International Journal of Advance Engineering and Research Development (IJAERD)
Volume 1,Issue 5,May 2014, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

SPEED CONTROL OF BRUSHLES DC MOTOR

Kajal D. Parsana[1], Prof. H.M. Karkar[2], Prof. I.N. Trivedi[3]

[1]*Department of Electrical Engineering, Atmiya Institute of Technology & Science, Rajkot, India.*
kajal.parsana@gmail.com
[2]*Department of Electrical Engineering, Atmiya Institute of Technology & Science, Rajkot, India.*
hmkarkar@aits.edu.in
[3]*Department of Electrical Engineering, L.E. college Morbi, Rajkot, India*
hmkarkar@aits.edu.in

Abstract— The main goal of today's applications and future applications are high efficiency and low manufacturing cost. Now these goals are achieved by the use of brushless DC motors (BLDC) in a more number of applications. The BLDC motor has various applications used in industries like in drilling, lathes, spinning, electric vehicles, elevators, home appliances where BLDC replace the conventional brushed DC motor. Further, the BLDC motors offer a good control which is very much required for the vehicles and they are suitable for variable speed applications. They can be used where space is less because of its compact size. So in this paper overview of BLDC motor MATLAB simulation of open loop speed control technique and close loop control techniques are represented.

Keywords – BLDC motor, PWM, Inverter, Gate driver circuit, Decoder

I. INTRODUCTION

Since 1980's the new prototype concept of permanent magnet brushless motor has been developed. There are two types of permanent magnet brushless motor depends upon the back EMF waveform, Brushless AC (BLAC) and Brushless DC (BLDC) motors.[1] BLDC motors have trapezoidal back EMF and quasi-rectangular current waveform due to concentrated winding [2]. Now a day's BLDC motor is mostly used in home appliances. BLDC motor has various applications in industries like drilling, lathes, elevators, electric vehicle, aircrafts, automotive, military component, hard disk drive, HVAC system and instrumentation. BLDC motors have compact size and high efficiency. As compared to conventional DC motor and induction motor, BLDC motor offers many advantages like higher speed, no maintenance, lower noise because of brushes and commutator are absent also offers linear speed-torque characteristics, high starting torque and better heat removal [3]. In the residential and commercial applications BLDC motor is used, so the speed control of BLDC motor is very essential. The simple control technique of BLDC motor is open loop technique [4]. As there no brushes are present so commutation of BLDC motor is done by electronic circuit. Inverter can be used as a electronic circuit. Open loop with PWM technique and close loop control technique are simulated in MATLAB/SIMULINK.

II. BRUSHLESS DC MOTOR

Operating principle and model of BLDC motor are described as follows:

A. Operating principle:

BLDC motor having mainly three parts for its construction: stator, rotor, hall sensor. Stator is made up coil placed in a slot to form a winding. Rotor is made up of permanent magnet and can alter from 2-8 pole pairs with alternate N and S poles. As compared to conventional DC motor, in BLDC motor there is no brushes and commutator. So commutation is done by electronically. Thus, in the BLDC motor, the rotor position must be known to energize the phase pair and control the phase voltage. So BLDC motor uses three Hall sensors embedded in the stator for sensing the rotor position. BLDC motor is as shown figure 1.

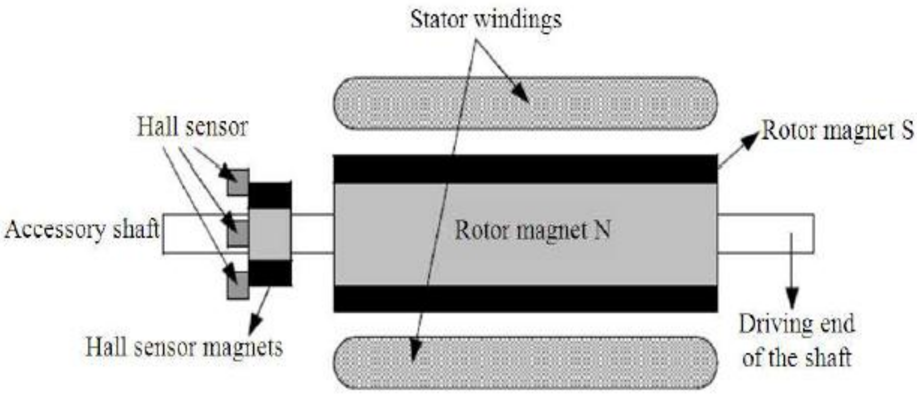

Figure 1 BLDC motor cross section

The principle of BLDC motor is based on synchronising the magnetic field produced by the stator winding and magnetic field by rotor winding. According to rotor position stator winding is switched on and off, so that the magnetic field produced by the stator and rotor will be synchronized. This interaction of magnetic field produces electromagnetic torque [5]. This Torque increases with increase in stator current. These three stator windings are fed from a three phase inverter bridge. Inverter topology is as shown in figure 2. The three phase inverter operation can be divided into six modes (1-6) according to current conduction states and conduction sequence. The switches in are operated such that each phase carries current only during the 120° period when the back EMF is constant. [6] Commutation sequence decides according to the Hall sensor signal. Hall sensor produces high or low signal according to N or S pole passes near the sensor. The three currents are controlled to take a form of quasi square waveform in order to synchronize with the trapezoidal back EMF to produce constant torque.

