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RESEARCH ARTICLE

ENGINEERING

Design and Simulation of Micro-controller Based Electric Vehicle Controller Using Proteus Design Suite

Baharul Islam[1], Manash Jyoti Borah[1*]

[1] Faculty of Engineering, Assam down town University, Panikhaiti, Guwahati, Assam-781026, India
[*]Corresponding author: Manash Jyoti Borah, *Email: manashppp@gmail.com*

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Abstract

This paper aims to design and simulate a low cost, efficient Brushless Direct Current (BLDC) motor controller for use in Electric Vehicles, with the objective of controlling the speed of the BLDC motor. The Pulse Width Modulation (PWM) speed control method, coupled with the sensor controlled technique (Hall Effect Sensor), is utilized to achieve optimal performance of the BLDC motor. Control operations for the BLDC motor are performed using an Arduino Nano board, which features an embedded Atmega 328 microcontroller. A 3 phase BLDC motor rated at 3300 rpm, 48V, 850W, and with a rated torque of approximately 2.2Nm is used in this study. The performance of the BLDC motor drive framework is modeled and simulated using the real time simulation tool software, Proteus Design Suite, to predict its performance prior to hardware implementation. Through this software, all components used in the framework are virtually simulated and the expected results are monitored and analyzed.

Keywords: *BLDC Motor, IRFZ44N Power MOSFET, IR2112 MOSFET Drive, Arduino Nano Board, PWM*

1 Introduction

The Arduino based brushless direct current (BLDC) motor controller system is designed to rotate the rotor and control the speed of a 850watt, 48volt BLDC motor for the application purpose in an electric vehicle**?**. This BLDC motor is driven by using position feedback method. The speed control is performed by generating pulse width modulation (PWM) signal of the input voltage with the help of Arduino Nano. The microcontroller chip used in Arduino Nano is ATmega328. It consists of 22 input/output pins out of which 14 are digital and 8 are analog pins. 6 of the digital pins are PWM pins. The BLDC motor controller system consists of four main parts: a power converter, a permanent-magnet synchronous machine (PMSM), sensors and control algorithm. 3 phase inverter transforms power from DC source to a proper AC form to drive the motor, hence, converts electrical energy to mechanical energy**?**. The presence of hall sensor in the motor makes it possible for the microcontroller to detect the rotor-position, hence, the proper instant to commutate the winding currents can easily be known. Therefore, by processing data from the Hall sensor output of the motor, the PWM generation process for triggering power switches will be carried out**?**.

2 Components Used

The controller for BLDC motor is made out of different components. Some of the main components are metallic oxide semiconductor field effect transistors (MOSFETs), MOSFET drivers, and microcontroller. The specific MOSFETs used to create the inverter bridge is IRF5305 and IRFZ44N, while IR2112 MOSFET driver is used to drive the MOSFETs in required order. Arduino Nano board which is embedded with ATmega328 microcontroller is used to generally control the whole circuit. Some of the other components that are used for running the circuit in smooth manner are capacitor with the capacitance 0.01µF, IN4148 diode, Hex Schmitt trigger inverter 74HC14, 48V lithium ion cell, voltage regulators 7805 with 5v as output voltage and 7815 with 15v as output voltage, and a 10k potentiometer. Oscilloscope is used to analyze the input and output wave forms of the circuit. The whole circuit is designed, simulated and tested in Proteus 8 software.

1. **Brushless Direct Current Motor (BLDC Motor)**

Basically, the brushless direct current motors are in configuration of single phase, 2 phase or 3 phase. The motor used to imply the BLDC motor controller model is a 3 phase BLDC motor with rated voltage of 48V and 800W. The 3 phase BLDC motor has a rotor with permanent magnet and a stator with 3 coil or windings**?**.

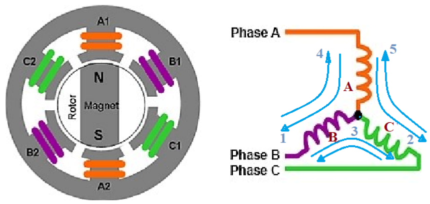

Figure 1: Internal structure of a BLDC motor

When the current flows between any two of the three phases, the third phase remains idol. In other words, one of the windings is energized to positive power, the second winding is negative and the third one is in a non energized state. As shown in the figure, if DC voltage source is applied between any two ends, the current flows between two phases connected to them in series, leaving the third phase un energized. This defines the trapezoidal voltage strokes that are not possible in a delta connection**?**. The numbers one to six on stator winding represents the commutation sequence.

