Modeling and Implementation of Intelligent Commutation System For BLDC Motor in Underwater Robotic Applications

Surendra Singh Patel, B A Botre, Krishan K, Kaushal K, Samarth S and S A Akbar
CSIR-Central Electronics Engineering Research Institute,
Pilani, Rajasthan, India
patelsurendra333@gmail.com

Yogesh Biradar and Prabhu K.R.
School of Electrical Engineering
VIT University
Vellore,Tamil Nadu,India

***Abstract*—Now-a-days, brushless DC (BLDC) motors are becoming very popular in the field of underwater robotic propulsion systems. Since the thrusters which are being used in underwater robotic vehicles has incorporated Brushless DC motors for its propulsion system. Hence, it is very important to precise control of the speed of brushless DC motor for the underwater robotic application. It is difficult to derive the transfer function of BLDC motor because it is 3 phase non linear system. Hence, modeling and simulation of the BLDC motor is developed in Simulink environment and tested using the embedded dsPIC controller and inverter driver. It is very important to give proper sequences of commutation to run BLDC motor smoothly.**

Keywords: BLDC Motor, Underwater Robotics, Hall sensors, Back EMF, dsPIC controller

I. INTRODUCTION

Underwater robotic vehicles are becoming very popular due to their applications in sea surface area exploration and sea border surveillance since these areas are very hazardous for a human being to go and explore. The thrusters coupled with propellers are used to maintain constant heading and proper movement of these underwater vehicles in different planes [2] [3].To obtain the required thrust the Brushless DC motors extensively used due to their high torque, greater efficiency and control. All the heat dissipating circuits are on the stator, cooling is much better than in a conventional motor, so higher specific outputs can be achieved [4]. BLDC motors offer better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation and higher speed ranges [5]. So as to run BLDC motor smoothly a proper sequence of commutation should be given for Hall sensors. Due to their favourable electrical and mechanical properties, BLDC motors are widely used in servo applications such as automotive, medical, instrumentation, submarine, robotics. BLDC motors are inherently electronically controlled and require rotor position information for proper commutation of currents in its stator windings. For speed control of BLDC motor various control techniques have been proposed. [1]

A fuzzy logic based control is developed for speed control of BLDC motor using its mathematical model [1]. A detailed cross sectional view of BLDC motor with Permanent Magnet, windings and Hall Elements [1].

II. MATHEMATICAL MODELING OF BLDC MOTOR

For designing any kind of controller, a mathematical model is needed which comprises all the dynamics of particular system. Hence a transfer function model was derived for Hurst BLDC motor (Model No. DMB0224C10002)[1]. Typically, the mathematical model of a Brushless DC motor is not totally different from the conventional DC motor. The major addition is the phases involved which affect the overall results of the BLDC model. The phase peculiarly affects the resistive and the inductive nature of the BLDC arrangement. For BLDC motor the mechanical and electrical constants are very important modelling parameters. The mechanical time constant of a BLDC motor can be given in equation (1)

$$\tau_m = \sum \frac{RJ}{K_e K_t} = J \frac{\sum R}{K_e K_t} \tag{1}$$

And the electrical time constant,

$$\tau_e = \sum \frac{L}{R} \tag{2}$$

Since, there is a symmetrical arrangement and a three phase, the mechanical and electrical time constant become:

$$\tau_m = \frac{3RJ}{K_e K_t} \quad and \quad \tau_e = \frac{L}{R} \tag{3}$$

Therefore the equation for BLDC can now be written in terms of its respective time constants as:

$$G(s) = \frac{\omega_m}{V_s} = \frac{\frac{1}{K_t}}{\tau_m \tau_e s^2 + \tau_m s + 1} \tag{4}$$

Where

ω_m = Angular Velocity (RPM)
V_s = Supply Voltage
K_t= Torque Constant
τ_m= Mechanical Time
τ_e= Electrical Time

III. MODEL OF BLDC MOTOR

BLDC motor modeling Simulink is similar to three-phase synchronous machine modelling. The BLDC motor is fed to a three-phase voltage source. The peak voltage produced over there should not exceed the maximum voltage of the motor.

