IJCTA
Vol.8, No.1, Jan-June 2015, Pp.59-70

Analysis of Speed Control of Brushless Dc Motor

[1]Arshiya Parveen, [2]J . E Muralidhar,
[1] M.E II year,PES , MuffakhamJah College of Engineering and Technology, Hyderabad (Telangana), India
[2]Assoc. Prof, EED, MuffakhamJah College of Engineering and Technology, Hyderabad (Telangana), India.
[1] ayesha290@yahoo.com; [2]muralidhareed@mjcollege.ac.in;

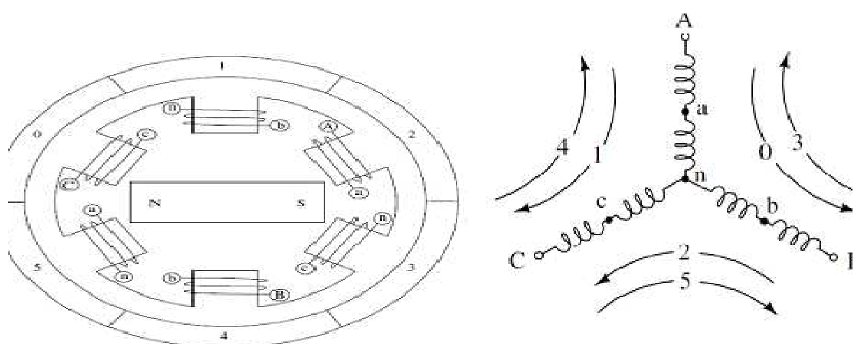
ABSTRACT:
Brushless motors have been gaining attention from various industrial and household appliance manufacturers because of its high efficiency, low maintenance, compact form and reliability. This paper compares two methods of controlling speed of BLDC motor. First method uses a controlled voltage source for controlling speed of BLDC motor. The speed is regulated by PI controller. Second method is a simplified one which is current controlled modulation technique. It is based on generation of quasi square wave current using only one current controller for three phases. The advantages are very simple control scheme, phase currents are kept balanced, and the current is controlled through only one dc component. This paper presents a comparative study on control of six-switch Inverter fed BLDC motor drive with variable speed presented using MATLAB/SIMULINK.
Keywords-Hall position sensors,Permanent Magnet BrushlessDC motor,PI controller,closed loop speed control

1.I NTRODUCTION

As the name implies, BLDC motors do not have brushes for commutation. Instead they are electronically commutated. BLDC motors have many advantages over brushed DC motors and induction motors, like better speed-torque characteristics, high dynamic response, high efficiency, noiseless operation and wide speed ranges .Electronic commutation of stator windings is based on rotor position with respect to the stator winding [1]. A new generation of microcontrollers and advanced electronics has overcome the challenge of implementing required control functions, making the BLDC motor more practical for a wide range of uses [2], [3], [4]. In this method the speed is controlled in a closed loop by measuring the actual speed of the motor. The error in the set speed and actual speed is calculated. A Proportional plus Integral (PI) controller is used to reduce the speed error and dynamically adjust the PWM duty cycle. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be achieved by varying the duty cycle of the PWM signal. For low-cost, low resolution speed requirements, the Hall signals are used to measure the speed feedback. Another method proposes a hysteresis current controlled method which compares the currents to generate pulses of the inverter and PI controller to control speed of the BLDC motor.

2. PRINCIPLE OF OPERATION

A BLDC motor is a permanent magnet synchronous that uses position detectors and an inverter to control the armature currents. The BLDC motor is sometimes referred to as an inside out dc motor because its armature is in the stator and the magnets are on the rotor and its operating characteristics resemble those of a dc motor. Instead of using a mechanical commutator as in the conventional dc motor, the BLDC motor employs electronic commutation which makes it a virtually maintenance free motor [5]. There are two main types of BLDC motors: trapezoidal type and sinusoidal type. In the trapezoidal motor the back-emf induced in the stator windings has a trapezoidal shape and its phases must be supplied with quasi-square wave currents for ripple free operation. The sinusoidal motor on the other hand has a sinusoidally shaped back – emf and requires sinusoidal phase currents for ripple free torque operation [6]. The shape of the back – emf is determined by the shape of rotor magnets and the stator winding distribution. The sinusoidal motor needs high resolution position sensors because the rotor position must be known at every time instant for optimal operation. It also requires more complex software and hardware. The trapezoidal motor is a more attractive alternative for most applications due to simplicity, lower price and higher efficiency. BLDC motors exist in many different configurations but the three phase motor is most common type due to efficiency and low torque ripple. The BLDC motor cross section and phase energizing sequence is shown in figure 1.