The interaction between the magnetic field generated by the stator coils and the permanent magnets produces torque.

The right angled position of the two fields causes the occurrence of the peak torque and falls off as the fields move together. In order to keep the motor running, the position of the magnetic field produced by the windings should be shifted as the rotor moves to catch up with the stator field.

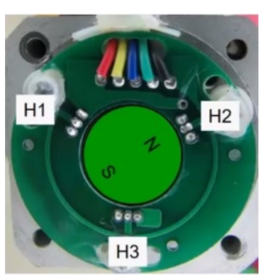

Figure 2: Hall sensor in a BLDC motor

The main function of hall sensor is to detect magnetic fields, and also to sense the rotor angle. Depending on the magnetic field nearby, the hall sensor generates the output as logical 1 or 0 for each sensor. Each sensor is placed at the back of the motor at 120º angle from each other. As the rotor turns, the hall sensors output logic bit activates indicating the angle.

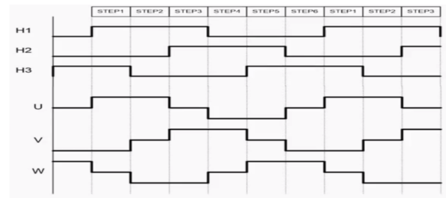

Figure 3: Hall sensor commutation

The combination of these three sensors generates six different logic combinations or steps. The motor phase combinations are decoded by the 3 bits from the hall sensors. This data from the phase combination then can be divided into individual transistor gate signals. Now the signal can be modulated by one transistor at a time to regulate the motor voltage, and also the speed**?**.

2. **IRF5305 Power MOSFET** IRF5305 is a p-channel fifth generation MOSFETs that utilizes advanced processing techniques to achieve extremely low on resistance per silicon area. Its fast switching speed and ruggedized device design are the reason for its popularity. It provides the designer with an extremely efficient and reliable device for use in a wide variety of applications**?**.

Figure 4: IRF5305 power MOSFET

According to the datasheet, IRF5305 is a single p-channeled MOSFET with the drain source breakdown voltage of -55V and continuous drain current(Id) of -31A. It's drain source resistance is 60mΩ, gate source voltage is 20V with the gate charge of 63nC. It operates at the temperature range of (-55 to 175) ºC, dissipating the power of about 110W.

3. **IRFZ44N Power MOSFET** The IRFZ44N is a N-channel MOSFET with a high drain current of 49A and low Rds value of 17.5 mΩ. Its threshold voltage being as low as 4V, it starts to conduct at low voltages making it very compatible to use with the microcontrollers. However a driver circuit is a necessity if the

Table 1: BLDC Motor Commutation Sequence Table

State	Conducting Phase	Switch A	Switch B	Switch C
1	AB	High	Low	-
2	AC	High	-	Low
3	BC	-	High	Low
4	BA	Low	High	-
5	CA	Low	-	High
6	CB	-	Low	High

Table 2: The Triggering of the Gate Pin of MOSFETS in the Commutation Circuit

Hall effect sensors			MOSFET Switch					
Sensor Y	**Sensor B**	**Sensor G**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
0	1	1	0	1	0	1	0	0
0	0	1	0	1	0	0	0	1
1	0	1	1	0	0	0	0	1
0	1	0	1	0	0	0	1	0
1	1	0	0	0	1	0	1	0
1	0	0	0	0	1	1	0	0

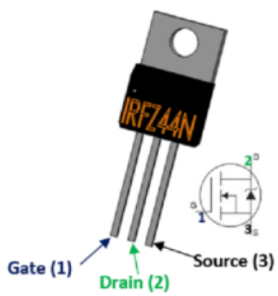

Figure 5: IRFZ44N N-channel power MOSFET

MOSFET has to be switched in entirely. The IRFZ44N has high drain current and fast switching speed. In addition, it also has a low Rds value which will serve in raising the efficiency of switching circuits. Some of its characteristics according to the datasheet are: small signal N-Channel MOSFET, continuous drain current (ID) is 49A at 25°C, pulsed drain current (ID-peak) is 160A, minimum gate threshold voltage (VGS-th) is 2V, maximum gate threshold voltage (VGS-th) is 4V, gate source voltage is (VGS) is ±20V (max), maximum drain source voltage (VDS) is 55V, rise time and fall time is about 60ns and 45ns respectively?.

