Motor Control Design for Position Measurement and Speed Control

Rajesh Kannan Megalingam, *Senior Member, IEEE*, Shree Rajesh Raagul Vadivel, Bhanu Teja Pula, Sarveswara Reddy Sathi, *Member, IEEE,* and Uppala Sai Chaitanya Gupta

***Abstract*—This paper delineates various Simulink based control model constructions of (BrushLess Direct Current) BLDC motors using microcontrollers. The constructed control models particularize the PWM phase computation, 3-phase bridge signal generation for sensor-less BLDC motors and BLDC motors with hall sensors, hall sensor based position measurement, speed control and monitoring the number of rotations of BLDC motor using digital sequential blocks. In order to assess the control model constructions, various scrutiny carried out to make sure the exactness of the models. Since the controller driver is one of the important components to control the BLDC motor effectively, the implementation of controller driver system is fundamental step in the development of actuators. Here, in this paper we are using Simulink to build the controller driver system for position and speed of BLDC motor with the help of semiconductor switching devices and digital sequential blocks.**

***Index Terms*—Simulink, BLDC, Hall Senso, PWM and Arduino.**

I. Introduction

BLDC motors have been playing a sophisticated role in various applications for its high precision and easy controlling than normal motors. Electronic controller is one of the main component to manipulate the BLDC motors. In this consideration, Simulink is one of the suitable simulation tool in MATLAB to develop the electronic controller system and evaluate the performance. There are many control models existing in Simulink for controlling BLDC Motors but this work discusses fundamental implementation of various Simulink control models of BLDC motors for sophisticated actuator development. Firstly, this paper discusses all theoretical concepts required to implement the Simulink constructions. Then it focuses the implementation of various Simulink constructions using semiconductor switch devices and digital switch blocks. Finally, we focus on the evaluation of Simulink constructions by measuring the position and controlling the speed using hall sensors. Although, there are many advanced Simulink constructions already available, this paper proposes the easy implementation of complex constructions. The rest of the paper is organized as mentioned below. The motivation, related works, system architecture and design is explained in section II, III, IV and V respectively. Section VI discuss about the experimental results of the work. Section VII and VIII concludes the paper with conclusion and future work respectively.

Dr. Rajesh Kannan Megalingam, Shree Rajesh Raagul Vadivel, Bhanu Teja Pula, Sarveswara Reddy Sathi and Uppala Sai Chaitanya Gupta are with the Department of Electronics and Communication Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, Kerala, India. (e-mail: rajeshkannan@ieee.org shreerajgul@gmail.com pulabhanuteja@gmail.com sarveswarareddysathi@gmail.com uschaitanyagupta776@gmail.com).

II. Motivation

As the technology inclines, the precision and manipulation of actuators plays an important role in determining the efficiency of equipment and machines. Among all, BLDC motors are one of the highest efficient motors. The construction of electronic controllers is the first step to commence the research in the field of actuator development. The motivation of this research work is to give comprehensive idea of control model techniques and analysis of BLDC motors using MATLAB.

III. Related works

The Simulink based control models in this research paper [1] introduces a cost effective technique for speed estimation with various scrutiny clearly elucidated. In the research study published in [2], the authors presented the modelling of five phase signal generation for induction motor controller of BLDC motor. The research paper [3] provides a brief information on PWM signal generation for BLDC motor drive which can be useful to avoid fault occurrence in the system. The research work in [4] gives information on position compensation technique for uneven hall effector magnetic flux which can be useful to run the motor even in irregular sensor reading. The research work in [5] delineates the precision control of BLDC motor. The authors in research work [6] presented a detailed expression on position control of four switch BLDC motor which can give a brief understanding of sensor less BLDC motor and signal generation of BLDC motors. In the research work [7], the author provides brief overview on speed measurement of BLDC motors based on 3 phase signal generation. The real time experiment of BLDC motors for electric vehicle is clearly implemented and elucidated in the research work [8]. The performance analysis of BLDC motor using various signal generation are carried out in the research work [9]. In the research work [10], the author carried out a clear dynamic analysis of BLDC motors with appropriate mathematical modelling.

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The research paper [11] provides basic implementation and design of BLDC prototype with pertinent testing of motor performance. In research work [12] modelling and analysis of BLDC motor using PIC microcontroller were presented. The research work published in [13] provides a brief analysis of BLDC motors using feed drives which can play important role in CNC machines. The research work published in [14] concentrates on mathematical analysis of basic BLDC motor drives using MATLAB and Simulink. In our case, we have our own controller board designed and fabricated to measure the position and control the speed of the BLDC motors using hall effect sensors by integrating with the Simulink software.