(a) **(b)**

Figure 1: BLDC (a) Motor Cross Section (b) Phase Energizing Sequence

Typically, a Brushless dc motor is driven by a three-phase inverter with, what is called, six-step commutation. The conducting interval for each phase is 120° by electrical angle. Fig.1 shows a cross section of a three phase star connected motor along with its phase energizing sequence. Each interval starts with the rotor and stator field lines 120° apart and ends when they are 60° apart. Maximum torque is reached when the field lines are perpendicular. The commutation phase sequence is like AB-AC-BC-BA-CA-CB. Each conducting stage is called one step. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60° so that current is in phase with the back EMF. The commutation timing is determined by the rotor position, which can be detected by Hall sensors as shown in the Fig.2 (H1, H2, and H3). Current commutation is done by inverter as shown in a simplified from in Figure 3. The switches are shown as bipolar junction transistors but IGBT switches are more common. Table I shows the switching sequence, the current direction and the position sensor signals

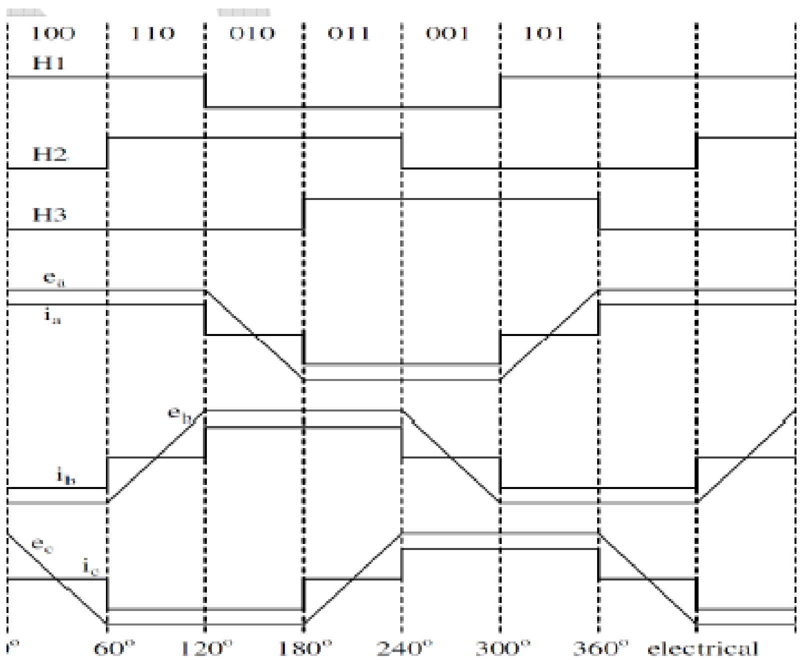


Figure 2: Ideal Back-Emf's, Phase Currents, and Position Sensor Signals

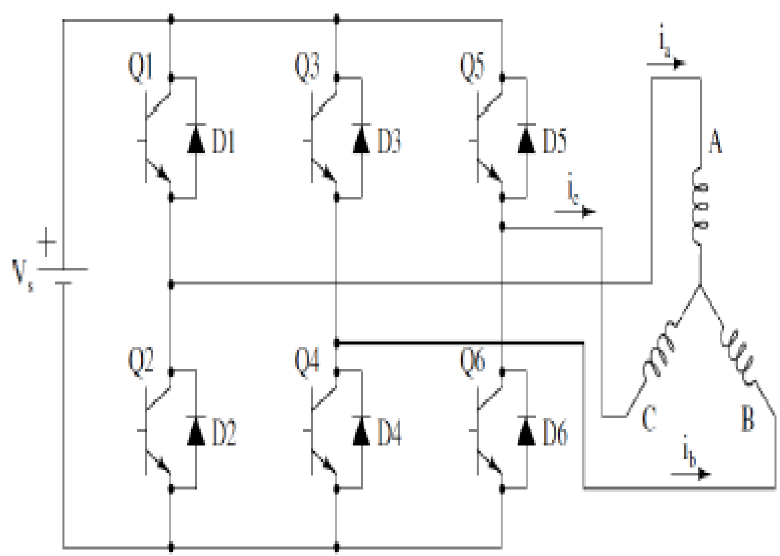


Figure 3: Simplified BLDC Drive Scheme

Switching interval	Seq. number	Pos. sensors			Switch closed		Phase Current		
		H1	H2	H3			A	B	C
0° – 60°	0	1	0	0	Q1	Q4	+	-	off
60° – 120°	1	1	1	0	Q1	Q6	+	off	-
120° – 180°	2	0	1	0	Q3	Q6	off	+	-
180° – 240°	3	0	1	1	Q3	Q2	-	+	off
240° – 300°	4	0	0	1	Q5	Q2	-	off	+
300° – 360°	5	1	0	1	Q5	Q4	off	-	+

Table 1: switching sequence

Implementation of a BLDC motor can be developed in the similar manner as a three phase synchronous machine. Since its rotor is mounted with a permanent magnet, some dynamic characteristics are different. Flux linkage from the rotor is dependent upon the magnet

Therefore, saturation of magnetic flux linkage is typical for this kind of motors. As any typical three phase motors, one structure of the BLDC motor is fed by a three phase voltage source as shown in Figure 3. The source is not necessary to be sinusoidal. Square wave or other wave- shape can be applied as long as the peak voltage is not exceeded the maximum voltage limit of the motor.

2.1. *mathematical model of the pmbldc motor*

The circuit model of PMBLDC motor is shown in figure 4.

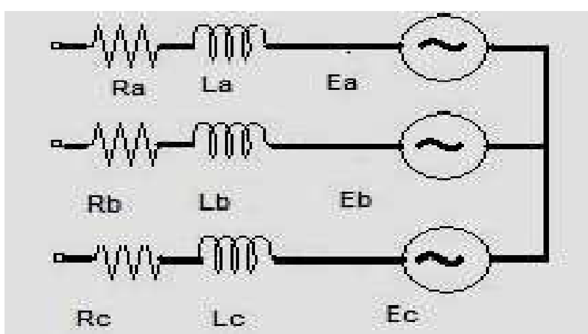


Figure 4: Motor Circuit Model