4. **IR2112 MOSFET Driver** The MOSFET driver used for this project is IR2112. The IR2112 is a high voltage IC that serves as a MOSFET driver and IGBT driver.

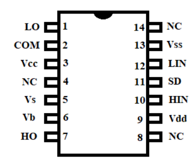

Figure 6: IR2112 Pin Diagram

It has high and low side independent referenced output channels with 600V as the threshold voltage. The Bootstrap feature this driver IC makes it suitable for high side driver applications. Furthermore, it has Schmitt triggered inputs that can fit to the CMOS and LSTTL outputs. IR2112 is basically a low and high side driver IC with a voltage range of 10V to 20V?.

5. **Arduino Nano Board** Arduino Nano is a microcontroller board designed by arduino.cc. Microcontroller used in Arduino Nano is ATmega328. It has 12 digital pins (D2 to d13), and 8 analog pins (A0 to A7). These digital and analog pins are assigned with multiple functions but their main function is to act as either input or output.

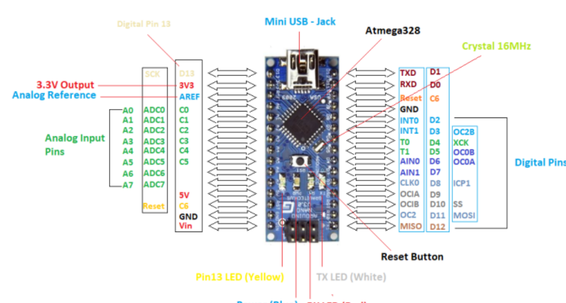

Figure 7: Arduino Nano with Pin Descriptions

Arduino Nano can perform 3 types of communication protocols i.e. serial protocol, SPI protocol, and I2C protocol. PIN 0 and PIN 1 are used for serial communication where PIN 0, Rx, is used to receive data and PIN 1, Tx, is used to transmit data. The pins used for SPI communication are PIN 10 to PIN 13 where PIN 10 is SS (slave select), PIN 11 is MOSI (master out slave in), PIN 12 is MISO (master in slave out) and PIN 13 is SCK (serial clock). The pins used for I2C communication are PIN A4 and PIN A5 where PIN A4 is SDA (data line) and PIN A5 is SCA (clock line). Arduino Nano also has six PWM pins which are PIN 3, PIN 5, PIN 6, PIN 9, PIN 10, and PIN 11. These six pins can be used for Pulse Width Modulation. It also has 2 reset pins. Arduino Nano uses crystal oscillator of 16MHz. Arduino Nano has 3 types of built in memories associated with it. The first one is flash memory with the size of 32 KB out of which 2 KB is used for boot loader which is pre installed in Arduino Nano. The flash memory is responsible for storing all the codes uploaded in Arduino Nano.

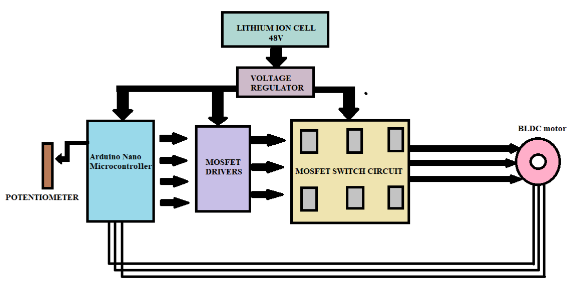

Figure 8: Block diagram of BLDC motor controller circuit

The SRAM memory of Arduino Nano is 2 KB while the EEPROM memory is of 1 KB. Input voltage range of Arduino Nano varies from 7v to 12v while the operating voltage is 5v.

