Design, Code Generation and Simulation of a BLDC Motor Controller usuuing PIC Microcontroller

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Abstract— **Brushless Direct Current (BLDC) motor are one of the electrical drives that are continually gaining popularity in motion control applications due to their high efficiency, good dynamic response and low maintenance. Unlike DC motors and Induction motors, BLDC motors needs a controller as the motor runs in 3 phases but takes DC input. The controller converts DC power to 3 phase AC power suitable for the motor. This paper propose a design, code generation method and digital logic control of a BLDC motor controller for turning the rotor clockwise or counter clockwise. A Pulse Width Modulation (PWM) speed control strategy is performed to adjust the rotor speed. The framework is modelled and simulated by using Proteus software.**

Keywords— **BLDC motor, BLDC motor controller, Code generation, Power electronics, Hall sensor, PIC microcontroller**

I. INTRODUCTION

The use of the general type dc motor has its own long history. This type of motor has been used in the industries for many years as they provide precise way of control and high efficiency. DC motors also have a high starting torque versus falling speed characteristics which helps to gain high starting torque and helps to prevent sudden load rise. Since the late 1980's new design concept of permanent magnet brushless direct current (BLDC) motors are gaining grounds in the industries especially in the areas of appliances production, HVAC industry, medical, electric traction, road vehicles, aircrafts, military equipment, hard disk drive, aeronautics, medicine, consumer and industrial automations and so on. The BLDC motors are typically permanent synchronous motors; they are well driven by dc voltage. BLDC motors have a trapezoidal back-EMF. They have a commutation that is done mainly by electronics application [1].

Comparing BLDC motors with DC brushed motors and induction motors, the DC brushed motor have smooth speed control, high starting torque capability. But they have a huge power lose which occurs mainly in the brushes and in the rotor which limits the heat transfer and consequently the armature winding current density, while in BLDC motor the power losses are all in the stator where heat can be easily transferred through the frame. In general the induction motor has also many advantages, such as: their simple maintenance, simplest construction, low price, robustness and reliability. Furthermore, there are some disadvantages of induction motor too. They are: lower torque at lower speeds, poor dynamic characteristics and lower efficiency [2]. These facts make the BLDC motors becomes more attractive and efficient option than induction motors and DC brushed motors. For other several of reasons, now-a-days BLDC motors are radically being used in many appliances worldwide [3].

The main objective of this research work is to design, develop and simulate a Brushless Direct Current motor controller to control the rotor speed and the rotating direction. So the defined goal in this research work is to generate code, circuit design and simulate test result of the BLDC motor controller. In order to fulfil this goal firstly the operating principle of BLDC motor should be understood. Then there will be a components (such as: Microcontroller, MOSFET/IGBT, Driver etc.) selection study. After that a C language code for the microcontroller will be made which will create the PWM signals to determine the phase sequence of that BLDC motor to rotate it clockwise or counter clockwise. A potentiometer will give analogue reference value to the microcontroller to adjust motor speed. The microcontroller will take feedback from the motors Hall Effect sensors to drive switches (MOSFETs) through driver circuit. Then the code and control circuit will be simulated in PROTEUS software. Fig.1 shows the basic block diagram of the motor controller. As shown in the picture, the microcontroller will take feedback from the Hall Effect sensors of the motor to determine the rotor position. According to the rotors position, the microcontroller will generate code to drive the proper switches through driver circuit. The microcontroller will also take input signal from a potentiometer to adjust the rotating speed of the motor.