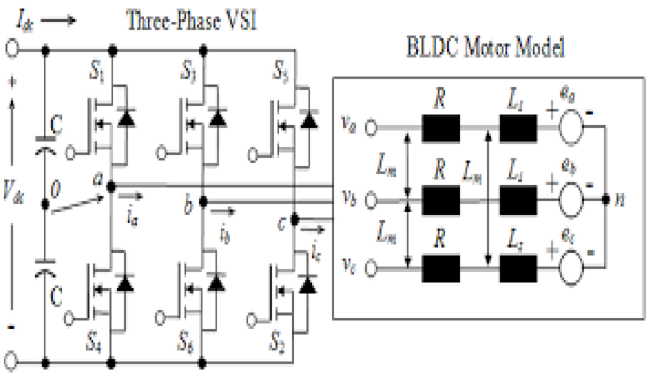

Fig.1: Driver circuit with inverter

The fundamental model of the armature winding for the BLDC motor is defined as [6],

$$V_a = R\, i_a + L\, \frac{di_a}{dt} + e_a \qquad (5)$$

$$V_b = R\, i_b + L\, \frac{di_b}{dt} + e_b \qquad (6)$$

$$V_c = R\, i_c + L\, \frac{di_c}{dt} + e_c \qquad (7)$$

Where, L and R are the armature self-inductance and armature resistance of the stator phase winding respectively Va, Vb, Vc are terminal phase voltage (V), ia, ib, ic are motor input current (A) and ea, eb, ec are trapezoidal motor back emf (V) of respective phases.

The above equations can be written in matrix form as:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_a & L_{ab} & L_{ca} \\ L_{ba} & L_b & L_{bc} \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (8)$$

Considering motor is not saturated and assuming iron loss as negligible, the stator resistances of all the windings are equal, self-inductance are constant and mutual inductance are zero.

$$L_a = L_b = L_c = L = 0$$

$$L_{ba} = L_{bc} = L_{ca} = M = 0$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + R\, \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (9)$$

The trapezoidal Back EMF of no conducting phases is given as:

$$e_a = K_e f(\theta_e)\omega_r \qquad (10)$$

$$e_a = K_e f\left(\theta_e - \frac{2\pi}{3}\right)\omega_r \qquad (11)$$

$$e_a = K_e f\left(\theta_e + \frac{2\pi}{3}\right)\omega_r \qquad (12)$$

The torque Equation is given as:

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_r} \qquad (13)$$

The above equation can be written as:

$$T_e = T_L + J\frac{d\omega}{dt} + B\omega \qquad (14)$$

$$T_e = K_t I \qquad (15)$$

Where

T_L = Load Torque
J= inertia
K_t= Torque Constant
B= Frictional coefficient

He output power is:

$$P = T_e \omega_r \qquad (16)$$

IV. Model of BLDC Motor in Simulink

The actual implementation is done in Matlab/Simulink

Fig.2 shows the overall block diagram of the developed model for BLDC motor drives. As shown in Fig.4 the proposed model consists of four functional blocks: MOSFET block, BLDC motor, gate pulse generator and decoder. In this proposed model is made into several functional modular blocks, so that it can be easily extended to other ac motor applications with a little modification, such as the induction motor, the permanent magnet ac motor, and the synchronous reluctance motor [7]. Fig.3 implies the development of BLDC motor using the mathematical model as derived in equations (5)-(15).This blocks contain look up tables for Hall Effect sensors and back emf. Phase voltage and Phase current waveforms are also checked. The output of Hall Effect sensors are given to the decoder.