The voltage equations of the BLDC motor are as follows

$V_a = R_a i_a + d/dt\ (L_{aa} i_a + L_{ab} i_b + L_{ac} i_c) + d\lambda_{ar}(\theta)/dt$

$V_b = R_b i_b + d/dt\ (L_{ba} i_a + L_{bb} i_b + L_{bc} i_c) + d\lambda_{br}(\theta)/dt$

$V_c = R_c i_c + d/dt\ (L_{ca} i_a + L_{cb} i_b + L_{cc} i_c) + d\lambda_{cr}(\theta)/dt$

In the balanced system the voltage equation becomes

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + d/dt \begin{bmatrix} La & Lba & Lca \\ Lba & Lb & Lcb \\ Lba & Lcb & Lc \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad \text{-----------} \quad eq1$$

The mathematical model for this motor is described in Equation (1) with the assumption that the magnet has high sensitivity and rotor induced currents can be neglected [3]. It is also assumed that the stator resistances of all the windings are equal. Therefore the rotor reluctance does not change with angle. Now

$L_a = L_b = L_c = L$

$L_{ab} = L_{bc} = L_{ca} = M$

Assuming constant self and mutual inductance, the voltage equation be comes

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + d/dt \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad \text{----------} \quad eq\ 2$$

In state space form the equation is arranged as

$$d/dt \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = -R/L \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} -1/L \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} + 1/L \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

The electromagnetic torque is given as $T_e = (e_a i_a + e_b i_b + e_c i_c)\ /\omega_r$

The equation of motion is given as $d\omega_r/dt= (T_e - T_l - B\omega_r)/\ J$

3. BLDC MOTOR SPEED CONTROL

3.A.Controlled voltage source method:

In servo applications position feedback is used in the position feedback loop. Velocity feedback can be derived from the position data. This eliminates a separate velocity transducer for the speed control loop. A BLDC motor is driven by voltage strokes coupled by rotor position. The rotor position is measured using Hall sensors. By varying the voltage across the motor, we can control the speed of the motor. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be obtained by varying the duty cycle of the PWM signal. The speed and torque of the motor depend on the strength of the magnetic field generated by the energized windings of the motor, which depend on the current through them. Hence adjusting the rotor voltage and current will change motor speed.

