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Modeling and Simulation of Brushless DC Motor Using PWM Control Technique

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ABSTRACT

This paper describes a simpler way to control the speed of PMBLDC motor using pwm control method. The performance of the PMBLDC system is simulated. The speed is regulated by PI controller. Simulink is utilized with MATLAB to get a reliable and flexible simulation. In order to highlight the effectiveness of the speed control method used. The method proposed suppresses torque oscillations. This drive has high accuracy, robust operation from near zero to high speed.

KEYWORDS: Hall position sensors, permanent magnet brushless DC motor, pwm, PI controller.

INTRODUCTION

Latest advance in permanent magnet materials, solid state devices and microelectronic have resulted in new energy efficient drives using permanent magnet brushless DC motors (PMBLDCM). Brushless DC motors are very popular in a wide array of applications in industries such as appliances, automotive, aerospace, consumer, medical, industrial automation for its reliability, high efficiency, high power density, low maintenance requirements, lower weight and low cost. As the name implies, BLDC motor do not have brushes for commutation. Instead they are electronically commutated. BLDC motor have many advantages over brushed DC motor and induction motors, like better speed- torque characteristics, high dynamic response, high efficiency, noiseless operation and wide speed ranges. Torque to weight ratio is higher enabling it to be used in applications where space and weight are critical factor [1]. A BLDC motor finds numerous applications in motion control. A BLDC motor has windings on stator and alternate permanent magnets on rotor. 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 amplify 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 got 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.

2. TYPES OF CONTROL TECHHIQUE OF PMBLDC MOTOR

Though various control techniques are discussed in [5] basically two methods are available for controlling PMBLDC motor. They are sensor control and sensor less control. To control the machine using sensors, the present position of the rotor is required to determine the next commutation interval. Motor can also be controlled by controlling the DC bus rail voltage or by PWM method. Some designs utilize both to provide high torque at high load and high efficiency at low load. Such hybrid design also allows the control of harmonic current [6]. In case of common DC motors, the brushes automatically come into contact with the commutatorof a different coil causing the motor to continue its rotation. But in case of BLDC motors the commutation is done by electronic switches which need the rotor position. The appropriate stator windings have to be energized when rotor poles align with the stator winding. The BLDC motor can also be driven with predefined commutation interval. But to achieve precise speed control and maximum generated torque, brushless commutation should be done with the knowledge of rotor position. In control methods using sensors, mechanical position sensors,such as a hall sensor, shaft encoder or resolver have been utilized in order to provide rotor position information. Hall Position sensors or simply Hall sensors are widely used and are popular. Three phase windings use one Hall Sensors each. They provide three overlapping signals giving a 60° wide position range. Whenever the magnetic poles pass near the sensors, they either give a high or low signal, indicating North or South Pole is passing the pole. The accurate rotor position information is used to generate precise firing commands for powerconverter. This ensures drive stability and fast dynamic response. The speed feedback is derived from the position sensor output signals.Between the two commutations signals the anglevariation is constant as the Hall Effect Sensors are fixed relative to the motor, thus reducing speed sensing to a simple division. Usually speed and position of a permanent magnet brushless direct current motor rotor is controlled in a conventional cascade structure. The inner current control loops runs at a larger width than the outer speed loop to achieve an effective cascade control [7]. Various senseless methods for BLDC motors are analyzed in [8-18.Modeling of BLDC is given in [3].[8] Proposes a speed control of brushless driveemploying PWM technique using digital signalprocessor. A PSO based optimization of PIDcontroller for a linear BLDC motor is given in [9-10],Speed Control of BLDC based on CMAC & PIDcontroller is explained in [11]. Direct torque controland indirect flux control of BLDC motor with non-sinusoidal back emf method controls the torquedirectly and stator flux amplitude indirectly using daxiscurrent to achieve a low-frequency torque ripple freecontrol with maximum efficiency[12-13]. Directback EMF detection method for sensorless control isgiven in [14]. [15] Proposes a novel architectureusing a FPGA-based system. Fixed gain PI speedcontroller has the limitations of being suitable for alimited operating range around the operating pointand having overshoot. To eliminate this problem afuzzy based gain scheduled PI speed controller isproposed in [16].A new module structure of PLLspeed controller is proposed by [17].A fixed structurecontroller (PI or PID) using time constrained outputfeedback is given in [18]. The above literature doesnot deal with reduction of speed oscillations inPMBLDC drive. This paper deals with controlmethod to reduce speed oscillations.To control a system, by any of these methods anaccurate mathematical model of the complete systemis required.