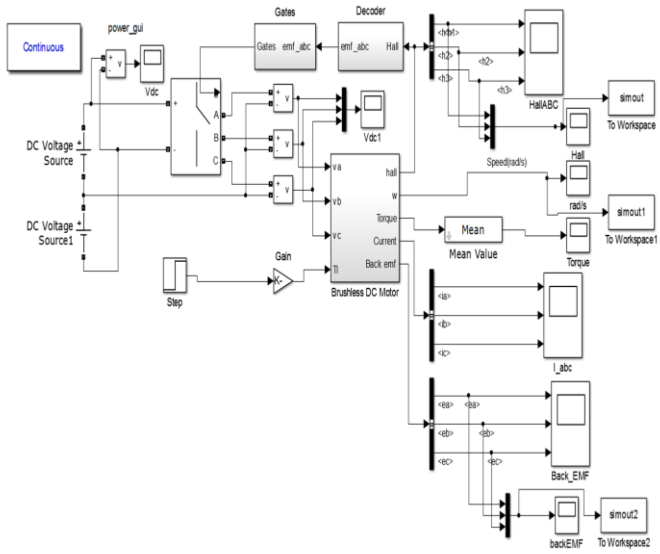

Fig.2: Simulink model of BLDC motor

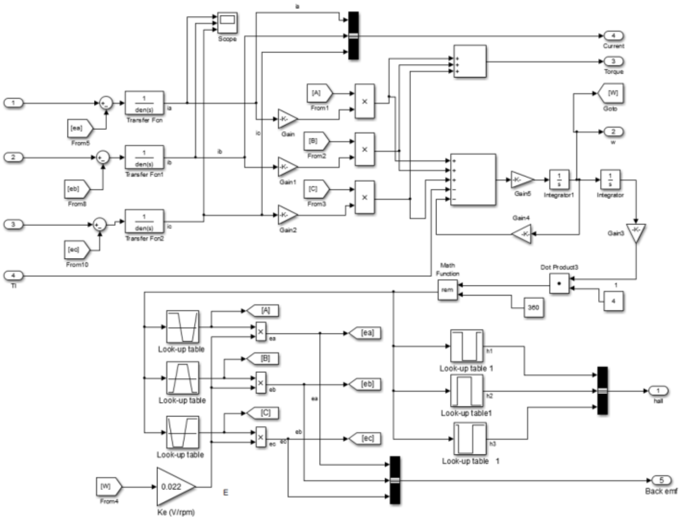

Fig.3: BLDC Motor model

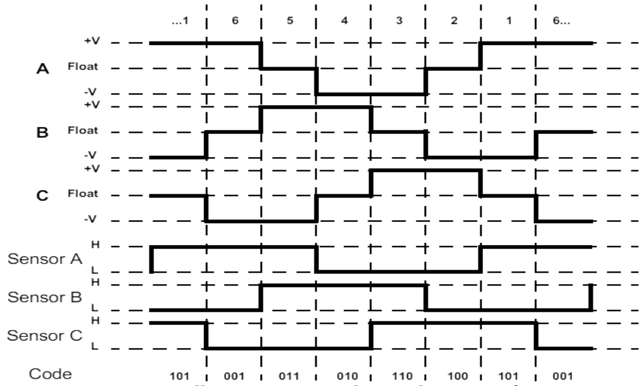

Fig.4: Hall Sensors versus phase voltage waveform

Fig.4 implies the ideal waveform of Hall Effect sensors and its corresponding phase voltages. Codes given below the waveform shows proper sequence of three Hall sensors. By reading the Hall Effect sensors, a 3-bit code can be obtained with values ranging from 1 to 6. Each code value represents a sector on which the rotor is presently located. Each code value, therefore, gives us information on which windings need to be excited. Thus a simple lookup table can be used by the program to determine which two specific windings to excite and, thus, turn the rotor [8].