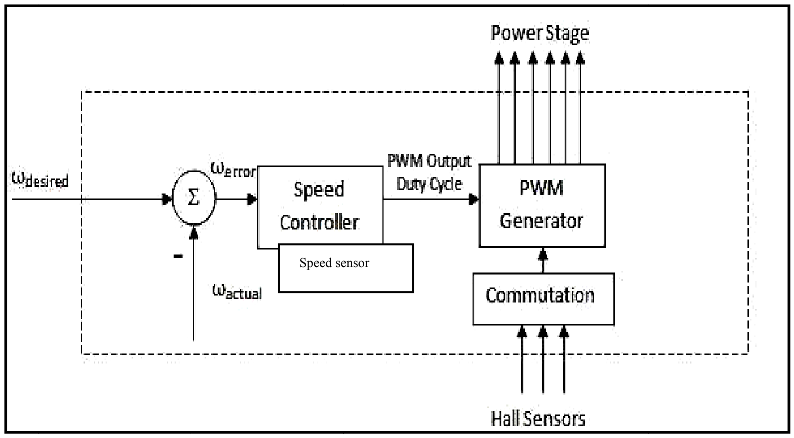


Figure 5: Schematic of a Speed Controller

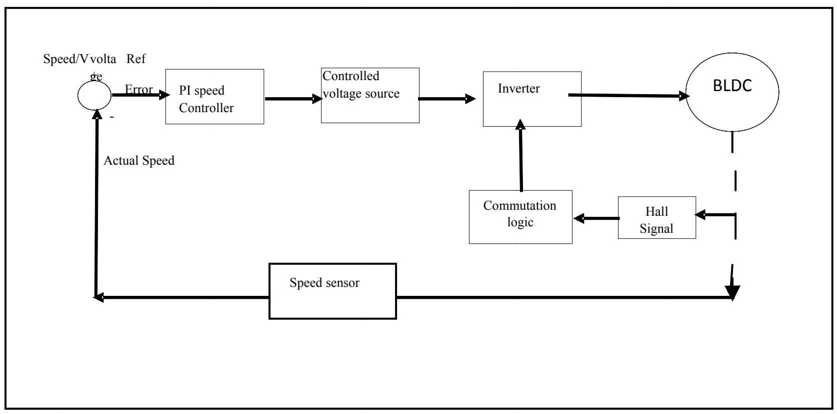


Figure 6: Closed Loop Speed Control

Figure 6 shows the closed loop speed control. The required speed is controlled by a speed controller. This is implemented as a conventional proportional-Integral controller. The difference between the actual and required speeds is given as input to the controller. Based on this data PI controller controls the duty cycle of the PWM pulses which correspond to the voltage amplitude required to maintain the desired speed. Variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal.

3.B. Hysteresis Current Modulation technique:

The BLDC motor is fed by a three phase IGBT based inverter. The PWM gating signals for firing the power semiconductor devices in the inverter is injected from a hysteresis current controller which is required to maintain the current constant within the 60° interval of one electrical revolution of the rotor. Figure 7 shows how controller regulates the actual current within the hysteresis band around the reference currents [5][6]. The reference currents are generated by a reference current generator depending upon the steady state operation mode. The reference currents are of quasi –square wave. They are developed in phase with the back-emf in motoring mode and out of phase in braking mode. The magnitude of the reference current is calculated from the reference torque [7]. The reference torque is obtained by limiting the output of the PI controller. The PI controller processes on the speed error signal (i.e. the difference between the reference speed and actual speed) and outputs to the limiter to produce the reference torque. The actual speed is sensed back to the speed controller and processed on to minimize the error in tracking the reference speed [8]. Thus, it is a closed loop control drive system.