3. MATHEMATICAL MODEL OF THE PMBLDC MOTOR

The circuit model of PMBLDC motor is shown in fig1

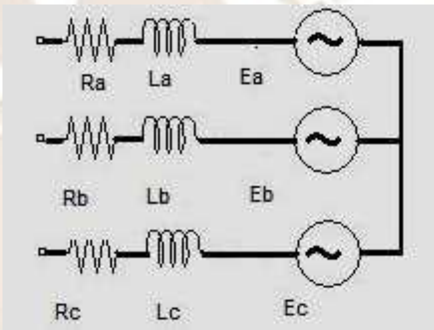


Fig 1: Motor circuit Model

The voltage equations of the BLDC motor are as follows:

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

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

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

In balanced system the voltage equation becomes

$$\begin{bmatrix} V_a \\ V_b \\ V_b \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_a & L_{ba} & L_{ca} \\ L_{ba} & L_b & L_{cb} \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The mathematical model for this motor is describedin Equation (1) with the assumption that the magnethas high sensitivity and rotor induced currents can beneglected [3]. It is also assumed that the statorresistances of all the windings are equal. Thereforethe rotor reluctance does not change with angle. Now

$$L_a = L_b = L_c = L$$

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

Assuming constant self and mutual inductance, thevoltage equation becomes

$$\begin{bmatrix} V_a \\ V_b \\ V_b \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In state space form the equation is arranged as

$$\frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{-R}{L} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \frac{1}{L} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + \frac{1}{L} \begin{bmatrix} V_a \\ V_b \\ V_b \end{bmatrix}$$

The electromagnetic torque is given as

$$T_e = (e_a i_a + e_b i_b + e_c i_c) / w_r$$

The equation of motion is given as

$$\frac{dw_r}{dt} = (T_e - T_L - Bw_r) / J$$

4. BLDC MOTOR SPEED CONTROL

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.

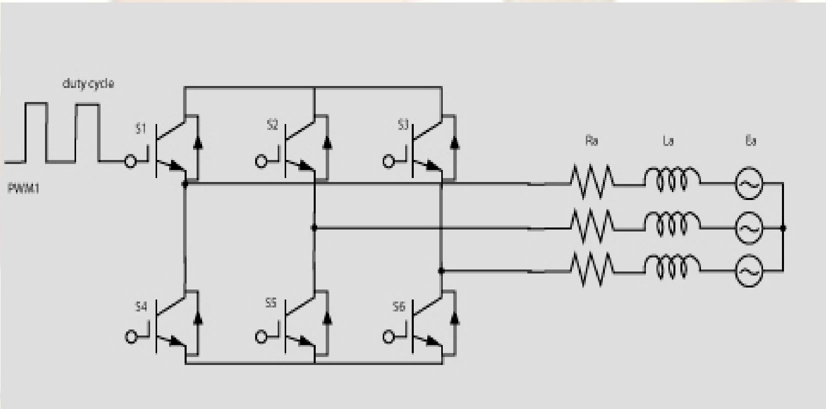


Fig 2: PWM Speed Control

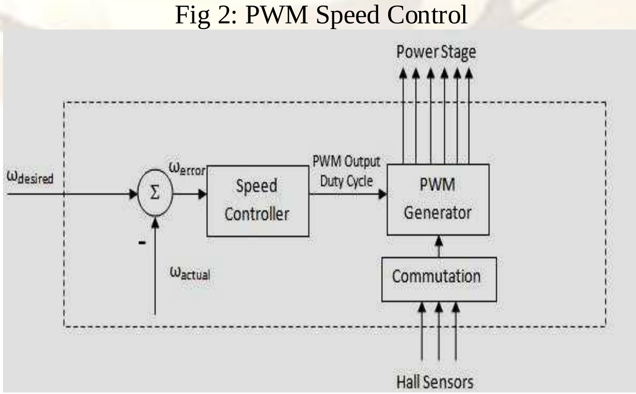


Fig .3 Schematic of a Speed controller

.Commutation ensures only proper rotation of the rotor. The motor speed depends only on the amplitude of the applied voltage. This can be adjusted using PWM technique. 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. When using PWM outputs to control the six switches of the three-phase bridge, variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal. In case of closed loop control the actual speed is measured and compared with the reference speed to find the error speed. This difference is supplied to the PI controller, which in turn gives the duty cycle.PMBLDC motor is popular in applications wherespeed control is necessary and the current must becontrolled to get desired torque. Figure 4.shows thebasic structure for closed loop control of thePMBLDC motor drive. It consists of an outer speedcontrol loop, an inner current control loop for speedand current control respectively. Speed loop isrelatively slower than the current loop.

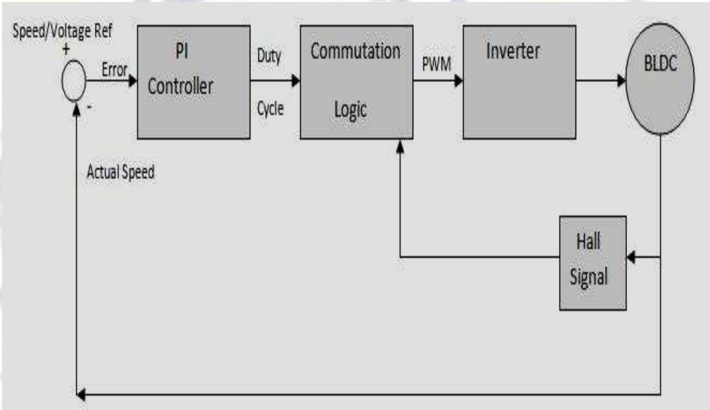


Fig.4.Closed Loop Speed Control

4. SIMULATION RESULTS

With the help of the designed circuit parameters,the MATLAB simulation is done and results arepresented here. Speeds are set at 1650 rpm and the load torque disturbances areapplied at time t=.04 sec. The speed regulations areobtained at set speed and thesimulation results are shown. The waveforms of theback EMF are shown in Fig.6. it can beseen that the phasor voltages are displaced by 120°.The stator current waveforms are shown in Fig 7.They are quasi sinusoidal in shape and displaced by120°.