V. Expereimental setup

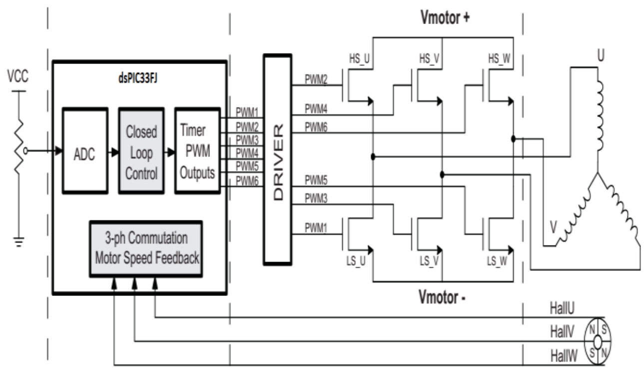

Fig.5: Block diagram of hardware implementation

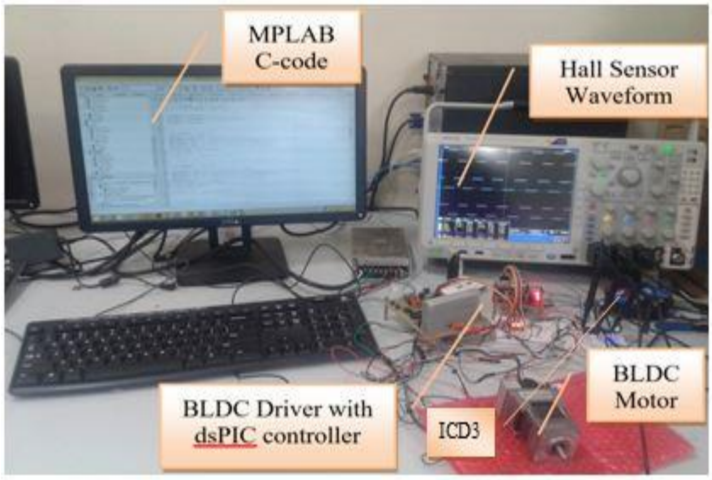

Fig.6: Hardware Setup

The experimental setup to test the commutation sequenece on BLDC motor is as shown Fig.5 and Fig.6. The development platform consists of x16 compiler, MPLAB IDE, ICD3 debugger. The embedded dsPIC33FJ digital signal controller is employed for the testing of the commutation sequence. The hall sensors are interface to the port pins AN0, AN1, AN2.The PWM signal to drive the BLDC motor is generated on pins PWM_1H1, PWM_1H2, PWM_1H3, PWM_1L1, PWM_1L2 and PWM_1L3.The MOSFET based inverter BLDC motor driver circuit is used to drive these PWM signals to the 3 phases of the BLDC motor [9]. The output pulses of PWM generated in dsPIC33FJ is given to driver circuit which has 3 MOSFET driver pairs .The three Hall Effect sensor output of the motor are filtered and connected to capture pins for monitoring a change in level. These inputs are enabled along with their interrupt [10]. The simulated commutations are impleted on to the dsPIC controller and tested. Their results obtained are discussed in continuation.

VI. Results and discussion

The back EMF generated is as shown in Fig.7, which is obtained after running the Simulink model of BLDC motor. The generated waveforms are in Trapezoidal.Fig.8 implies combined waveform pattern of back EMFs. The relation between speed and torque is inversely proportional. Fig.9 demonstrates as speed increases the corresponding torque decreases.Fig.10 indicates the phase voltage waveform for respective hall sensor. The gates pulses generated for the MOSFET drivers are as shown Fig.11. The hall sensor waveform simulated and dsPIC controller implemented is shown in Fig.12 and Fig.13 respectively. Fig.14 shows the PWM generated on the corresponding commutation sequence to drive the BLDC motor's next sequence.