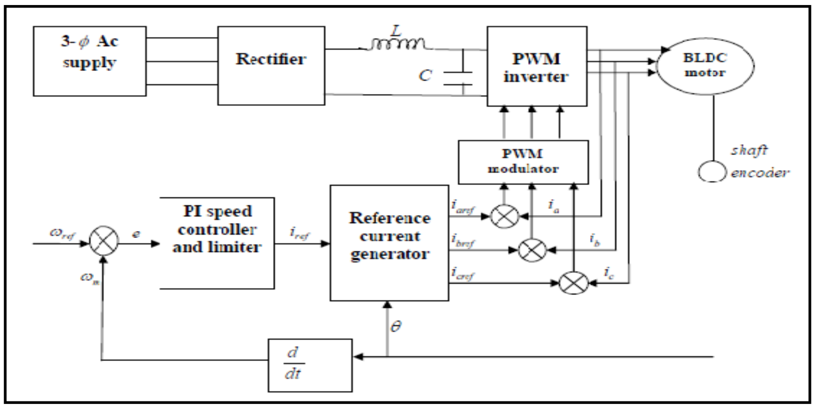


Figure 7: Block diagram for closed loop control of bldc motor

4. MATLAB MODEL OF CLOSED LOOP CONTROL OF BLDC MOTOR

4.A. Controlled voltage source method

Schematic diagram of a three level voltage source inverter fed PMBLDC motor is shown in Figure 8.This is a closed loop control circuit using 3 Hall Sensors. IGBTs are used as switching devices. To control the speed of the motor the output frequency of the inverter is varied. To maintain the flux constant the applied voltage is varied in linear proportion to the frequency. The MATLAB simulation is carried out and the results are presented. A precise speed control of PMBLDC motor is complex due to nonlinear coupling between winding currents and rotor speed. Also the nonlinearity present in the developed torque due to magnetic saturation of the rotor alleviates this problem. For very slow, medium, fast and accurate speed response, quick recovery of the set speed is important keeping insensitiveness to the parameter variations. In order to achieve high performance, many conventional control schemes are employed. At present the conventional PI controller handles these control issues. Moreover conventional PI controller is very sensitive to step change of command speed, parameter variation and load disturbances. With higher frequency switching, the PMBLDC motor rotates at a higher speed. But without the strong magnetic field at stator, the rotor fails to catch up the switching frequency because of weak pull force. Speed of BLDC motor is indirectly determined by the applied voltage.

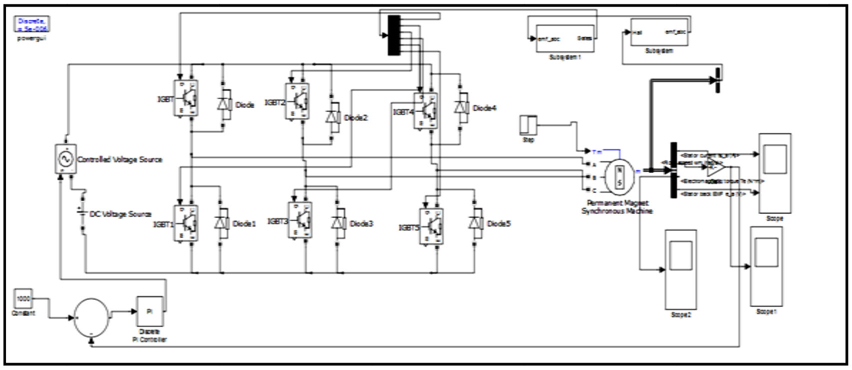


Figure 8: Closed Loop Speed Control of PMBLDC Motor

Magnitude Current in the winding is increased by increasing the voltage. This produces stronger magnetic pull to align the rotor's magnetic field faster with the induced stator magnetic field. The rotational speed or the alignment is proportional to the voltage applied to the terminals.

4.B. Hysteresis current modulation technique

Figure 9 Shows the Matlab model for closed loop control of Brushless DC motor. Where, current controller is used in the feedback loop. Closed loop control is done using PI controller speed control and current control technique was implemented. Where the speed error is generated and given to PI controller, output of this controller was taken as torque reference which is multiplied with back EMF in order to get the current reference, and this is compared with each phase current of the motor, which gives the error, this error is used to generate the switching pulses for the 3-phase inverter to control the inverter output voltage in turn to control the speed of the BLDC motor.

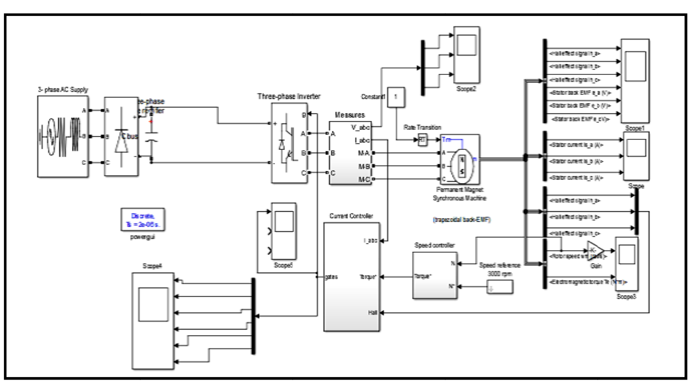


Figure 9: Closed loop control of BLDC motor.