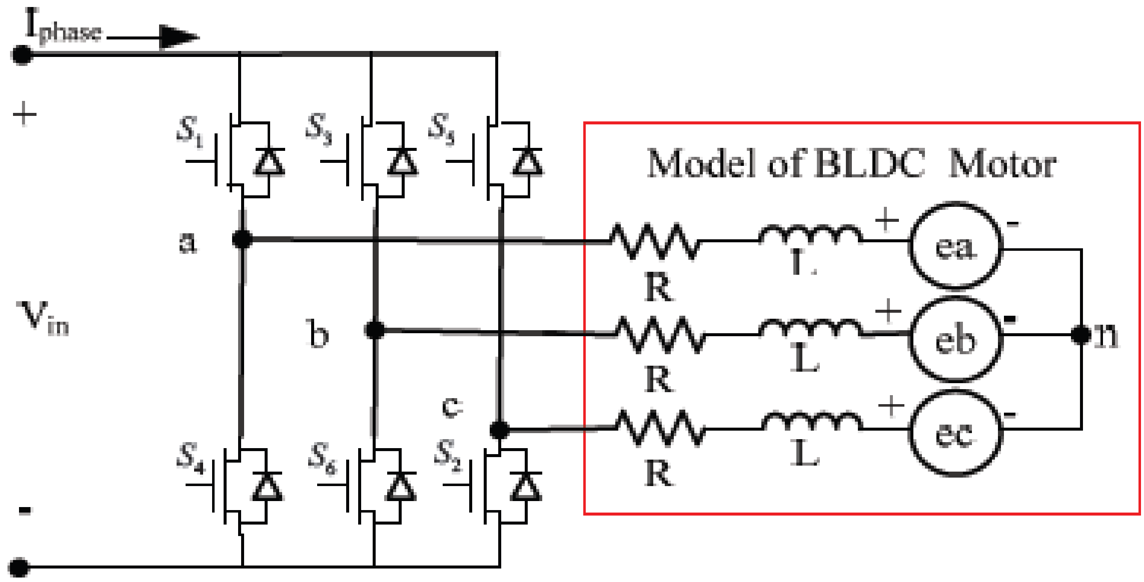

Figure 2 BLDC motor drive systems

The waveforms of Hall sensor output and Back EMF are shown in figure 3.

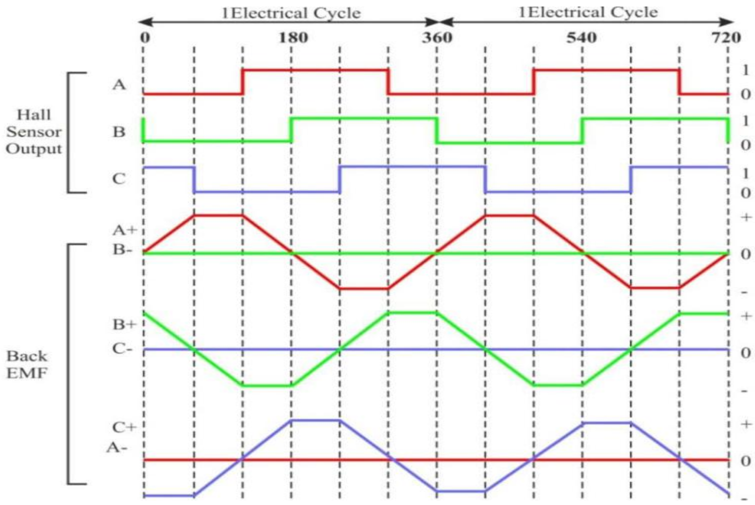

Figure 3 Hall sensor output and Back EMF waveform

B. Modelling:

BLDC motor having a trapezoidal flux distribution, but given non sinusoidal flux distribution, model of BLDC motor in terms of phase variable is derived.[7] The analysis of a BLDC motor is represented the following circuit equations:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

where V_a, V_b, V_c, are the stator phase voltages, R is the stator phase resistance, i_a, i_b, i_c are the stator phase currents, e_a, e_b, e_c are the phase back emf, L is the self inductance of each phase, M is the mutual inductance. So the electromagnetic torque can be expressed as:

$$T_e = (e_a i_a + e_b i_b + e_c i_c)/\omega_r \quad (2)$$

where Te is the electromagnetic torque. The speed equation is given below:

$$\frac{d\omega_r}{dt} = (T_e - T_L - B\omega_r)/J \quad (3)$$

where B is the damping constant, J is the moment of inertia, and T_L is the load torque. The electrical frequency is:

$$\omega_e = \left(\frac{P}{2}\right)\omega_r \quad (4)$$

where P is the number of pole .

C. Control Technique Of BLDC Motor

In resent BLDC motor is widely used in home appliances and commercial application. So speed control of BLDC motor is very essential. Speed control in a BLDC motor involves changing the applied voltage the motor phases. This can be done using a sensored method based on the concept of pulse width modulation.

1. Open loop speed control technique of BLDC motor
2. Close loop speed control technique of BLDC motor

III. OPEN LOOP SPEED CONTROL TECHNIQUE OF BLDC MOTOR

A. Block Diagram of Open Loop Speed Control Method

An interesting property of brushless DC motors is that they will operate synchronously to a certain extent. This means that for a given load, applied voltage, and commutation rate the motor will maintain open loop lock with the commutation rate provided that these three variables do not deviate from the ideal by a significant amount. The ideal is determined by the motor voltage and torque constants. How does this work? Consider that when the commutation rate is too slow for an applied voltage, the BEMF will be too low resulting in more motor current. The motor will react by accelerating to the next phase position then slow down waiting for the next commutation. In the extreme case the motor will snap to each position like a stepper motor until the next commutation occurs. Since the motor is able to accelerate faster than the commutation rate, rates much slower than the ideal can be tolerated without losing lock but at the expense of excessive current.