IV. System Architecture

The System architecture is meticulously illustrated in the Fig. 1. The system architecture consists of five main units. The microcontroller unit receives the hall sensor signals from the BLDC motor and sends the computed MOSFET gate signals to the BLDC Driver unit. The BLDC drive unit generates phase signal with respect to signals received from the microcontroller unit. The generated phase signals in microcontroller are used to find the position of BLDC rotor. The speed of the BLDC motor can be controlled by varying the duty cycles of phase signal generated in microcontroller. The number of rotations of BLDC rotor can be controlled by phase commutation in hall sensor unit. The microcontroller is programmed using Simulink-MATLAB.

A. Simulink

Simulink is a graphical programming tool for modelling and analysis of various dynamic systems. Because of its modelling and analysis compatibility, it is used in developing stage of various research works. It has provision to convert the graphical program models into other programming languages like c language, C++ and so on. Not only converting the models, it also has provision to burn the code dynamically into other embedded boards like Arduino, STM32 and so on. Simulink is extensively using in domains like digital signal processing, control system for design and simulation of various control models. The simulation blocks in Simulink which is exact replication of real-time hardware systems and accurate real time simulation results made it so popular to test the research work before implementing in hardware.

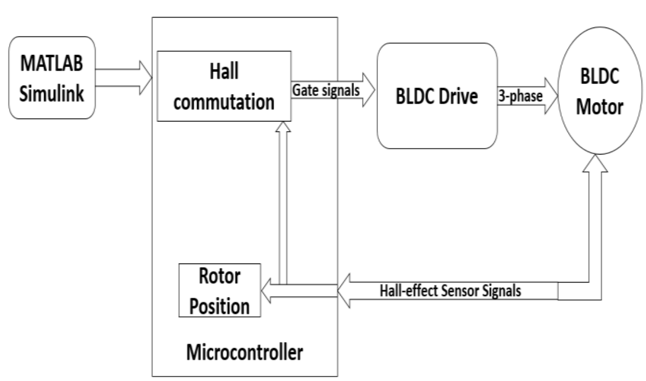

Fig. 1. Architecture Diagram of Proposed System.

B. Arduino Mega

The microcontroller we use is Arduino Uno which is an open source electronic device and prototyping device which is developed primarily for students. The microcontroller in Arduino Mega is ATMEGA2560. It is an input-output device which can span various different electronic devices. It is not only input and output the data but also provides 3.3v and 5v for electronic devices. The analog ports and digital ports in Arduino can manipulate both digital and analog devices. Based on various application requirements, there are different types of microcontroller boards. We implemented this system with the help of Arduino Mega because it has more ability to process and interrupt pins than Arduino Uno.

C. Motor Driver

The customized BLDC drive is designed and fabricated by us with three BTN8982TA MOSFET integrated circuits which are responsible for switching mechanism in PWM signal generation. The motor driver is responsible for manipulation of BLDC motor for given input. The MOSFETS works with respect to the hall sensor and encoder inputs and accomplish the given task.

D. Brushless DC Motor

The specification of BLDC motor that we used in our research work is listed in the Table I.

V. Design and Implementation

The Simulink design of BLDC motor encompasses phase signal generation because the BLDC motors work only if the phase of input voltage is varying. For a three phase BLDC motor, it is required to generate the signal with three different phase delay. These three phase signals are generated with the help of PWM signal generator blocks and MOSFET. The Fig. 2 explains the design of three phase sinusoidal signal generation for BLDC motor. The input PWM Generator blocks are designed in such a way that output signal consists of different phase delays. The input PWM signals are elucidated with the help of scope block in Simulink. The verified delays are included in experiments and results section.

The generated PWM signals in Simulink are programmed to Arduino. The programmed Arduino gives the output PWM signal to BLDC motor drive. The Simulink model of PWM generation are clearly depicted in the Fig. 3, for Pins 3 to 11 of Arduino. All these PWM generation blocks looks same but the phase will vary at the output of each of the pins 3 to 11 for the PWM signals generated.