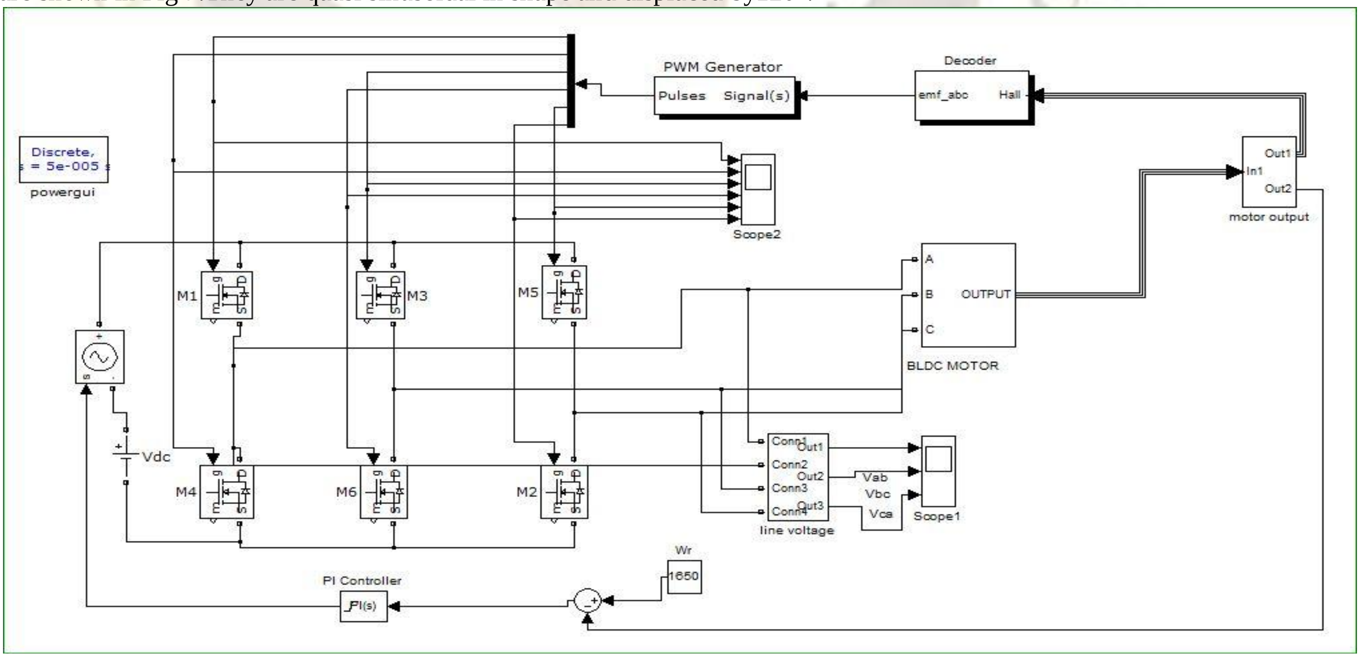
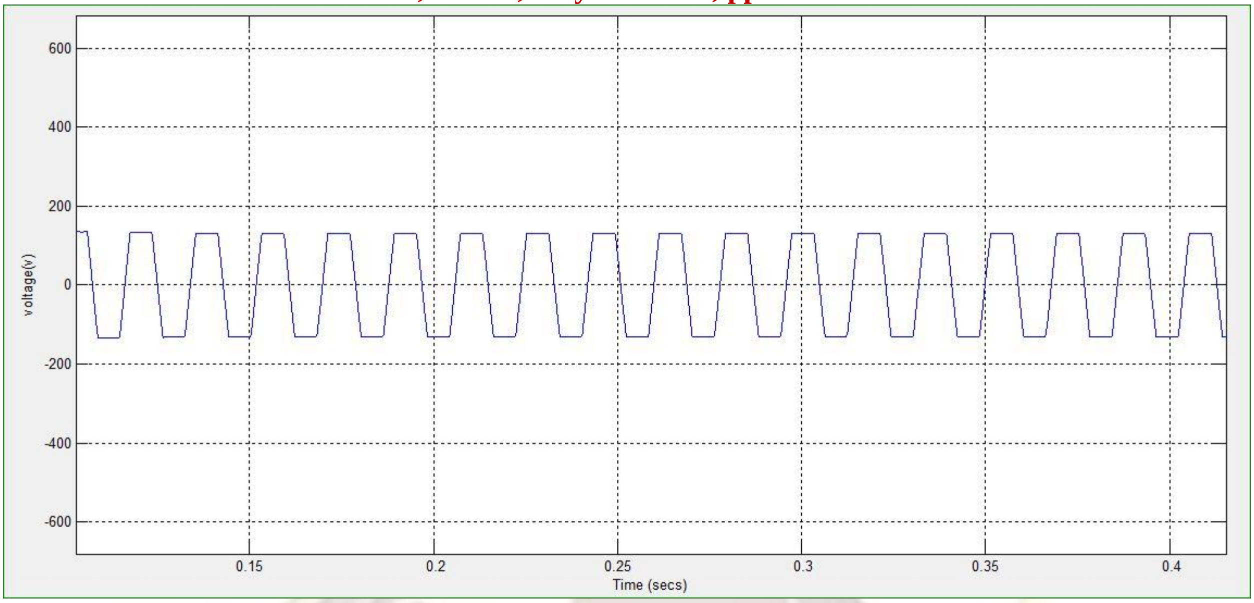
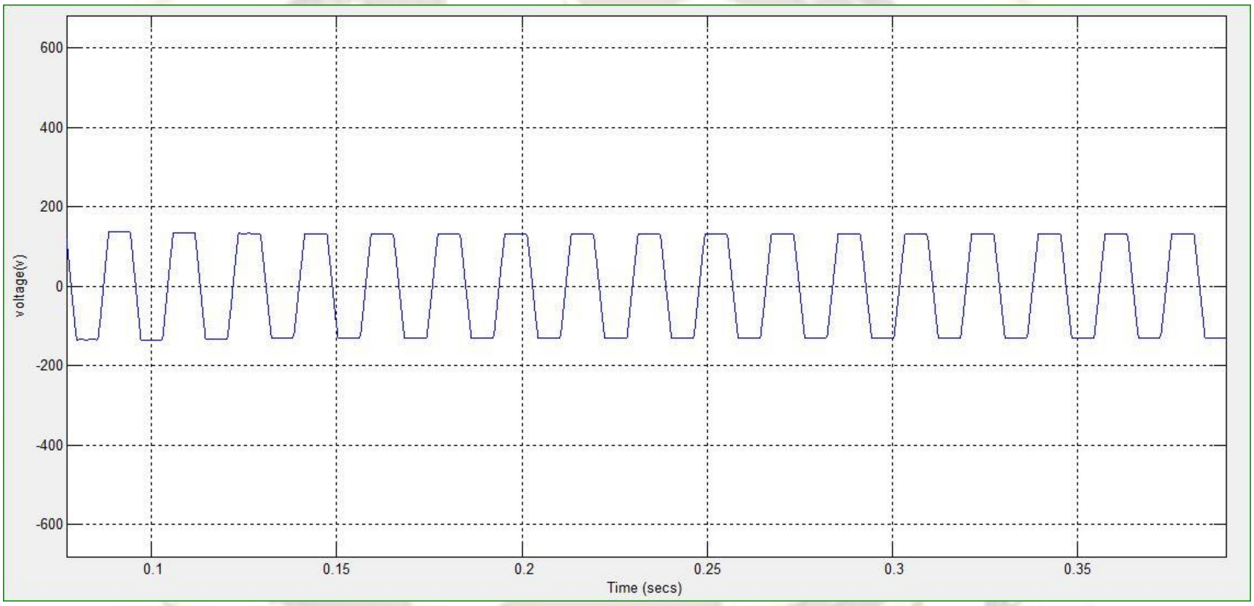