3 Working Principle

As shown in the block diagram, a 3 phase BLDC motor is driven by using 3 phase power MOSFETs bridge IRF5305 (high side) and IRFZ44N (low side). This bridge is fed with a dc voltage from 48V battery and power switches are controlled in compliance with the directive from the rotor position circuitry and from the users speed torque commands. The DC source from the battery is transformed to a proper AC form by 3 phase inverter to drive the BLDC motor, hence, converting the electrical energy to mechanical energy. The microcontroller controller, Arduino Nano board, is programmed in such a way that it generates the PWM signals from the input voltage to determine the phase sequence of the BLDC motor to rotate. The microcontroller will take feedback from the motors Hall Effect sensors to determine the rotor position and accordingly drive the switches (MOSFETs) through driver circuit. According to the rotors position, the microcontroller will generate code to drive the proper switches through driver circuit. The microcontroller will also receive the command signal from the potentiometer to alter the rotating speed of the motor. The potentiometer will deliver analogue reference value to the microcontroller to adjust motor speed.

4 Circuit Design

The most common configuration for applying current to a 3 phase BLDC motor sequentially is to use three pairs of power MOSFETs arranged in a bridge fabric, as shown in Figure **??**

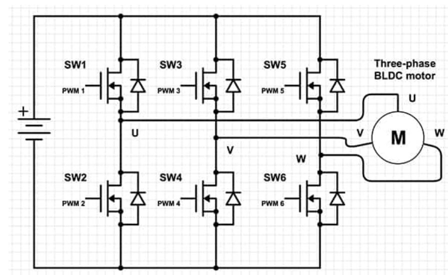

Figure 9: General circuit of a 3 Phase Inverter

The most common configuration for applying current to a 3 phase BLDC motor sequentially is to use three pairs of power MOSFETs arranged in a bridge fabric, as shown in figure. The switching of one phase of the motor is regulated by each pair of the power MOSFET. Pulse width modulation(PWM) technique is used to control the high-side MOSFETs where the input DC voltage is converted into a modulated driving voltage. Furthermore, this technique of PWM also allows the initial current to be limited and proposes precise control over speed and torque**?**.

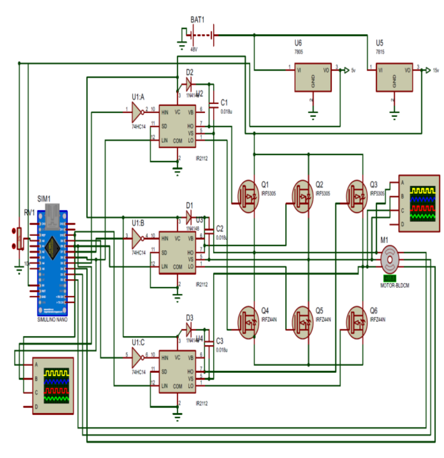

Figure 10: Full schematic circuit of BLDC motor controller in Proteus

According to the circuit designed in Proteus 8 software, SIM1 is referred to Arduino Nano micro controller, Rv1 is referred to variable resistor or potentiometer, U1:A, B and C are the inverter for Hex Schmitt trigger. D1, D2 and D3 represent diodes and C1, C2 and C3 are the capacitors of 0.01µF. The MOSFET drivers are represented by U2, U3 and U4, while the voltage regulators are U5 and U6. The six switches Q1 to Q6 are three pairs of power MOSFETs which together makes a 3 phase inverter. In this circuit the combination of p-channel and n-channel is used in which the p-channel MOSFETs are connected to the high voltage bus and n-channel bus to the low voltage bus. To run the motor the desired switching has to be performed by the microcontroller according to the hall sensor signal. Firstly, Q1 and Q4 are turned ON and the current flows from the battery to the motor. During this switching, the motor inductor stores energy and in the next cycle Q1 is turned off and Q4 is still ON. The inductor releases its energy via Q4 and freewheeling diode of Q2. This operation is described for one state i.e. 60°. Similarly, there will be six states in total. In the described state, Q4 is always ON and Q1 is operated by PWM. The position of the rotor which is detected by the hall sensors regulates the entire BLDC motor operation. The necessary switching is done based on the hall signal data **?**. Three hall sensors are provided in the motor for position sensing which are placed at the phase difference of 120°. DC source gives 5V and 15V output through voltage regulator (7805 and 7815) for operation of controller, driver and the main inverter circuit respectively. The potentiometer, connected to one of the analog pins (A0) of the Arduino Nano microcontroller, is used to set reference speed.