4. b.1. pi speed control of bldc motor:

Figure 9 describes the basic building blocks of the PMBLDCM drive. The drive consists of speed controller, reference current generator, PWM current controller, position sensor, the motor and IGBT based current Controlled voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in proportional- integral (PI) speed controller ωm (t) is compared with reference speedω_{ref}. And the resulting error is estimated at the nth sampling instant as; the output of this controller is considered as the reference torque. A limit is put on the speed controller output depending on permissible maximum winding currents. The reference current generator block generates the three phase reference currentsi_a,i_b, i_c using the limited peak current magnitude decided by the controller and the position sensor.

4. b.2. speed controller:

In figure 9 the speed controller block actual speed is in radian per second hence is converted to radian by gain multiplier of 2*□/60 and filtered by low pass filter to block high signals. The set speed reference is given to the ramp for smooth starting of motor. After this both actual speed and reference speed is compared by the summing block, which generates the speed error. Then this speed error is given to the PI controller in turn to generate the torque reference, this torque reference is used in speed controller block.

4. b.3. current controller:

In figure 9 the current controller block hall effect signals is given to the decoder block, which decodes the hall signals and produces the back EMF in the form of discrete values that is plus one and minus one which is multiplied with the torque reference to get the current reference value this current reference value and actual sensed currents are compared.

5. RESULTS OF CLOSED LOOP CONTROL

This chapter comprises of output waveforms of the Speed, torque, backemf of closed loop control of Brushless DC motor

5. A. Controlled voltage source method.

The BLDC motor is simulated and presented under variable speeds and the motor speed output waveform are observed in fig 10 at 0.4 sec it is settled at 600rpm, at 2 sec it is settled at 800rpm and the stator current, torque and backemf are also observed. We can see the initial torques is high. And also the speed is fluctuating not a perfect constant.

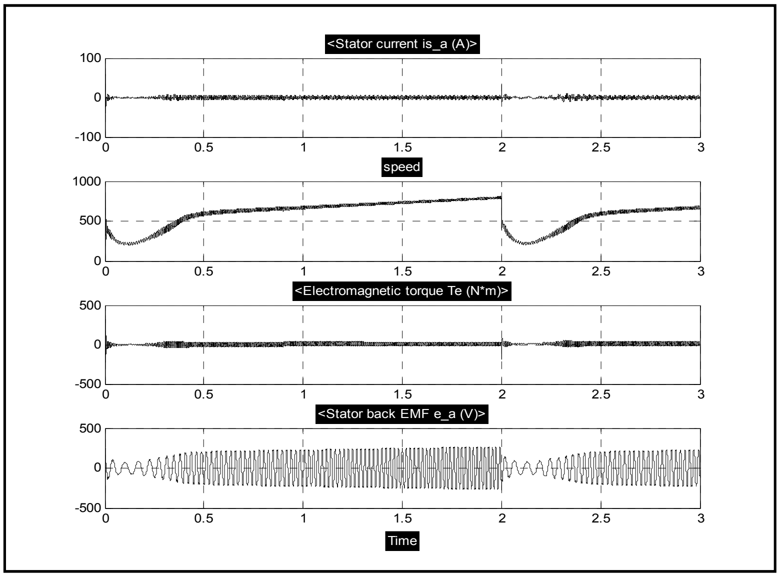


Figure 10: Parameters of BLDC motor

5.B. Hysteresis current modulation technique

The BLDC motor is simulated and presented under variable speeds and the motor speed output waveform are observed in fig 11 at 0.4 sec it is settled at 600rpm, at 2 sec it is settled at 800rpm and the stator current, torque and backemf are also observed. Initial torque ripples are very less and speed is not fluctuating as errors are reduced.