Fig.5. BLDC MOTOR CONVENTIONAL PWM CONTROL USING HYSTERESIS CONTROLLER

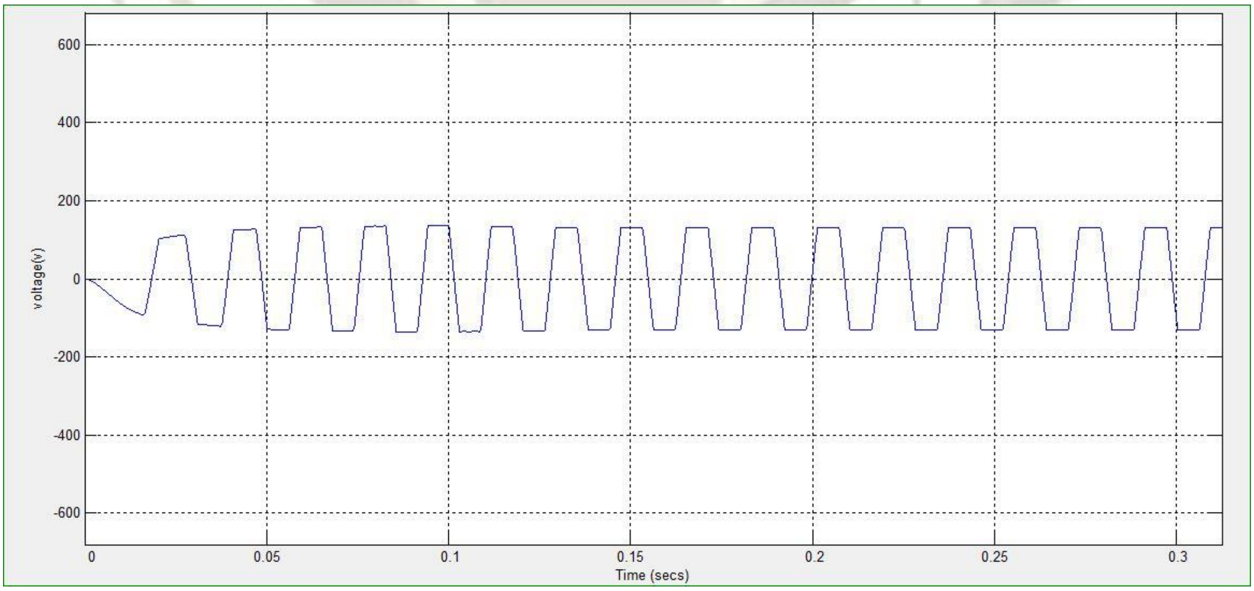
Simulink results for the conventional pwm control scheme for a BLDC motor are shown below.