TABLE I
BLDC Motor Specifications

S.No	Motor Model	JK57BL(S)01
1	Hall effect angle	Electrical Angle
2	Poles	4
3	Phases	3
4	Voltage	36 V
5	Speed	4000 RPM
6	Peak Current	6.8 A

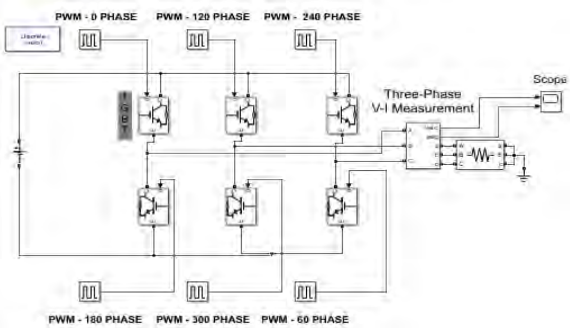

Fig .2. Three phase signal generation

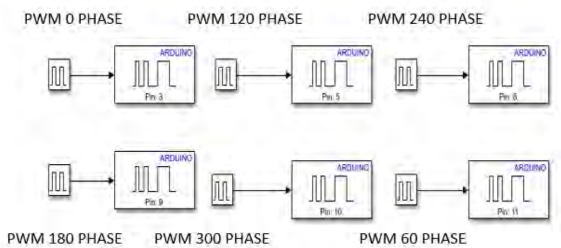

Fig .3. Six PWM signals to Arduino

So far, the above mentioned procedure is to run the BLDC motor. But, we don't have any control over position of the rotor. To get the control over the position of the BLDC rotor, we need hall sensor or back EMF input to locate the rotor position. In our case, we are using hall sensor input to calculate the rotor position. The function of design depicted in Fig. 4 is to receive the hall sensor input from Arduino pins.

To get the control over the BLDC rotor position, the BLDC motor has to rotate with respect to the hall sensor input. Indirectly, it is the phase that has to vary with respect to the hall sensor inputs. We also know the respective phase signals activate only for specific pair of MOSFETs is in use. So, we need to map hall sensor input to the MOSFET pair states to get appropriate phase signals. Generally, the input pattern of hall sensor consists of 101, 001, 011, 010, 110, 100. The MOSFET pairs shown in Fig. 5 exactly replicates the structure of switches present in BLDC drive. The mapping of hall sensor input and switch conditions to get control over the BLDC rotor position are shown in Table II.

We considered two hall sensor input signals to control the position and number of rotations of rotor. The outer Simulink design to find position and rotations of rotor is depicted in Fig. 6.

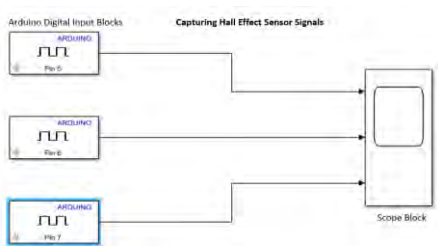

Fig. 4. Visualization of Hall-effect sensors in scope

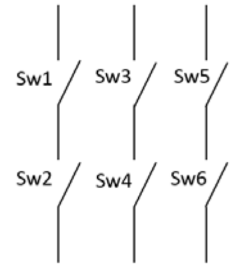

Fig. 5. MOSFET switch arrangement

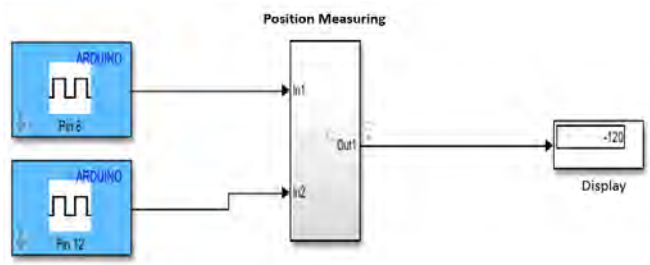

Fig. 6. Overall Simulink design to find position and rotations

The position and rotations of BLDC rotor are determined by the hall sensor input signals with the help of up-counter and down-counter. We designed the Simulink model in such a way that, the up-counter and down-counter change the values with respect to the position and rotations in forward and backward directions of BLDC motor. The Simulink design depicted in Fig. 7 is used to find position and rotations of BLDC rotor with the help of up-counter and down-counter.

To get the control over the speed of BLDC motor, we need to vary the duty cycle of the PWM phase signal. Here, the duty cycle of PWM phase signal is varied using the potentiometer which is provided through the analog pin of the Arduino. Indirectly, the speed of the BLDC motor is controlled using potentiometer connected to Arduino analog pin. The Simulink design depicted in Fig. 8 is successfully able to control the speed of the BLDC motor.