Now consider what happens when commutation is too fast. When commutation occurs early the BEMF has not reached peak resulting in more motor current and a greater rate of acceleration to the next phase but it will arrive there too late. The motor tries to keep up with the commutation but at the expense of excessive current. If the commutation arrives so early that the motor cannot accelerate fast enough to catch the next commutation, lock is lost and the motor spins down. This happens abruptly not very far from the ideal rate. The abrupt loss of lock looks like a discontinuity in the motor response which makes closed loop control difficult. An alternative to closed loop control is to adjust the commutation rate until self locking open loop control is achieved. This is the method we will use in our application. [8]

When the load on a motor is constant over its operating range then the response curve of motor speed relative to applied voltage is linear. If the supply voltage is well regulated, in addition to a constant torque load, then the motor can be operated open loop over its entire speed range. Consider that with pulse width modulation the effective voltage is linearly proportional to the PWM duty cycle. An open loop controller can be made by linking the PWM duty cycle to a table of motor speed values stored as the time of commutation for each drive phase. The block diagram of open loop speed control of BLDC motor is as shown in figure 4.

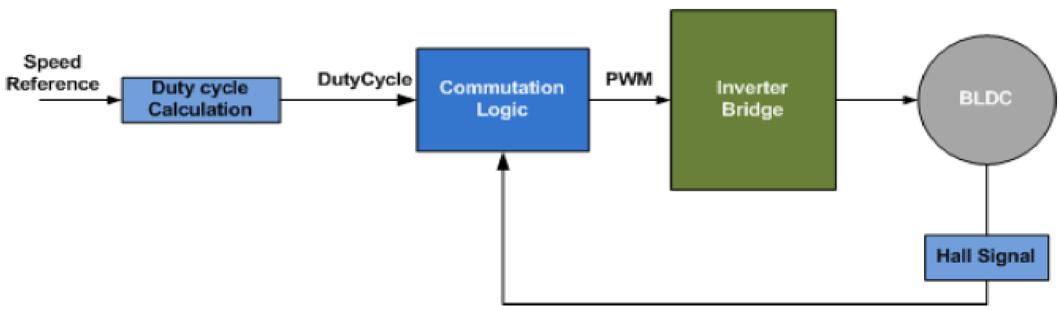

Figure 4 Block diagram of open loop technique

B. Simulation Circuit of Open Loop Speed Control Technique

Simulation circuit is as shown in fig. 5 here 24 V DC voltage is given to Inverter Bridge. This inverter bridge is used to supply the 3 phase stator winding of the BLDC motor. In decoder Hall sensor detects rotor position and according to this rotor position back emf is generated. Gate circuit produces PWM signal which is given to Inverter Bridge. These PWM techniques are used to switch ON and OFF the switches. In order to vary the speed, these signals should be PWM at a much higher frequency than the motor frequency [9]. The PWM frequency should be at least 10 times that of the maximum frequency of the motor. When the duty cycle of PWM is differed within the sequences, the average voltage supplied to the stator reduces, thus lowering the speed. If the DC voltage is much greater than the motor rated voltage, the motor can be controlled by limiting the percentage of PWM duty cycle corresponding to that of the motor rated voltage [5]. So, the commutation sequence of the inverter bridge depends on rotor position. According to this, electromagnetic torque is produced and also rotor speed will be analyzed.

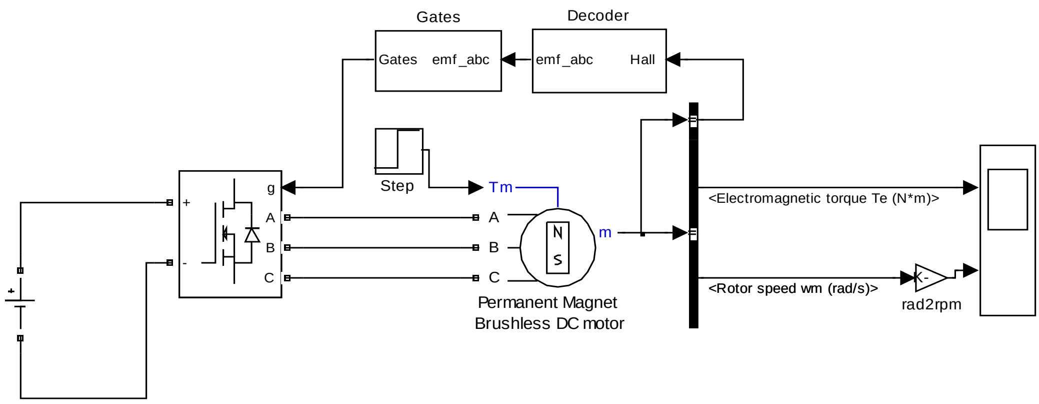

Figure 5 Open loop speed control of BLDC motor simulation circuit

C. Simulation Result of Open Loop Speed Control Technique

Speed and torque waveform when load torque=3 Nm is as shown in figure 6.