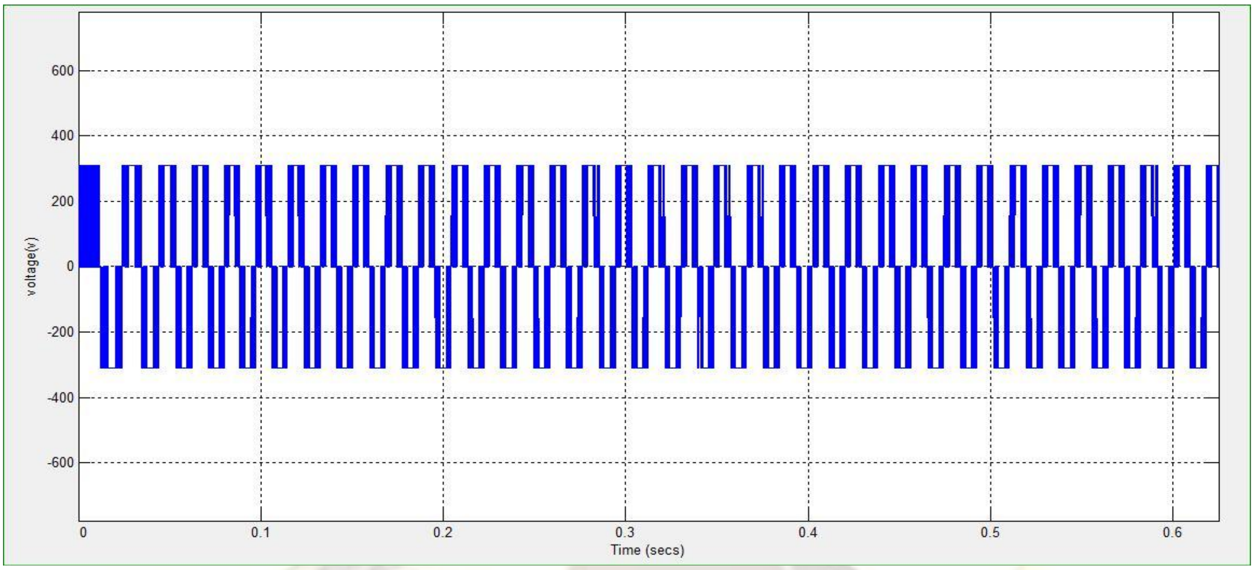
Backemf A



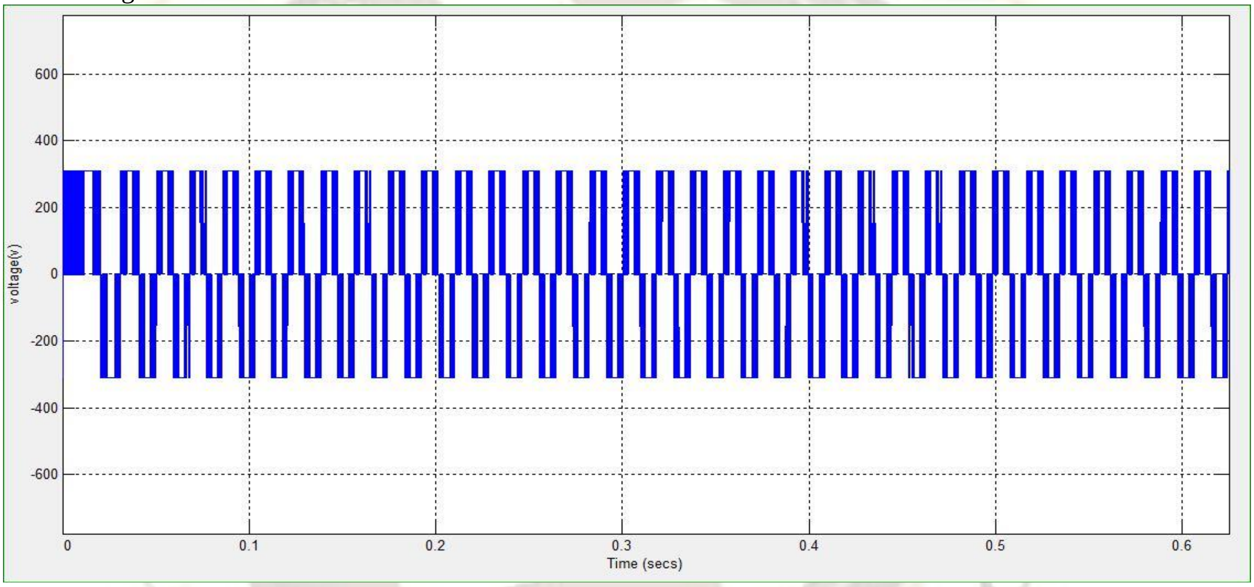
Backemf B



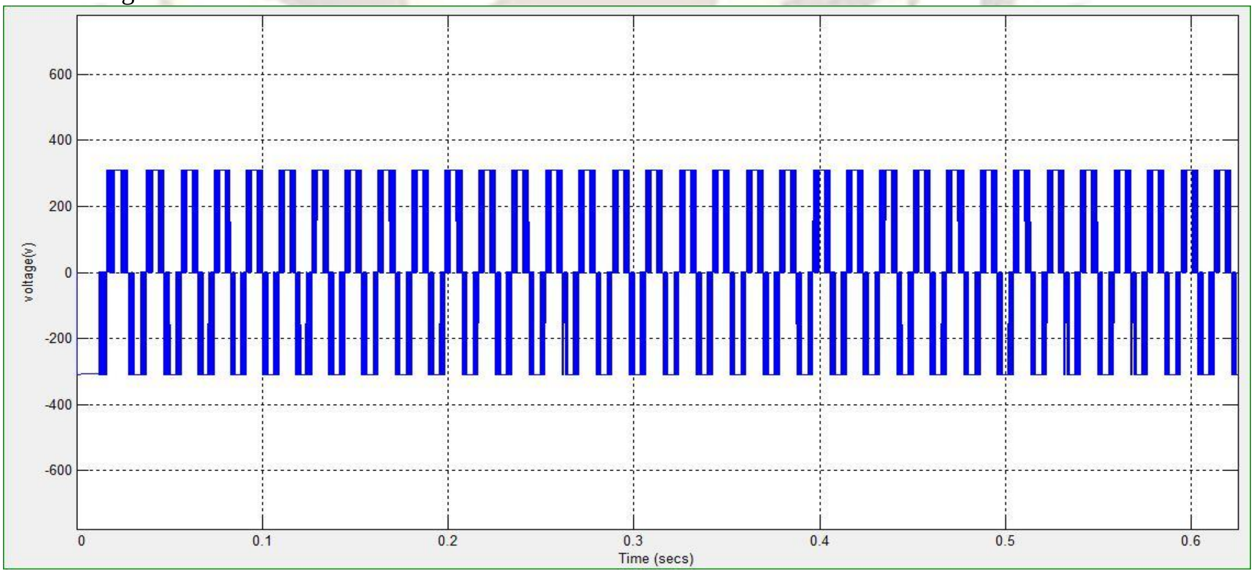