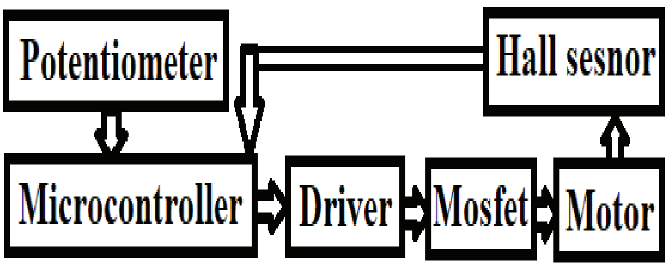

Fig.1. Basic block diagram of a BLDC motor controller

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II. CONTROLLER DESIGN & CODE GENERATION

A. Winding connection of BLDC motor

BLDC motors come in single-phase, 2-phase and 3-phase configurations. Out of these, 3-phase motors are the most popular and widely used. It has a rotor with permanent magnets and a stator with 3 coil or windings. Current flows unidirectional between any two phases and the third phase remains idol, so it can be concluded that BLDC motors are always star (Y) connected because only in star connection if DC voltage source is applied between any two end, the current flows between two phases connected them in series, leaving the third phase un-energized (shown in Fig.2). This is called trapezoidal voltage strokes which are not possible in a delta connection.

B. Hall Effect Sensor logic level

Brushless DC Motors are driven by DC voltage but current commutation is controlled by solid state switches. The commutation instants are determined by the rotor position. The rotor shaft position is sensed by a Hall Effect sensor which provides signals to the microcontroller and the microcontroller gives gate drive signals to the respective switches via misfit/IGBT driver. Whenever the rotors magnetic poles pass near the Hall sensors, they give a high signal indicating North Pole and low for South Pole. Generally 3 Hall Effect sensors are used in BLDC motor as there are three phases are connected in star connection. So 8 (2 to the power 3 = 8) different signal combinations are possible to generate by the Hall Effect sensors. They are: 000, 001, 010, 011, 100, 101, 110, and 111. Among them 000 and 111 are odd combinations as they will never be formed. The remaining 6 combinations are the six different rotor position or six fundamental steps of a BLDC motor rotation shown in Fig.2 (either 1 or 2 sensors gives high signal at a time).

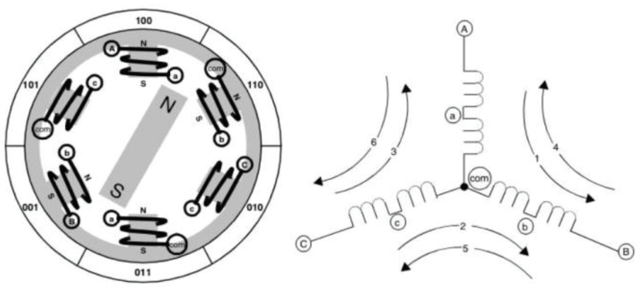

Fig.2. Simplified BLDC motor winding diagram [4]

C. Phase commutation sequence

By putting three Hall sensors output in a waveform we will find that each sensor gives 3 high and 3 logic level outputs. Arranging them uniformly the commutation sequence will be found: 101, 100, 110, 010, 011 and 001. Based on this combination of three Hall sensor signals, the exact sequence of commutation of three different phases can be determined easily by applying equation [5].

The equation is:

Phase A = Hall A – Hall B
Phase B = Hall B – Hall C
Phase C = Hall C – Hall A

In the first sequence Hall A = 1, hall B = 0. So Phase A = 1-0 = +1. Similarly in the second sequence Phase A will be 1-0 = +1. By this way the total commutation sequence of Phase A, Phase B and Phase C will be respectively (shown in table-1):

Phase A = +1, +1, 0, -1, -1, 0
Phase B = -1, 0, +1, +1, 0, -1
Phase C = 0, -1, -1, 0, +1, +1

These are the six fundamental commutation sequences to run the rotor counter clockwise [6]. Suppose the Hall sensors give a logic level output of 101. So the Phase A and B will be energized positive and negative respectively. That means positive voltage will be applied in Phase A, negative voltage in Phase B and nothing in Phase C. It will make the rotor slightly turn counter clockwise. In a new rotor position Hall sensors logic level output will be different. It will be 100. So Phase A will now receive positive voltage, Phase B negative and Phase C will remain idle. Now the rotor will turn again counter clockwise slightly. Again the Hall sensors will give another logic level output. Thus the rotor keeps rotating by repeating these six commutation sequence.