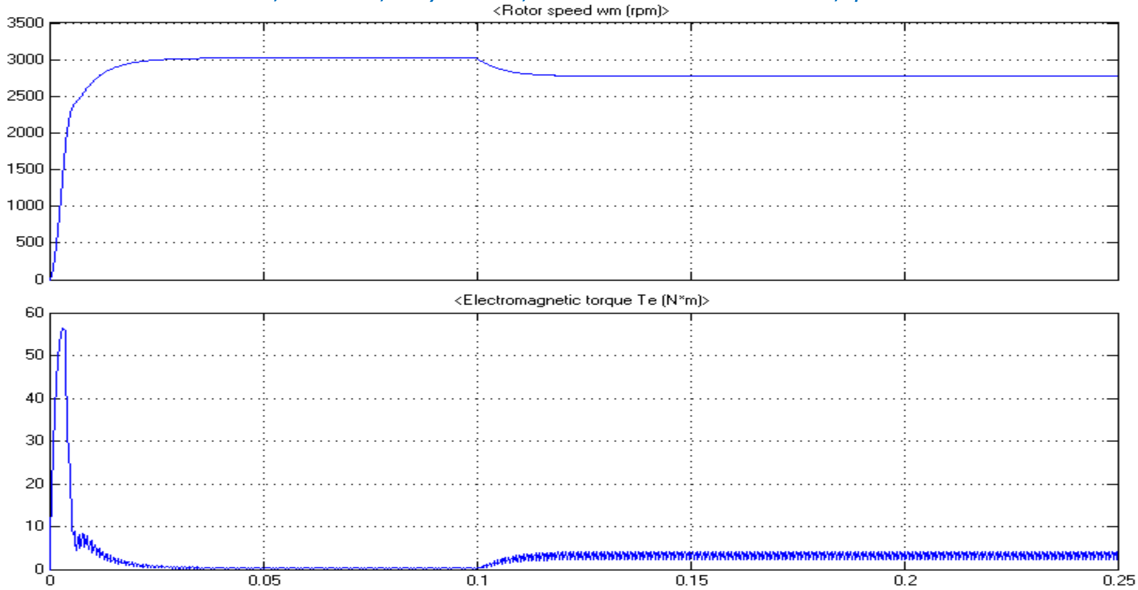

Figure 6 Waveform of rotor speed and electromagnetic torque

TABLE 2
Simulation Result of BLDC Drive

Sr. No.	Load Torque (N.m)	Rotor Speed (RPM)
1	0	3000
2	3	2770
3	5	2615

D. Advantage of open loop technique:

1. It is a simple technique for designing purpose.
2. Feedback path is not required.

E. Disadvantage of open loop technique:

1. In open loop speed control, the duty cycle is directly calculated from the set reference speed.
2. There is no actual speed feedback for control purpose.

So for this problem close loop speed control technique is used.

IV. CLOSE LOOP SPEED CONTROL TECHNIQUE OF BLDC MOTOR

A. Block Diagram of Close Loop Speed Control Technique

Block diagram of Close loop speed control of Permanent Magnet BLDC motor is as shown in below figure 7. Speed of motor is controlled using PI controller. Reference speed and actual speed are compared with each other by feedback loop. This speed error is given to

PI controller and according to this error controller produces duty cycle. Commutation logic generates PWM pulses which are given to Inverter Bridge.[9]

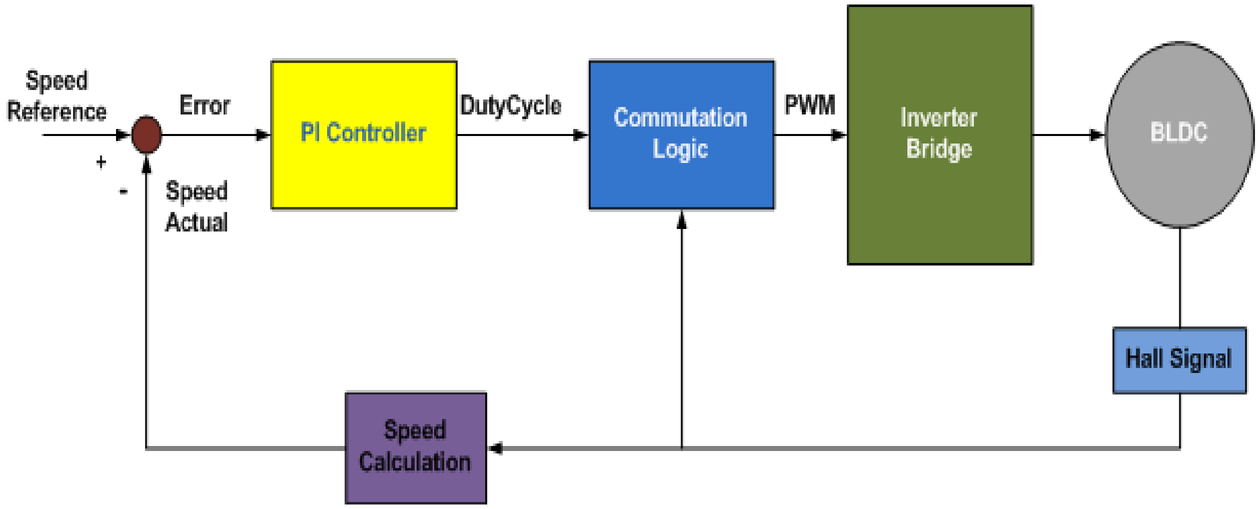

Figure 7 Block Diagram of Close Loop Speed Control technique

B. Simulation Circuit of Close Loop Speed Control Technique

Simulation circuit of Close loop speed control of Permanent Magnet BLDC motor is as shown in below figure 8.

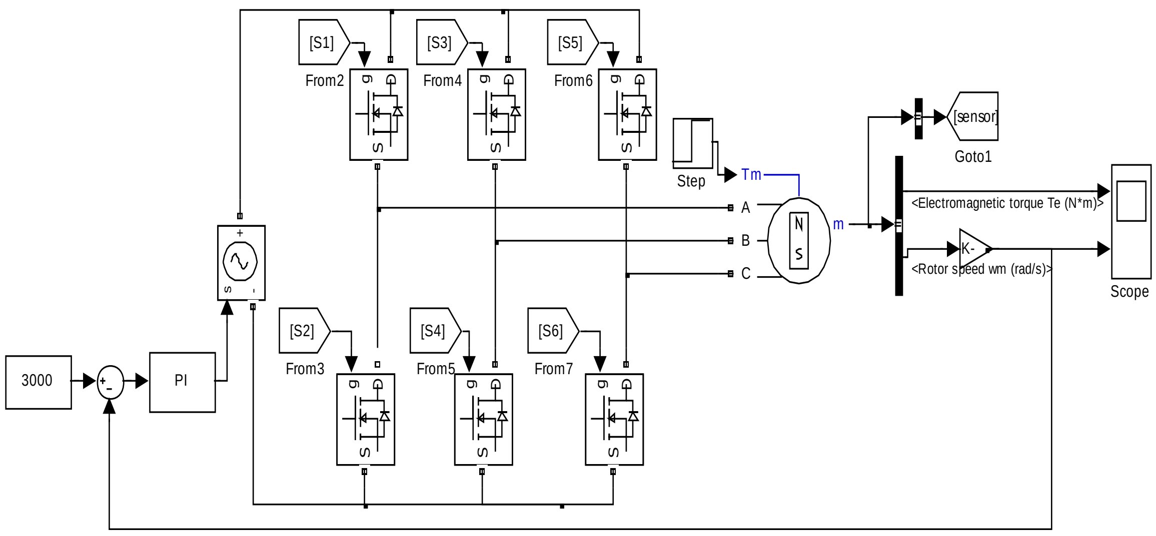

Figure 8 Simulation circuit of close loop speed control technique

Switching sequence is given to switches according to the rotor position. This rotor position is sensed by hall sensors the simulation circuit is as shown in below figure 9.