Backemf C



Phase voltage A

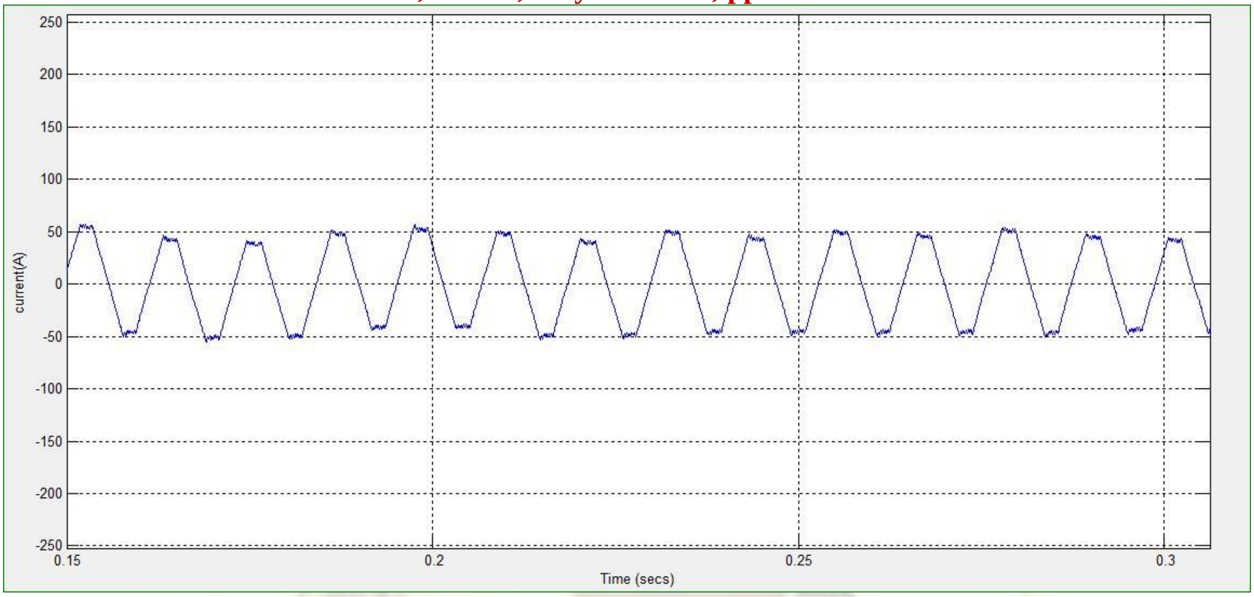


Phase voltage B

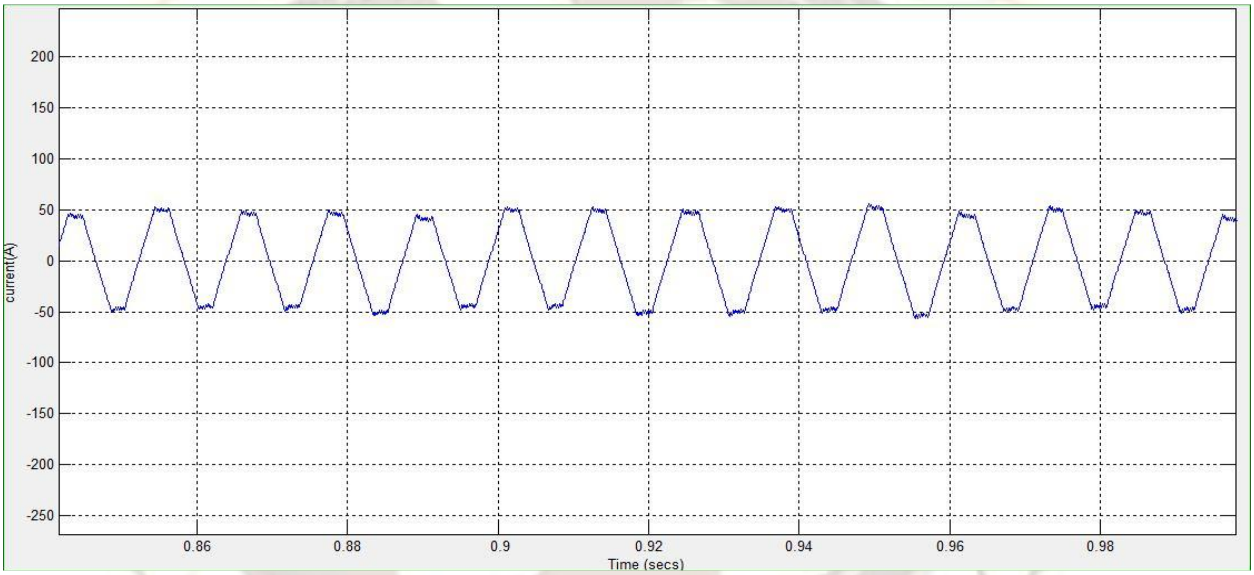


