate of IGBT.

DSC dsPIC30F4011 based PWM inverter is used; which is used to implement the control system. The workspace for this application was created using MPLAB IDE v7.2. Figure 3 shows control circuit for the controller.

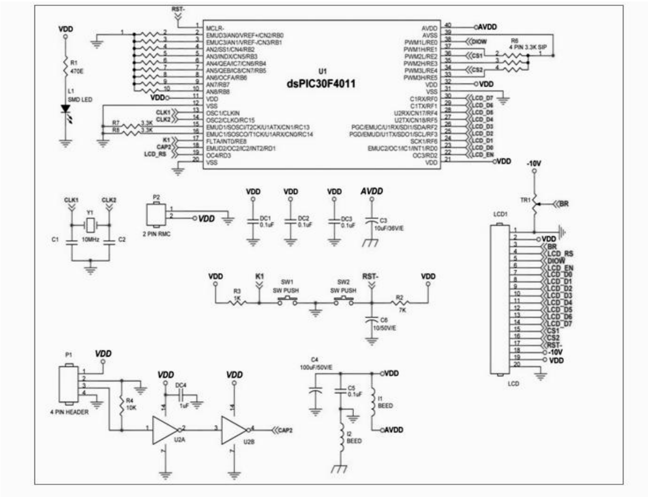

Fig 3: Control circuit for controller

Look-Up Table for clockwise rotation and anti clockwise rotation of the motor based on Hall signals is generated which is shown in Table 2 and 3 respectively.

Table 2: Look-Up Table for clockwise rotation of the motor based on Hall signals

Sequence	Hall Sensor Input			Active PWMs		Phases Active		
	Hall-A	Hall-B	Hall-C			R	Y	B
1	0	0	1	PWM1	PWM6	$+V_{dc}$	NC	$-V_{dc}$
2	0	0	0	PWM1	PWM4	$+V_{dc}$	$-V_{dc}$	NC
3	1	0	0	PWM4	PWM5	NC	$-V_{dc}$	$+V_{dc}$
4	1	1	0	PWM2	PWM5	$-V_{dc}$	NC	$+V_{dc}$
5	1	1	1	PWM2	PWM3	$-V_{dc}$	$+V_{dc}$	NC
6	0	1	1	PWM3	PWM6	NC	$+V_{dc}$	$-V_{dc}$

Table 3: Look-Up Table for anti clockwise rotation of the motor based on Hall signals

Sequence	Hall Sensor Input			Active PWMs		Phases Active		
	Hall-A	Hall-B	Hall-C			R	Y	B
1	0	0	1	PWM3	PWM6	NC	$+V_{dc}$	$-V_{dc}$
2	0	1	0	PWM2	PWM5	$-V_{dc}$	NC	$+V_{dc}$
3	0	1	1	PWM2	PWM3	$-V_{dc}$	$+V_{dc}$	NC
4	1	0	0	PWM1	PWM4	$+V_{dc}$	$-V_{dc}$	NC
5	1	0	1	PWM1	PWM6	$+V_{dc}$	NC	$-V_{dc}$
6	1	1	0	PWM4	PWM5	NC	$-V_{dc}$	$+V_{dc}$

The setup is tested for open & closed loop control of motor and the corresponding values are tabulated. The waveforms are viewed using Digital Storage Oscilloscope.

In open-loop the duty cycle of the PWM signal controls the ON time of the IGBTs in the half bridges of the motor-drive circuit and this in turn controls the average voltage supplied across the motor windings. Table 4 shows the experimental values of duty cycle and actual speed in rpm for open-loop control.

Table 4: Experimental values of duty cycle & actual speed in rpm for open-loop control

DUTY CYCLE	ACTUAL SPEED (rpm)
20	490
25	608
30	789
35	917
40	1123
45	1236
50	1424
55	1514
60	1765
65	1946
70	2117
75	2117

In closed-loop operation, the operator of the system sets a desired speed, and the system compensates the voltage fed to the motor to get the actual speed.

