

# Simulation of Brushless DC Motor for Performance Analysis using MATLAB/SIMULINK Environment

Pramod Pal, TM Shubhum and Dr. Amit Ojha

**Abstract:** Brushless DC Motor is widely used for many industrial applications because of their high efficiency, high torque and low volume. This paper presents the model construction of a brushless DC motor via MATLAB/SIMULINK so that one can evaluate the performance of the BLDC motor control with PWM Control scheme. In the presented model the speed is regulated by PI Controller. The proposed method offers suppress torque oscillation.

**Keywords-** BLDC, Model construction, MATLAB/SIMULINK, Back emf

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## I. Introduction

In variable-speed control of AC motor drives, utilization of BLDC motor has been widely used because the BLDC motor has simpler structure and lower cost than the other AC motors [1]-[2]. They have better speed versus torque characteristics, high efficiency and better dynamic response and also the torque delivered to the motor size is higher making it useful where space and weight are critical factor. BLDCM also need position information for torque producing and this information is obtained by using hall sensors it increase machine size and rotor inertia it also make drive system complex and mechanically complex.

A three phase BLDC Motor has three phase stator winding on stator and permanent magnet rotor. The torque developed in BLDCM is affected by the waveform of back-Emf waveform. Usually the BLDCM has trapezoidal back-Emf waveform and stator is fed by rectangular stator current and theoretically it gives a constant torque but the torque ripple exists due to emf waveform imperfection, current ripple and phase current commutation.

The variation in emf waveform results from variation in shapes of the slots, skew and magnet of BLDC Motor and they are subjected for the design consideration... This presents a BLDCM Model with the trapezoidal and sinusoidal back-EMF waveform. The block diagram of BLDC Motor control system is shown in fig.1. A brush less dc motor is defined as a permanent magnet synchronous machine with rotor position feedback. The brushless motors are generally controlled using a three phase power semiconductor bridge.

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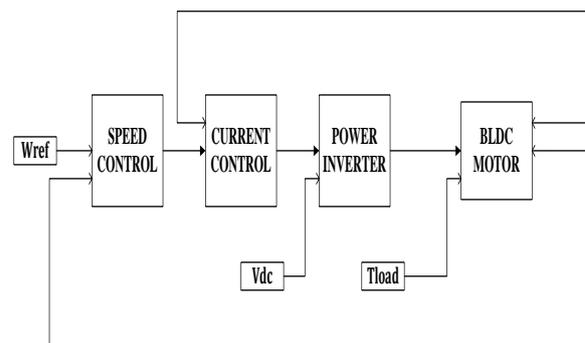


Fig 1. Block diagram of Speed Control of BLDC Motor

The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees. Instead of commutating the armature current using brushes, electronic commutation is used for this reason it is an electronic motor. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator brush arrangement, thereby, making a BLDC more rugged as compared to a dc motor.

The basic block diagram of brushless dc motor as shown Fig1. The brush less dc motor consist of four main parts power converter, permanent magnet-synchronous machine (PMSM) sensors, and control algorithm. The power converter transforms power from the source to the PMSM which in turn converts electrical energy to mechanical energy. One of the salient features of the brush less dc motor is the rotor position sensors ,based on the rotor position and command signals which may be a torque command, voltage command ,speed command and so on the control algorithms determine the gate signal to each semiconductor in the power electronic converter. The structure of the control algorithms determines the type of the brush less dc motor of which there are two main classes voltage source based drives and current source based drives. Both voltage source and current source based drive used with permanent magnet synchronous machine with either sinusoidal or non-sinusoidal back-Emf waveforms.

Machine with sinusoidal back-Emf may be controlled so as to achieve nearly constant torque. However, machine

with a non sinusoidal back-Emf offer reduces inverter sizes and reduces losses for the same power size.

According to the back-Emf signal of the BLDC motor it can be categorized in two different ways as sinusoidal back-Emf type or Trapezoidal back-Emf type. There is another type of classification according to the type of sensors are used. Hall Effect sensors are used for low resolution and low cost and optical sensors are used for high resolution application [3].

## II. Mathematical Modelling

In the present paper 3 phase 4 pole BLDC motor is modeled. BLDC Motor can also be considered as a synchronous machine with Permanent magnet rotor and the rotor construction is the only difference it leads to change in the dynamic characteristics of the machine the motor is fed by three phase voltage source. Source is not necessarily to be sinusoidal square wave or the other wave shape can also be used but it should not be exceed to the maximum voltage limits. The modeled equations for the armature winding are as follows:-

$$V_a = R i_a + L \frac{d i_a}{dt} \quad (1)$$

$$V_b = R i_b + L \frac{d i_b}{dt} \quad (2)$$

$$V_c = R i_c + L \frac{d i_c}{dt} \quad (3)$$

Where

L-armature self induction in [H]

R-armature resistance in [ $\Omega$ ]

$V_a, V_b, V_c$ —terminal phase voltage in [V]

$i_a, i_b, i_c$ —motor input current in [A]

$e_a, e_b, e_c$ —motor back-Emf in [V]