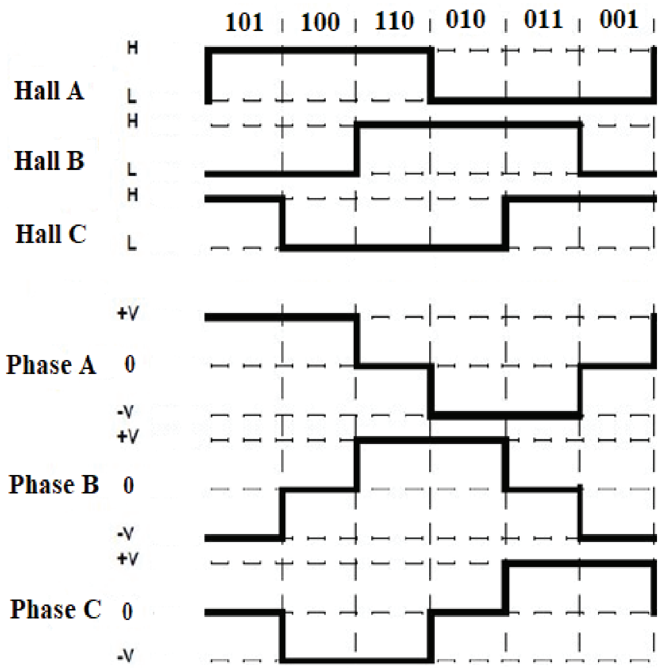

Fig.3. Hall Effect sensor vs Phase waveform of BLDC motor

D. Controlling terminal voltage

To energize these three phases, their windings terminals should receive either positive or negative voltage. Terminal voltages on the stator windings of each phase are controlled by power electronic switches such as MOSFETs, IGBTs, BJTs or Transistors [7]. Two phases should conduct at any instant, one will be positive, another will be negative and the other one will remain non-polar.

TABLE I. MICROCONTROLLER'S PIN PWM LOGIC LEVEL GENERATION CHART

Code generation for Counter-clockwise (CCW), Forward turn																	
Hall sensor			Phase			MOSFET		PWM		Code							
C2	C1	C0	A	B	C												
Y	B	G	Y	B	G					PWM7	PWM6	PWM5	PWM4	PWM3	PWM2	PWM1	PWM0
0	0	1	0	-	+	S5	S3	3	4	0	0	0	1	1	0	0	0
0	1	0	-	+	0	S4	S2	1	2	0	0	0	0	0	1	1	0
0	1	1	-	0	+	S4	S3	1	4	0	0	0	1	0	0	1	0
1	0	0	+	0	-	S1	S6	0	5	0	0	1	0	0	0	0	1
1	0	1	+	-	0	S1	S5	0	3	0	0	0	0	1	0	0	1
1	1	0	0	+	-	S2	S6	2	5	0	0	1	0	0	1	0	0
Code generation for clockwise (CW), Reverse turn																	
0	0	1	0	+	-	S2	S6	2	5	0	0	1	0	0	1	0	0
0	1	0	+	-	0	S1	S5	0	3	0	0	0	0	1	0	0	1
0	1	1	+	0	-	S1	S6	0	5	0	0	1	0	0	0	0	1
1	0	0	-	0	+	S4	S3	1	4	0	0	0	1	0	0	1	0
1	0	1	-	+	0	S4	S2	1	2	0	0	0	0	0	1	1	0
1	1	0	0	-	+	S5	35	3	4	0	0	0	1	1	0	0	0

Each phase will connect with DC power source through two switches, one switch with positive terminal (upper side) and other switch with negative terminal (lower side) as shown in Fig.4. To control terminal voltage of the phases in a BLDC motor controller, there are generally 6 switches to connect all the three phases with DC power link.