In the first part of the closed loop, the desired speed is read from an external potentiometer by the A/D converter. The A/D converter establishes a software value called Reference Speed.

The second part of the closed-loop system is the measured speed, which is used to either increase or decrease the output voltage of the motor depending on the calculated error between the desired speed (set point) and the measured speed.

The proportional value K_P is set to 0.30 and K_I is set to 0.20 for the closed loop control of the motor. Table 5 shows the experimental values of set speed and actual speed in rpm for closed-loop control.

Table 5: Experimental values of duty cycle & actual speed in rpm

SET SPEED (rpm)	ACTUAL SPEED (rpm)
300	301
400	409
500	503
600	592
700	715
800	816
900	903
1000	1009
1100	1103
1200	1245
1300	1311
1400	1429
1500	1521
1600	1597
1700	1715
1800	1808
1900	1901
2000	2065
2200	2100
2500	2447

The waveforms of the hall sensors A, B & C are shown in Figure 4.The different PWM pulses are shown in Figures 5 to 10, these waveforms are directly acquired from the Digital Storage Oscilloscope. The stator current of the phases R, Y & B are shown in figures 11 to 13. The dc offset voltage is shown in figure 14.

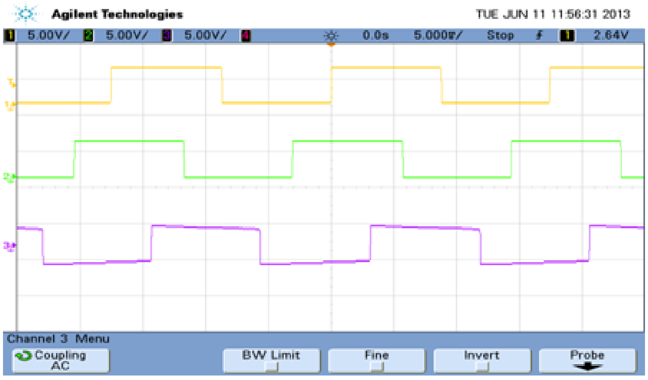

Fig 4: Hall sensor signals ABC

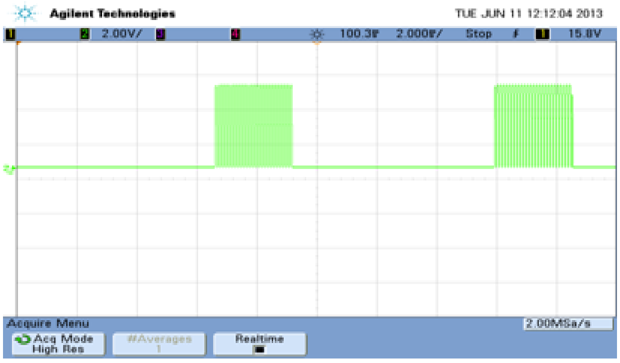

Fig 5: Pulse-1