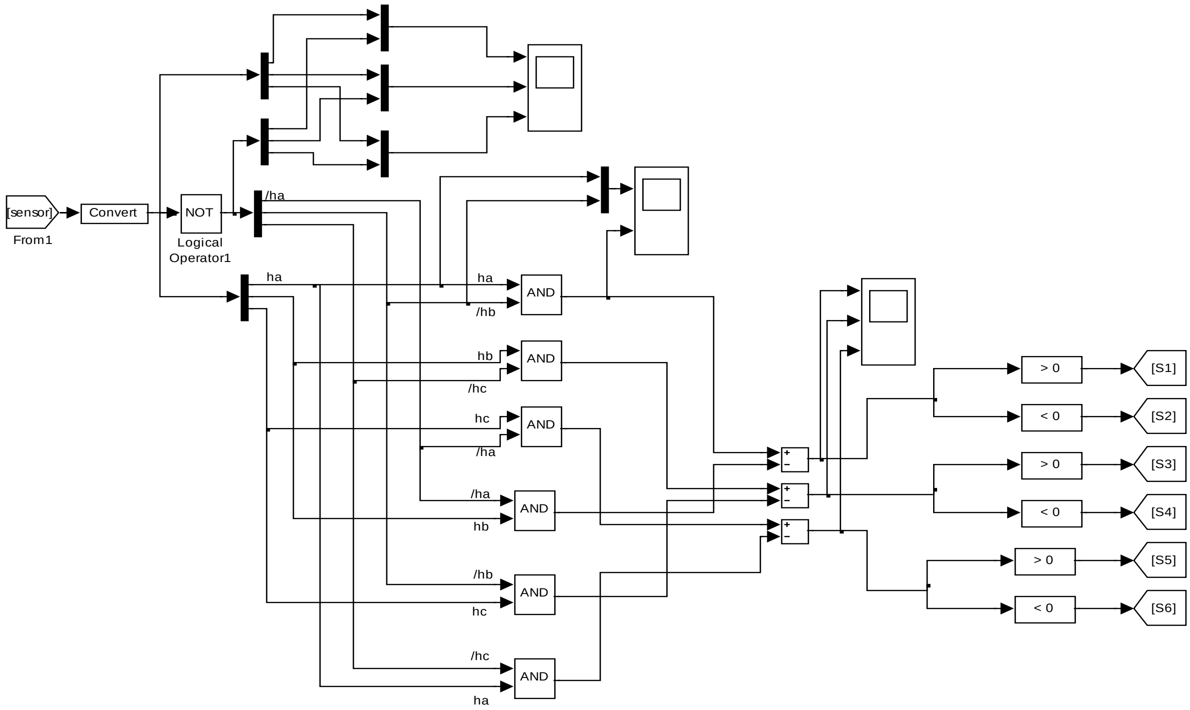

Figure 9 Simulation circuit of close loop speed control technique

Table-3

Switching sequence table:

Emf_a	Emf_b	Emf_c	S1	S2	S3	S4	S5	S6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