In above procedure, we mentioned the mapping of hall sensor input signals from Arduino to the switching conditions of MOSFET's in the BLDC drive. This mapping is achieved with the help two internal logic blocks which are shown in Fig. 9 and Fig. 10 respectively. The first gate block receives the hall sensor input signals and perform the computation in decoder blocks. And then the computed outputs from decoder blocks are feed to the comparison logic in second gate block.

TABLE II
MOSFET SWITCHING CONDITIONS.

Hall Sensor 1	Hall Senor 2	Hall Sensor 3	Active Switches
1	0	0	Sw1 and Sw6
1	1	0	Sw3 and Sw6
0	1	0	Sw2 and Sw3
0	1	1	Sw5 and Sw2
0	0	1	Sw5 and Sw4
1	0	1	Sw1 and Sw4

To get the control over the speed of BLDC motor, the duty cycle of PWM signal should vary. The Simulink block depicted in Fig. 11. Generates the variable duty cycle signal and feed these signals to respective Arduino pins.

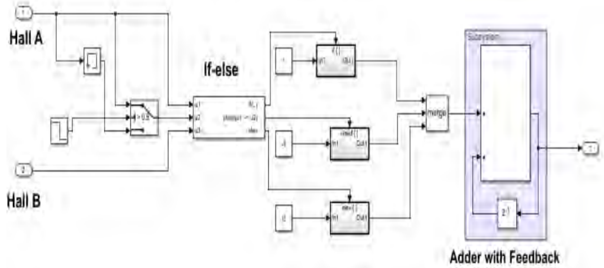

Fig. 7. Internal Simulink design to find position and rotations

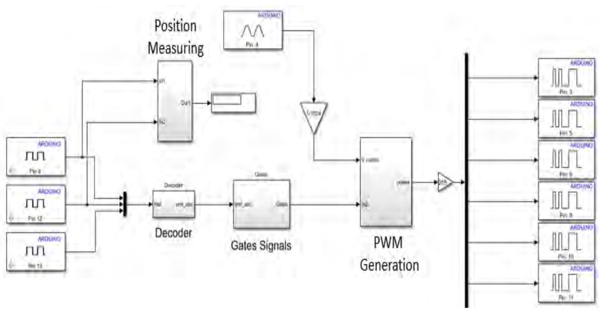

Fig. 8. Speed control Simulink design for BLDC motor

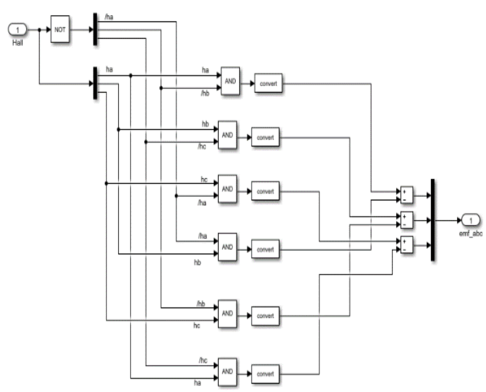

Fig. 9. Decoder block design for computation of Hall sensor input

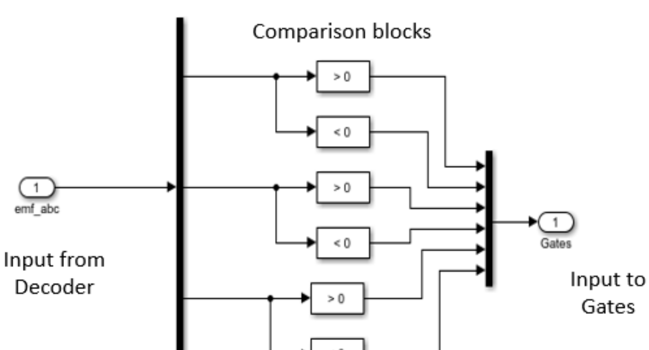

Fig. 10. Comparison logic design for PWM signal selection

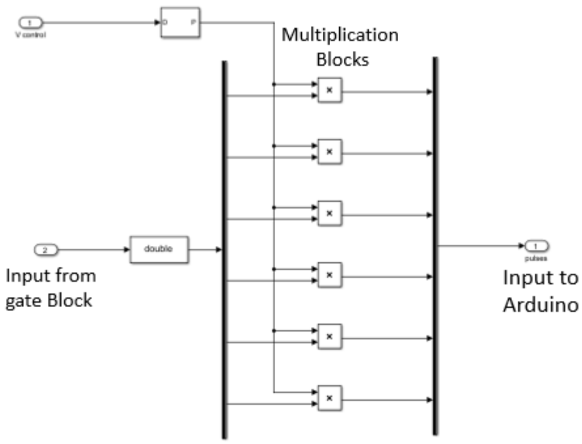

Fig. 11. PWM duty cycle variation.