Phase voltage C

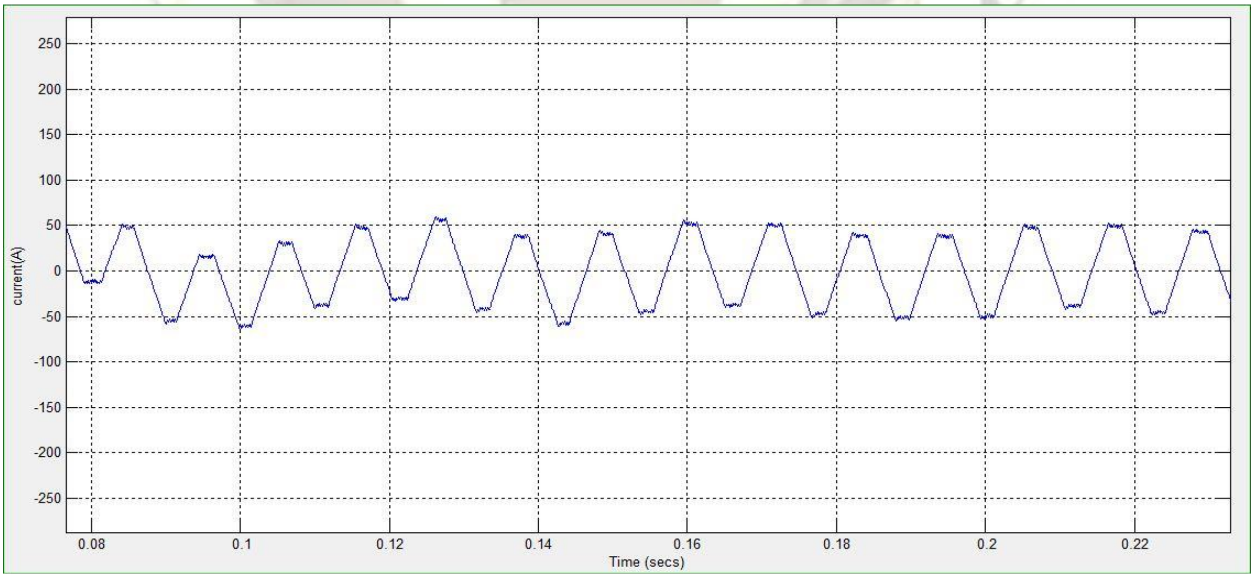
Fig.6. Back EMF and phase voltage in three phases