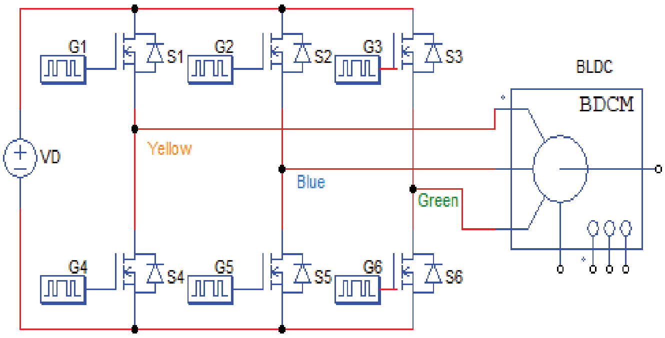

Fig.4. Phase connection with motor controller

If any upper switch triggered, the respective phase will get positive voltage and if any lower switch triggered then the phase will get negative voltage [8]. If both the switches of one phase remain open, the phase will remain non-polar. But if both switches conduct at a time, the power source will get shorted which may burn out the switches. So if any upper switch of any phase turns on, the lower switch of that phase must be turned off.

The three wires of a BLDC motor generally are Green, Blue and Yellow [9]. Assume that Phase A is connected with the switches via Yellow wire, Phase B is Blue and Phase C is connected through Green wire. Assuming first commutation sequence where Phase A receives positive voltage, Phase B receives negative voltage and Phase C remains non-polar. So now switch 1 should engage to connect Phase A with positive end through Yellow wire and switch 5 should also engage to connect Phase B with negative terminal of the source through Blue wire. Other four switches (2, 3, 4 and 6) should remain open so that Phase C will remain non-polar. This is how terminal voltages will be controlled during six commutation sequences using 2 switches (1 in upper side, 1 in lower side) engaging at a time. Table-1 shows the engaging switch number of the six commutation sequence respectively. In this research work IRFP250n (200V, 30A) MOSFET is used to simulate the phase waveforms.

E. PWM generating using PIC microcontroller

It is now clear that to control the 3 phases of a BLDC Motor, 3-phase Inverter Bridge is mandatory which consists of 6 MOSFETs. Almost all power-electronics products have become microcontroller controlled in recent years. The main advantage of using microcontroller is that it reduces the complex control hardware where the control functions can be changed as many times as it is required without extra hardware. To generate 6 PWM signals to drive the 6 MOSFETs a PIC microcontroller is used in this motor controller. In 2004, the Microchip released the PIC18FXX31 microcontroller for controlling 3-phase synchronous motors which fulfils the objectives of this research work. The main objective of this microcontroller will be generating 6 PWM signals according to Hall sensors logic level output to detect the rotor position [10]. A PIC18F4431 is used in this controller which has 8 PWM (PWM0 to PWM7) pins. First 6 PWM pin is used in this motor controller. The microcontroller generates PWM signals of 5V, but the MOSFETs gate drive needs 10-20V to operate. So additional drivers are needed to convert 5V PWM signals to 12V PWM signals. In this motor controller, IR2101 600 V High and Low Side Driver IC is used which has two individual High and Low input and two independent High and Low output. This driver IC takes two 5V PWM signals from the microcontroller as input and gives two 12V PWM signals as output. The High output signal drives the upper MOSFET and the Low output signal drives the lower MOSFET of one phase. So 3 IR2101 driver IC is used to drive all the MOSFETs of the controller. As there are six commutation sequence and two MOSFETs needed to be engaged in each sequence, the microcontroller will generate two PWM signals according to Hall sensor output in each step. Table-1 shows the PWM pin number which will give PWM signals in respective sequence.

F. Code generation

In PIC15F4431 microcontroller the operation of the PWM module is controlled by a total of 22 registers, eight of them are used to configure the features of the module. The microcontroller will generate the PWM signals according to the hall sensors input in C0, C1 and C2 pin to know the rotor's current position. A potentiometer is used to control the speed of the motor which gives a REF value to the AN0 pin of the microcontroller. The width of the PWM signals will be controlled by the potentiometer. By varying the signals width, MOSFET switching will be controlled which will vary the speed of the rotor. A FWD and a REV buttons are used to select the rotational direction of the motor. Finally source code is generated in PIC-C compiler with the help of Table-1. PIC-C compiler is a rich Integrated Development Environment (IDE). The program was then burn to the PIC18F4431 microcontroller using PICKIT-2 software.