VI. EXPERIMENTS AND RESULTS

The test setup includes Arduino mega 2560, Brushless DC Motor, Bread board, BLDC drive, DC power supply and oscilloscope. The output signals are verified using Simulink Scope block and the signals from the BLDC drive is verified using oscilloscope. Some of the simulated results are included in this section.

The 3-phase signals are generated in Simulink and tested the phase delay. The desired output signals are verified using scope block is shown in Fig. 12. The direct PWM signals with different phase delay are used to drive the BLDC motor without considering the hall effect-sensor signals. The Simulink model is depicted in the Fig. 3.

To drive the BLDC motor with respect to the hall effect sensor signals, the output of the hall sensors is taken into the Simulink for processing. The Simulink design depicted in the Fig. 4 is used to program Arduino. The three hall effect sensor signals are obtained from the BLDC motor using Arduino is shown in the Fig. 13.

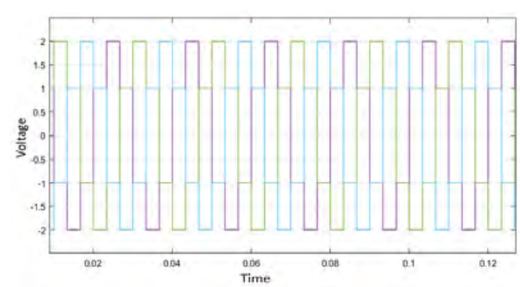

Fig. 12. Three phase signal generation

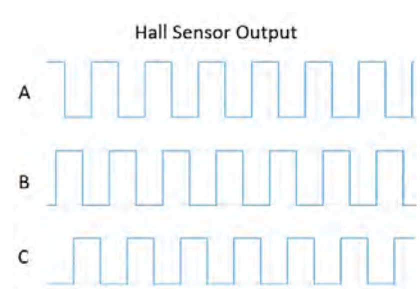

Fig. 13. Hall sensor signals

The number of motor rotations are calculated using two hall sensor signals. Up-counters are used when the motor is rotating in the clockwise direction and down-counters are used in anti-clockwise direction. The number of rotations is shown in the Fig. 14. when the motor is rotationg in forward direction. The respective simulink model to count the rotations is depicted in Fig. 6.

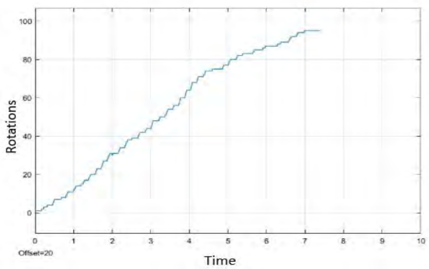

Fig. 14. Rotations of BLDC motor

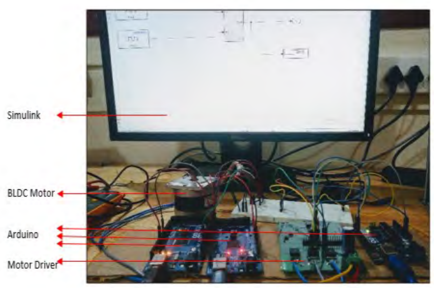

Fig. 15. Hardware test setup

And all above discussed models are integrated into a single simulink model. The final simulink model is programmed into arduino and tested to run and control the speed of the BLDC motor. The final hardware test setup is shown in the Fig. 15.

VII. CONCLUSION

The understanding of various elementary control models of BLDC manipulation is essential for every researcher to commence the research in the field of actuator development. Here, in this research work we successfully implemented and evaluated various control models in very comprehensible manner. In this paper, we have successfully proved that our control models are efficiently working and also validated the control models with appropriate graphs.

VIII. FUTURE WORK

We will extend our research work by developing some advanced manipulations like closed loop, torque and impedance of BLDC motors which can easily understandable by fresh researchers. Based on results obtained, we will manufacture our own control drives for BLDC motors.

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