4.1 Speed Control

One of the most beneficial and effective techniques for motor control applications is the pulse width modulation (PWM) method. Using this method, the speed of the motor can be varied smoothly from 0 to the rated speed, and the initial current of motor as well as torque can be kept within these limits. The frequency of the Pulse Width Modulated (PWM) signals should be higher than the motor frequency**?**. The speed is reduced when the duty cycle of PWM is varied within the sequences, since the average voltage supplied to the stator reduces. A potentiometer is used to control the speed of the motor which gives a reference value to the A0 pin of the microcontroller (Arduino Nano board). Here, the width of the PWM signals will be controlled by the potentiometer**?**. By varying the width of these signals, MOSFET switching will be controlled which will eventually vary the speed of the rotor. This analog voltage corresponds to reference speed. The reason behind using PWM to control the speed is due to the occurrence of the condition that the loss of torque may lead to the stalling of the motor.

4.2 Algorithm for Coding Arduino

The source code is generated according to the data from the Table **??**. The logic of the code is built in accordance with the position of the rotor. The obtained condition is verified within the code triggering the respective gates to activate.

5 Results and Discussions

After completing code generating part, a circuit diagram was created in Proteus software to analyze the output waveform. Upon completion of designing the circuit in Proteus 8 software, a virtual oscilloscope was connected to the three phases of the motor and at the PWM pin of the Arduino to show the output waveform and PWM pulses.

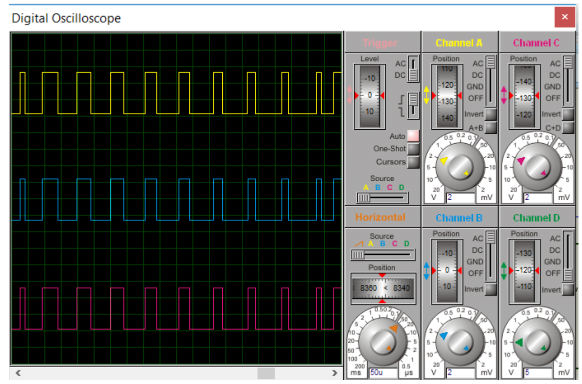

Figure 11: Generation of PWM signals from the microcontroller

The proposed circuit design has been virtually tested and simulation results are shown in the Figure **??** and Figure **??**. The simulation is performed using Proteus software to observe the input and the output signals including PWM signals. The use of Proteus software reduces programming time greatly. The reference hall sensor signals are 120º phase shifted from each other. Hence, those signals can be achieved using three phase supply module, Op-amp comparator and diode combination.

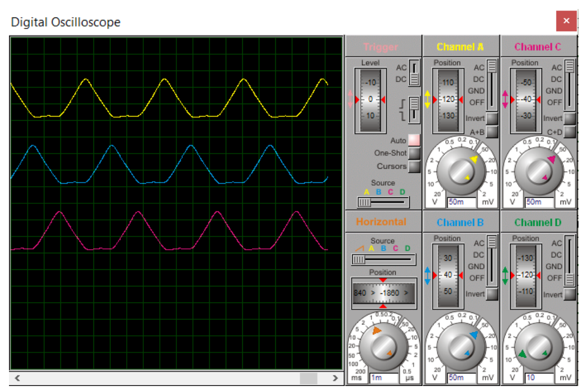

Figure 12: Output waveforms of the 3 phase terminals of BLDC motor

The microcontroller is programmed to generate six PWM switching signals based on these hall sensor logical data. All the PWM output signals (PWMA, PWMB, PWMC) corresponds to the reference hall sensor signals. 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 from inverter is found to be trapezoidal in nature. The BLDC motor can be also controlled by sensing the back emf voltage of the motor**?**. The software used for the designing and simulation, Proteus 8, can be declared as one of the most efficient and time saving way to design the BLDC motor controller.

6 Conclusion

In this paper, design and simulation of a BLDC motor controller has been presented along with rotation control done by Arduino Nano board microcontroller. Speed control of the motor is done using a potentiometer. The Hall Effect sensor embedded with the stator of the BLDC motor gives the logical signal of the position of the rotor and accordingly generates the required phase sequence. Source code is generated and compiled using Arduino IDE software. The simulation test results confirmed that the designed controller of the BLDC motor operates at different speed by varying the duty cycle PWM of the controller using potentiometer. Considering the specifications of all the components used, we can say the BLDC controller circuit designed in this project has the rated voltage of up to 55V with the torque ripple of about 2.2Nm. It should be able to handle the BLDC motor of about up to 1000 watt.

Conflict of Interest

The authors declare no conflict of interest in this reported communication.

Acknowledgments

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