III. FLOWCHART OF THE PROGRAM

Fig.5 shows the main loop of the program in block diagram.

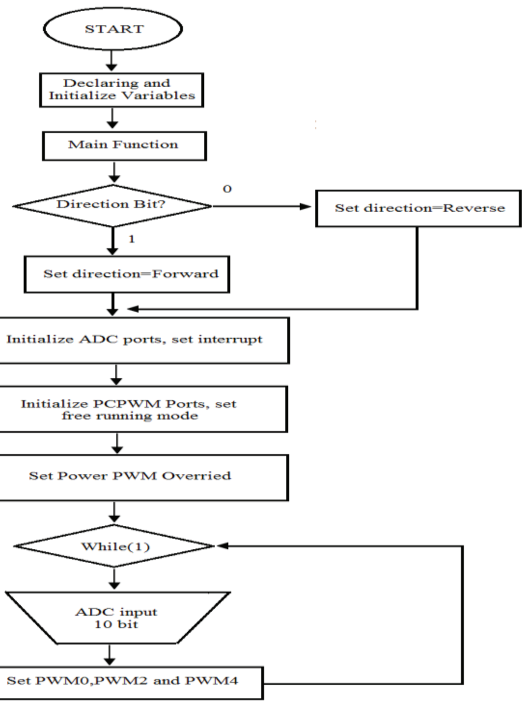

Fig.5. Main loop of the program

The whole program of this controller is under a main function and another one is PWM time base interrupt service routine. This program has also another two sub function, one is forward table and another one is reverse table.

Interrupt Service Routine(ISR)

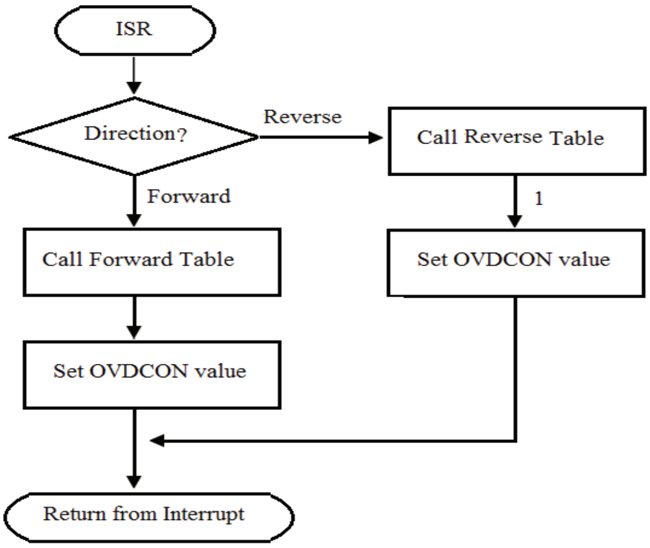

Fig.6. Interrupt Service Routine (ISR) of the program.

In this is interrupt service routine (ISR) interrupt function works when a full cycle of PWM signal is complete and then the processor come to this interrupt function to check whether the motor is commanded to rotate in forward or reverse direction. Then according to direction it calls another function to know the rotors position in that moment to get values of x variable. Then this value will set to OVDCOND. Another thing is that OVDCONS is always zero to get PWM. After completing its task it returns that line from which it interrupts. During every completion of a full cycle PWM it comes to this time based interrupt function and checks the rotor position on that moment, then set the OVDCOND and OVDCONS resister value to change the active state of PWM module.

G. Frequency vs speed

The speed of BLDC motor does not depend on frequency of PWM. Because if the poles of BLDC motor are energized at a random frequency, the rotors will not response to it. That's why variable duty cycle PWM is used to control speed and required pole is energized according to Hall Effect sensors outputs as well as rotors position. If maximum duty cycle PWM is generated then it energizes the poles by maximum voltage so the rotor will go to next position quickly as well as BLDC motor will rotate quickly. On the other hand if minimum duty cycle PWM is generated then it energizes the poles by minimum voltage so the rotor will go to next position slowly as well as BLDC motor will rotate slowly.