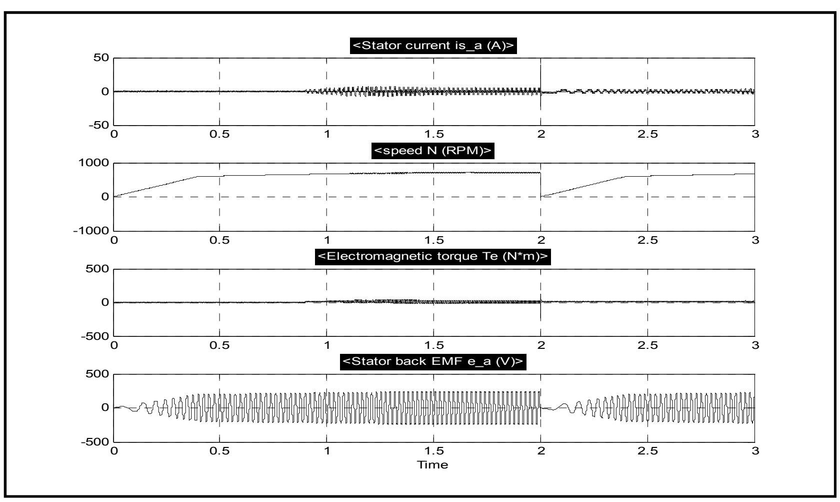


Figure 11: Parameters of BLDC motor

6. CONCLUSION

Both the methods are analyzed and simulated. The simulation models of the BLDC motors drive system with PI control based six switch three phase inverter on MATLAB/Simulink platform are presented. The performance of the developed methods based speed controller of the drive has revealed that the methods devise the behavior of the PMBLDC motor drive systems work satisfactorily. As it is observed in controlled voltage source method the initial torques ripples are high and in hysteresis current modulation technique we have very low initial torques and even settled at very low value. And also speed does not fluctuate in hysteresis current modulation technique. Thus we can conclude hysteresis current modulation technique works better when compared with controlled voltage source method.

REFERENCES

[1] T.J.Sokira and W.Jaffe,: Brushless DC motors: Electronic Commutation and Control, Tab Books, USA, 1989

[2] Tay Siang Hui, K.P. Basu and V.Subbiah Permanent Magnet Brushless Motor Control Techniques, National Power and Energy Conference (PECon) 2003 Proceedings, Bangi,Malysia

[3] Nicola Bianchi,Silverio Bolognani,Ji-Hoon Jang, Seung-Ki Sul," Comparison of PM Motor structures and sensorless Control Techniques for zero-speed Rotor position detection" IEEE transactions on power Electronics, Vol 22, No.6, Nov 2006.

[4] P.Thirusakthimurugan, P.Dananjayan,'A New Control Scheme for The Speed Control of PMBLDC Motor Drive' 1-4244-0342-1/06/ ©2006 IEEE

[5] R.Krishnan, "Electric Motor Drives Modeling, Analysis,and Control, Prentice-Hall Internationa Inc., New Jersey, 2001

[6] J.EMuralidhar and Dr. P.Varanasi "Torque Ripple Minimization & Closed Loop Speed Control of BLDC Motor with Hysteresis Current Controller" SecondInternational Conference on Devices,Circuits and Systems (ICDCS'14) , March-2014 , pp.121-127

[7] B. K. Bose , Modern Power Electronics And Drives , Prentice Hall PTR, 2002

[8] P. S. Bimbhra ,Power Electronics , Khanna Publishers ,5th edition 2012.

[9] Hemchand Immaneni "Mathematical Modelling And Position Control Of Brushless DC (BLDC) Motor" International Journal of Engineering Research and Applications Vol. 3, Issue 3, May-Jun 2013, pp.1050-1057

[10] Keliang Zhou and Danwei Wang "Relationship Between Space-Vector Modulationand Three-Phase Carrier-Based PWM:A Comprehensive Analysis" IEEE Transactions on Indutrial Electronics, VOL. 49, NO. 1, February 2002.

[11] R. Civilian and D. Stupak. 1995. Disk drive employing multi-mode spindle drive system. US patent 5471353, Oct 3.

[12] G.H. Jang and M.G. Kim. 2005. A Bipolar-Starting Spindle Motor at High Speed with Large Starting Torque. IEEE Transactions on Magnetics. 41(2): 750- 755, Feb.

[13] E. Grochowski and R.F. Hyot. 1996. Future trends in hard disk drives. IEEE Tran. On Magnetics. 32(3): 1850-1854, May.

[14] J.D. Ede, Z.Q. Zhu and D. Howe. 2001. Optimal split ratio control for high speed permanent magnet brushless DC motors. In: Proceeding of 5th International Conference on Electrical Machines and Sytems. 2: 909-912.