Phase current A

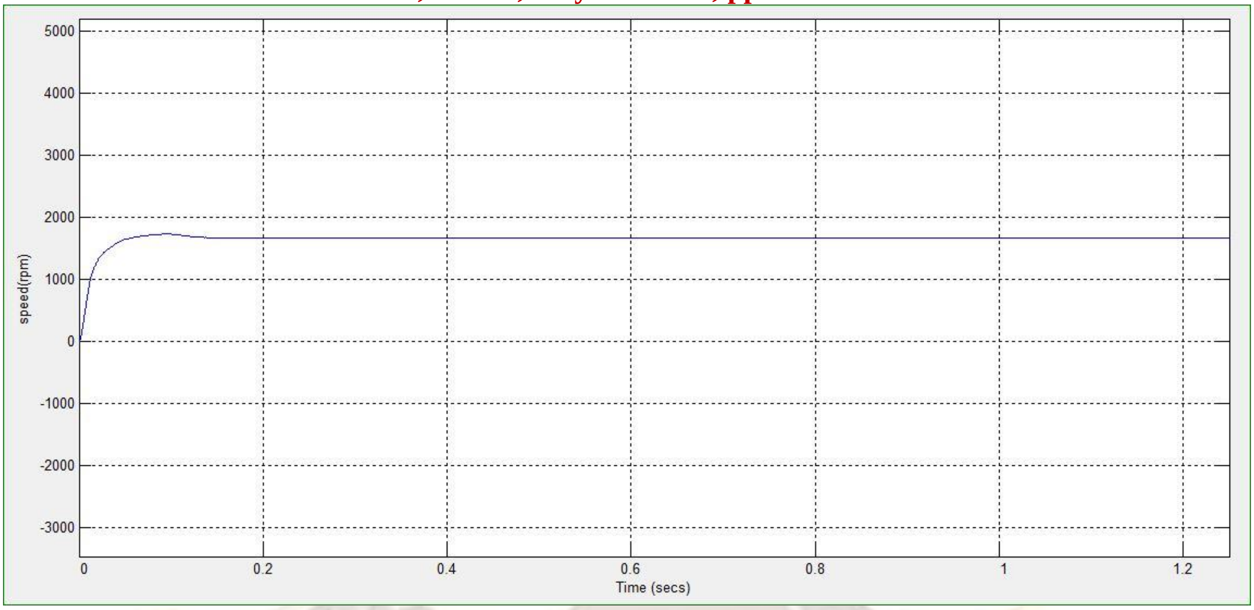


Phase current B

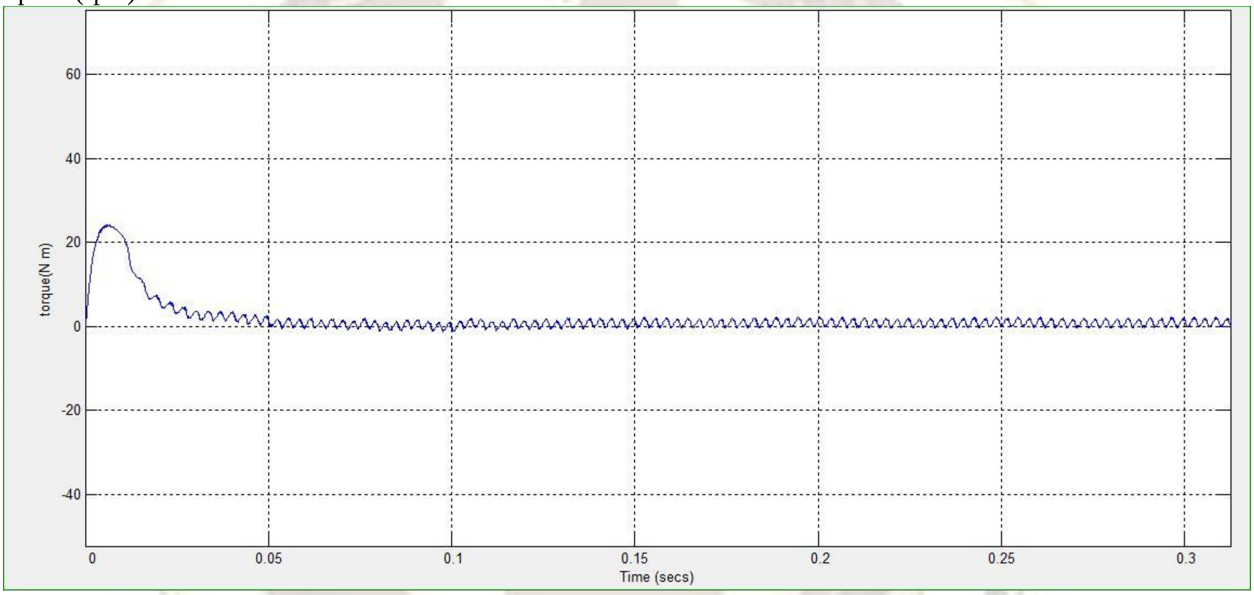


Phase current C

Fig.7. Phase current in three phases



Speed (rpm)



Electromagnetic torque

Fig.8. speed and electromagnetic torque

5. CONCLUSION

Closed loop controlled VSI fed PMBLDC motor using pwm control is modeled and simulated. Feedback signals from the PMBLDC motor representing speed and position are utilized to get the driving signals for the inverter switches. The simulated results shown are at par with the theoretical predictions. The simulation results can be used for implementation of PMBLDC drive. The speed oscillations are minimized using closed loop system.

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