Fig 6: Pulse-2

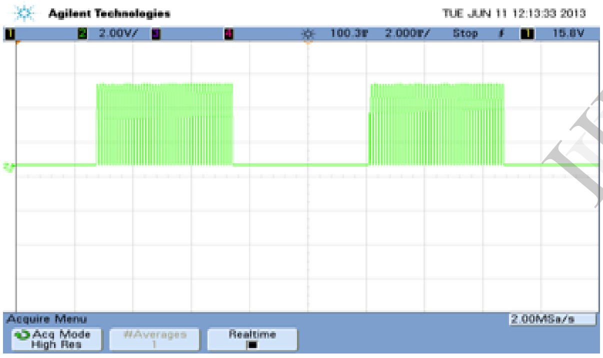

Fig 7: Pulse-3

Fig 8: Pulse-4

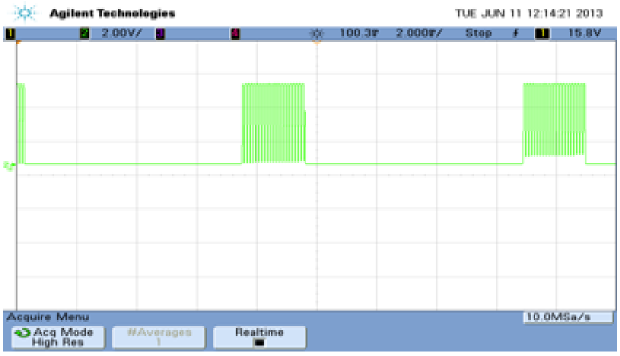

Fig 9: Pulse-5

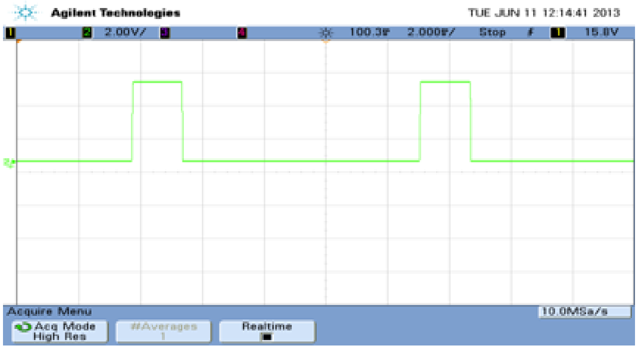

Fig 10: Pulse-6

Fig 11: Stator current of R-phase

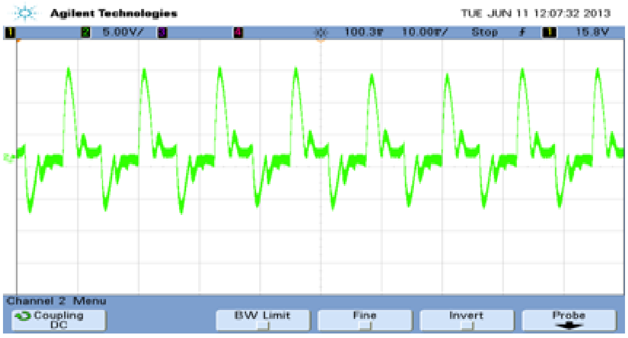

Fig 12: Stator current of Y-phase

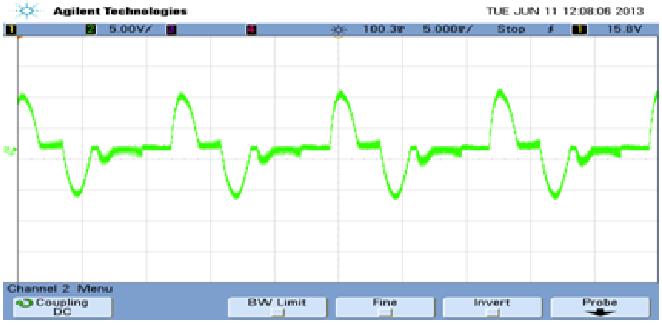

Fig 13: Stator current of B-phase

Fig 14: DC offset voltage

Fig 15: Photograph of the complete set up

IV. CONCLUSION

The proposed algorithm has been implemented, and it generates the firing pulses required to drive the IGBTs of three phase fully controlled bridge converter. The generated PWM signals for driving the power inverter bridge for BLDC motor have been successfully tested using a dsPIC30F4011 Digital Signal Controller. The output from the converter is fed to the three phase stator winding of 48V, 250 W, 3850 rpm BLDC motor and the motor is found to run at constant speed which is set by the external potentiometer connected to the microcontroller circuit. The program is found to be efficient and the results with the designed hardware are promising. The developed control and power circuit functions properly and satisfies the application requirements. Experimental results justify effectively the developed drive designs.

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