C. Simulation Result of Close Loop Speed Control Technique

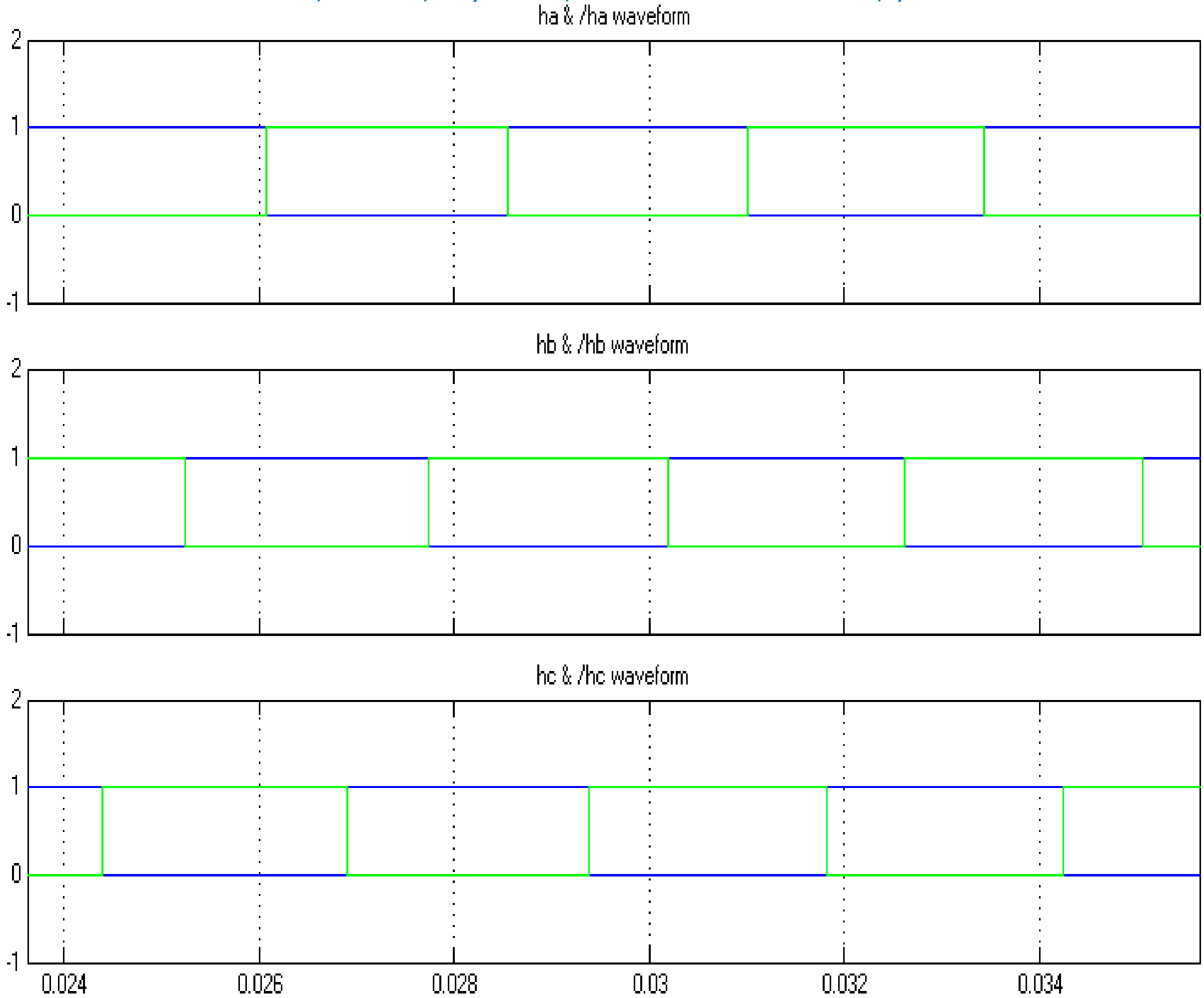

Figure 10 Waveform of Hall Sensor signal ha,hb,hc

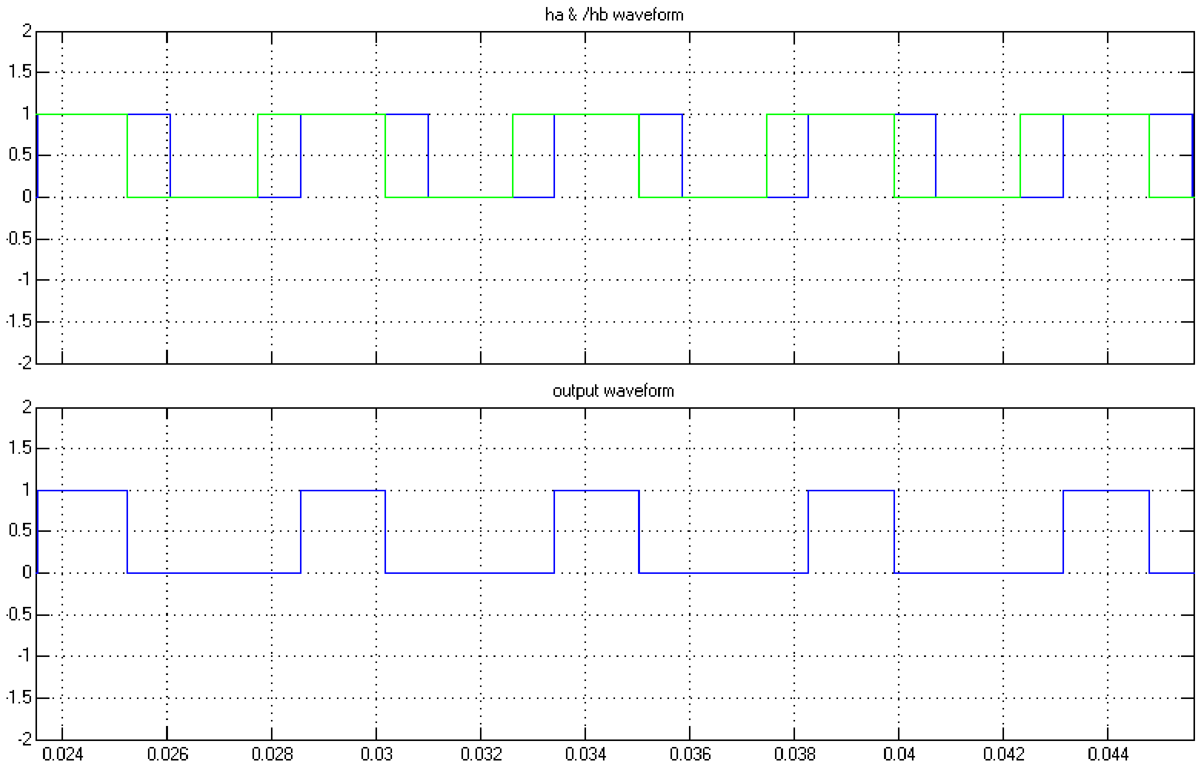

Figure 11 Waveform of Hall Sensor signal ha&/hb

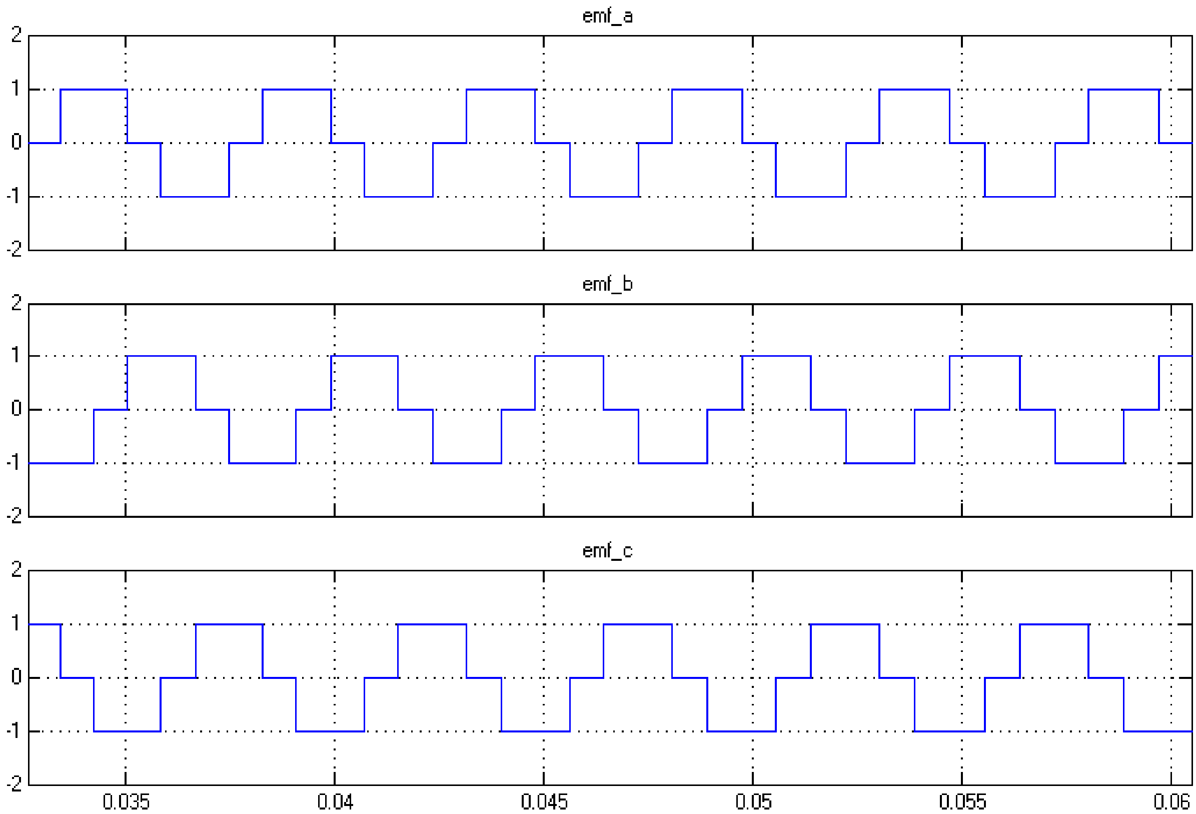

Figure 12 Waveform of emf a, emf_b & emf_c

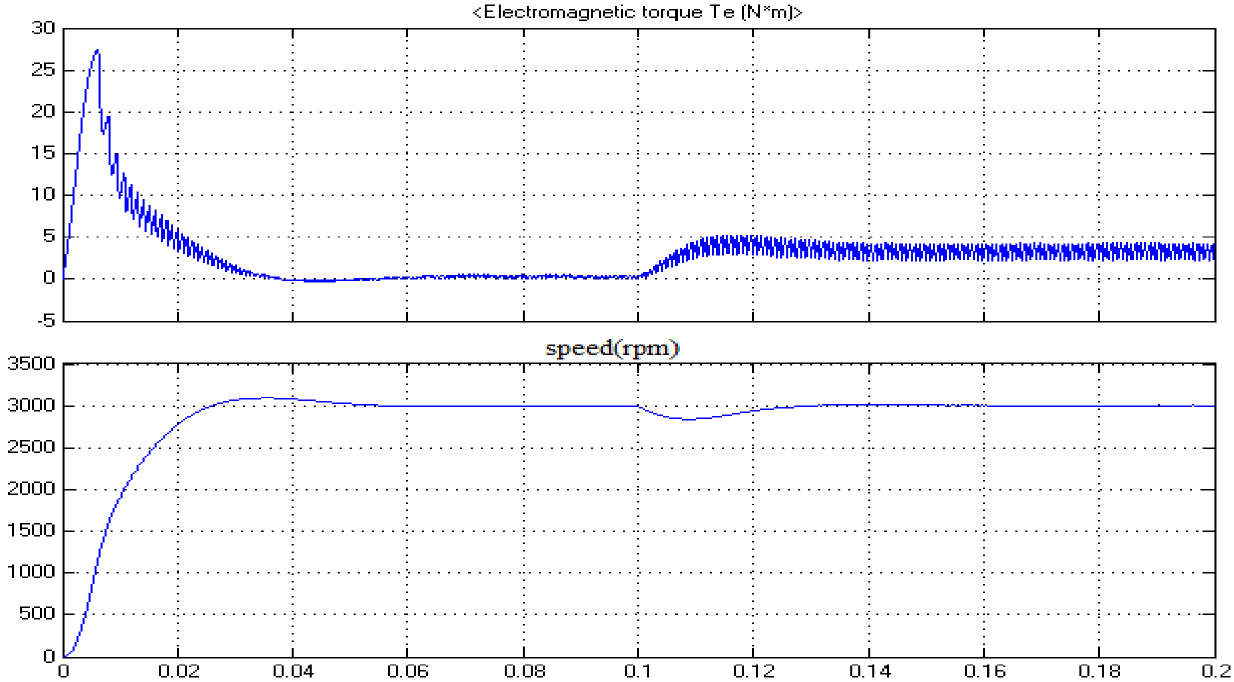

Figure 13 Waveform of torque and rotor speed

V. COMPARISION OF VARIOUS METHODS

Rotor speed of open loop & close loop speed control methods are as shown in below figure. 14. As shown in figure 14 when load torque is applied to motor the open loop speed is redused to certain level but close loop speed is mantained constant not decreases.