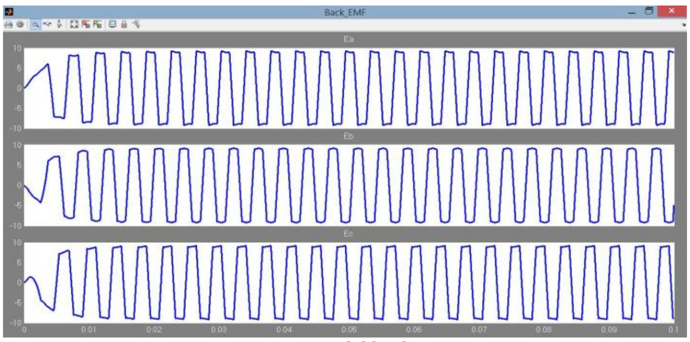

Fig.7: Trapezoidal back EMF

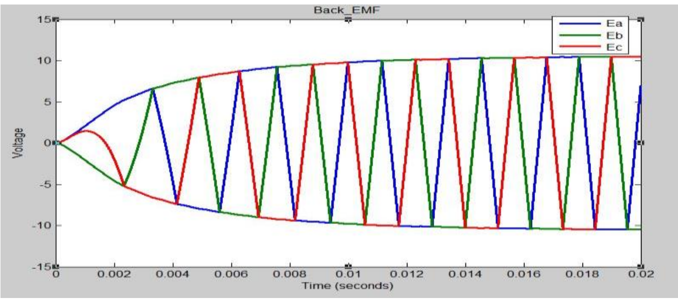

Fig.8: Combined BEMF

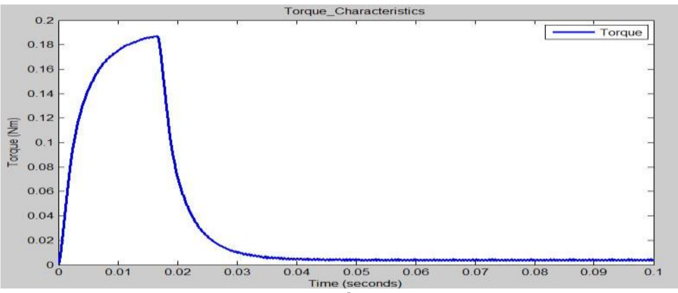

Fig.9: Torque characteristics

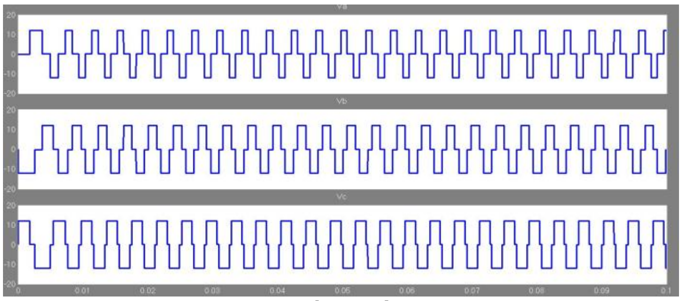
Fig.10: Phase Voltages

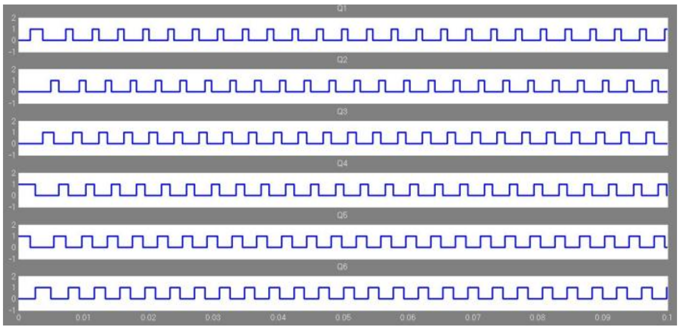
Fig.11: Gate pulses

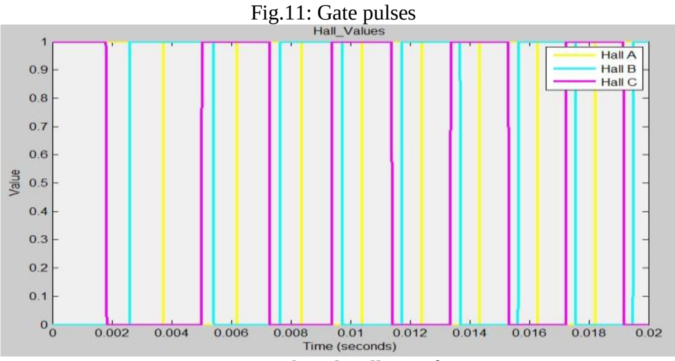

Fig.12: Combined Hall waveforms

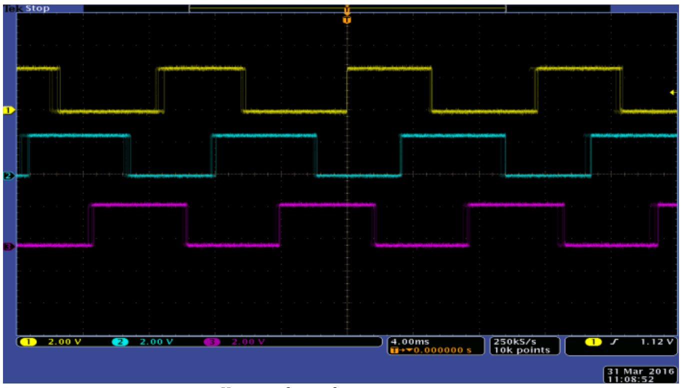

Fig.23: Hall waveform from Hurst BLDC motor

Fig.14: PWM waveforms

VII. CONCLUSIONS

The modeling of the BLDC motor is developed in Matlab/Simulink. The intelligent commutation sequence is simulated and implemented using dsPIC controller for the BLDC motor. The simulated and experimental results are compared and discussed. The model of BLDC motor is used instead of transfer function to obtain the accurate response and implementing the same on the hardware setup.

ACKNOWLEDGMENT

The authors thank Director, CSIR-CEERI, for the guidance and availing the lab facilities. The authors would also like to thanks VIT University, Vellore and team members of ECS lab, CSIR-CEERI for their constant help and support.

REFERENCES

[1]. Yogesh Biradar, Surendra Singh Patel, manish Maharana, Krishan Kumar, BA Botre, SA Akbar, “Simulation and Implementation of PID and Fuzzy Logic Controller for Speed Control of BLDC motor in Underwater Robotics Applications”, Journal of Instrument Society of India, Vol. 46 No. 1, March 2016.