IV. Result and Discussion

After completing code generating part, a circuit diagram was created in Proteus software to analyse the output waveform. Fig.7 shows the circuit diagram of the motor controller. After completing designing the circuit, a virtual oscilloscope was connected to the three phases of the motor to show the output waveform.

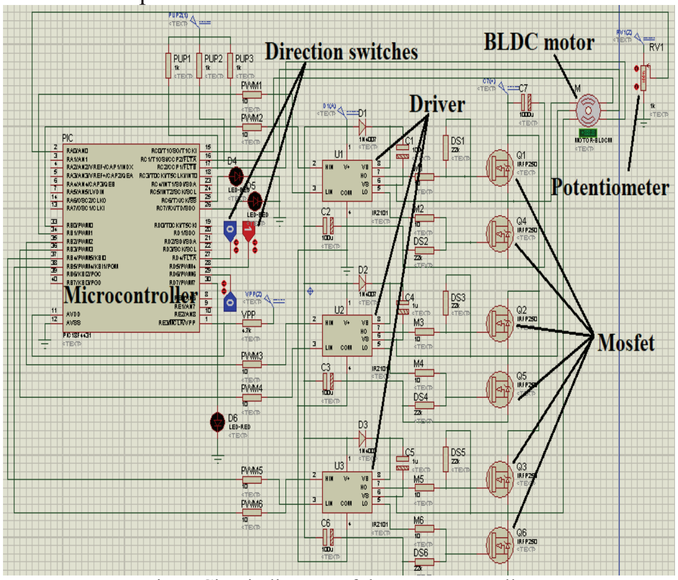

Fig.7. Circuit diagram of the motor controller

Fig.8 shows the output waveform of the motor controller. The time division scale is set on 10ms and voltage division is set on 20V. In the circuit 60V DC power is provided. As a result here we can see these three phases has peek to peek of 60V. The first phase is quite nice but there are some overshot a ringing in the second and third phases. Adjusting parameters can solve this problem.

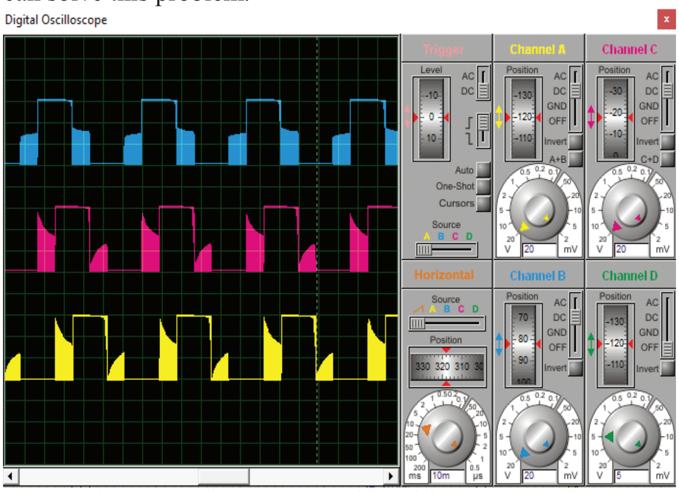

Fig.8. Three phase output waveform of the motor controller

V. Conclusion

In this paper, design and simulation of a BLDC motor controller has been presented along with rotating direction control that has been done by a PIC18F4431 microcontroller. Speed control of the motor also has been done using a potentiometer. The required phase sequence to rotate the BLDC motor is generated according to the output of the Hall Effect sensors which is embedded with the stator of the BLDC motor. Source code is generated and compiled using PIC-C compiler where HSADC (High speed ADC) module used for the value of the PWM duty cycle, are very accurate and can operate without any acquisition delay. PCPWM module is also used to make the pulse generating for each sequence of the motor much easier. The simulation test results confirmed that the designed controller of the BLDC motor operate at different speed by varying duty cycle of the PWM of the controller using potentiometer and different direction using direction switch selection.

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