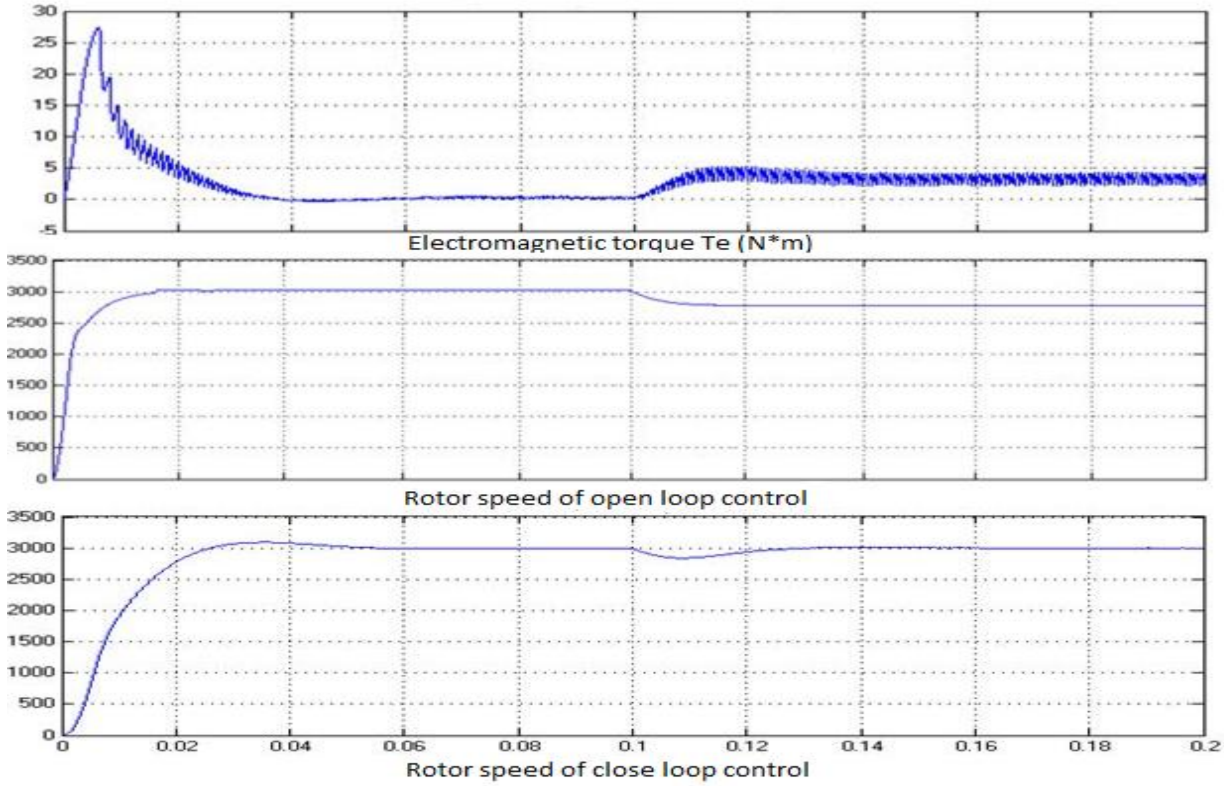

Figure 14 Waveform of rotor speed and torque of open & close loop speed control technique

VI. CONCLUSION

This paper represents the overview of BLDC motor and speed control technique of BLDC motor. Here open loop speed control with PWM duty cycle is simulated. Speed-torque waveform is obtained from this control technique. This PWM duty cycle control technique enable greater efficiency and versatility of the brushless DC motor to provide flexible control and novel cyclic operation. In open loop speed control speed is varied when different load torque is given. Here speed is not maintained constant in open loop method. So, close loop control method is simulated in matlab simulink. Speed is maintained constant in this close loop method with varying the load torque.

Ratings of the BLDC motor as shown in Table-4.

TABLE 4
Ratings of the BLDC Motor

Sr. no	Parameter	Ratings
1	Input voltage	24V
2	Speed	1500Rpm
3	Armature Resistance Ra	0.78Ω
4	Armature Inductance La	0.016H
5	Field Resistance Rf	150Ω
6	Field Inductance Lf	112.5H
7	Rated Speed	1750RPM
8	Rated Field Voltage	150V

REFERENCES

[1] M.V.Ramesh, S.Karmakshaiah and J.Amarnath, "Speed Torque characteristics of the BLDC motor in either direction on load using ARM controller" ISSN vol.2, pp.37-48, 2011.

[2] `G.R.Arab Markdesh, S.I. Mousavi and A. Kargar, "Position Sensorless Direct Torque Control of BLDC Motor" IEEE vol.3, 2008.

[3] Ming-Fa Tsai, Tran Phu Quy and Chun-Shi Tseng, "Model Construction and Verification of a BLDC Motor Using MATLAB/SIMULINK and FPGA Control" IEEE vol.1, pp.1797-18002, 2011.

[4] G.R.P Lakshmi and S. Paramasivam, "DCPIC BASED POWER ASSISTED STEERING USIN BRUSHLESS DIRECT CURRENT MOTOR" ISSN: 1546-9293, pp.1419-1426, 2013.

[5] H.R. Hiziroglu, "On the Brushless DC Motors" ELECO, pp.35-39, 2009.

[6] Alphonsa Roslin Paul, "Brushless DC Motor Control Using Digital PWM Techniques" ICSCCN vol.79, pp. 733-738 (2011).

[7] M.R. Feyzi and M. Ebadpour, "A New Single Current Strategy for High-Performance Brushlees DC Motor Drives" IEEE vol.1, pp.000419, 2011.

[8] Padmraja Yedamale, " BLDC motor fundamentals" Microchip technology.

[9] Vijay Bolloju, "PWM Control Methods Increases Efficiency, Reliability and Extend Battery Lifetime" Bodo;s power systems, August-2007