[2]. J.Yuh,“Design and Control of Autonomous Underwater Robots: A Survey”, Autonomous Robots 8, 7-24 (2000) Kluwer Academic Publishers, Netherlands.

[3]. Wael Salah, Dahaman Ishak and Khaleel J. Hammadi,“Development of PM Brushless DC Motor Drive System for Underwater Applications”, Proceedings of 2009 IEEE Student Conference on Research and Development (SCOReD 2009), 16-18 Nov. 2009, UPM Serdang, Malaysia.

[4]. Chang Liang Xia, “Permanent Magnet Brushless DC Motor Drives and Controls”. John Wiley, 2012.

[5]. P.Yedamale, “Brushless DC (BLDC) Motor Fundamentals”. Chandler, AZ: Microchip Technology, Inc.,last access; March 15,2009.

[6]. Somanatham.R, Prasad.P.V.N, Rajkumar.A.D, “Modelling and Simulation of Sensorless Control of PMBLDC Motor Using Zero-Crossing Back EMF Detection” IEEE SPEEDAM 2006

International Symposium on Power Electronics, Drives, Automotive and Motion
[7]. BYOUNG-KUK LEE, MEHRDAD EHSANI "Advanced Simulation Model for Brushless DC Motor Drives" ISSN: 1532-5008 print/1532-5016 online
[8]. Ward Brown, "Brushless DC Motor Control Made Easy", microchip Technology Inc.
[9]. Motor Control PWM, "dsPIC33F/PIC24 Reference Manual",DS7018E.
[10]. Bhargavi Nisarga, Daniel Torres, "Sensored 3-Phase BLDC Motor Control Using MSP430".