Back-Emf of each phase has a phase difference of 120 electrical degrees and back-Emf and rotor position are related via some function. Equation of each phase for back-Emf is as follows:-

$$e_a = K_w f(\theta_e) \omega \quad (4)$$

$$e_b = K_w f(\theta_e - 2\pi/3) \quad (5)$$

$$e_c = K_w f(\theta_e + 2\pi/3) \quad (6)$$

Where

$K_w$ —back-Emf constant of one phase [ $V/rads^{-1}$ ]

$\theta_e$ —rotor angle in electrical degree

$\omega$ —rotor speed [ $rad.S^{-1}$ ]

Rotor angle electrical [ $\theta_e$ ] and Rotor angle mechanical [ $\theta_m$ ]

are related as:-

$$\theta_e = P/2\theta_m \quad (7)$$

Where P is the no of poles on rotor

Thus the total electromagnetic torque  $T_e$  in N-M can be expressed as follows:-

$$T_e = (e_a i_a + e_b i_b + e_c i_c) / \omega \quad (8)$$

The mechanical torque transferred to the motor shaft:-

$$T_e - T_l = J \frac{d\omega}{dt} + B\omega \quad (9)$$

Where

$T_l$  = load torque [N-M]

$J$  = inertia of the rotor shaft [ $Kgm^2$ ]

$B$  = friction constant [ $Nms.rads^{-1}$ ]

## III. SIMULINK MODEL

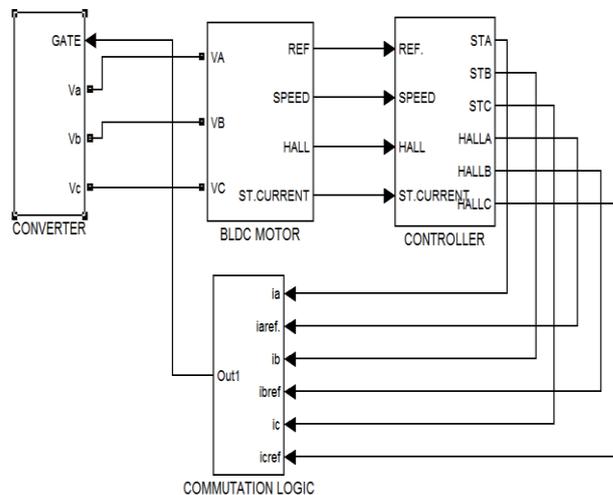


Fig.2 Simulation block of speed control of BLDC motor

For designing BLDC Motor drive system it is necessary for the model to give precise value of torque and it is related to back-Emf and torque [4]. The stator winding is energized in sequence for rotating the rotor and commutation has been done electronically therefore knowledge of rotor position is necessary for energizing the stator winding in correct sequence. Rotor position sensing has been done by Hall Effect sensors placed in the stator the present model has three Hall sensors embedded in the non driving side of the motor. When rotor magnetic pole passes through Hall sensors, sensor will give high or low according to the pole passes through the sensors. After every 60 degree of rotation of rotor Hall sensor changes its signal and three hall sensors are used it will takes two signal from every sensor to complete one electrical cycle or we can say six steps are required to complete one electrical cycle. Thus switching scheme of the inverter bridge will consider six different combinations. Here one electrical cycle does not mean one complete mechanical rotation and it will depend on no. of rotor pole pairs. For one rotor pole pair one electrical degree is completed. Fig.3 shows PWM generation block with hall synchronizing signals.

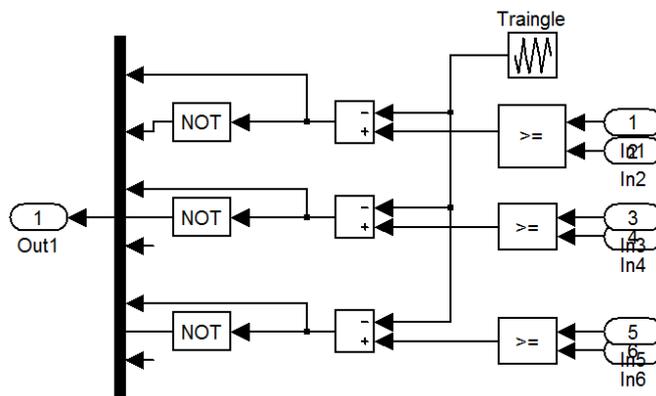


Fig.3 PWM Control scheme

### IV. Simulation Results

1. TABLE I. BLDC MOTOR SPECIFICATION

PARAMETER	VALUE	UNIT
Vd	126.966V	Volts
Stator Phase Resistance R	4.8750	$\Omega$
Stator Phase Inductance L	6.5e-3	H
No. of Poles	4	
Inertia	15.17 $\times 10^{-6}$	Kgm <sup>2</sup>
Kw	56.23 $\times 10^{-3}$	VradS <sup>-1</sup>

With the above design consideration the simulation has been done and the result is presented here. Speed is set at 983 rpm and load torque disturbance is applied at 0.01 sec and the speed regulation is obtained at the set speed. The back Emf and stator waveform are shown by the simulation waveform and it shows that back-Emf and phase voltage are both are displaced by 120 degree each and stator current are of quasi sinusoidal in nature and also displaced by 120 degree

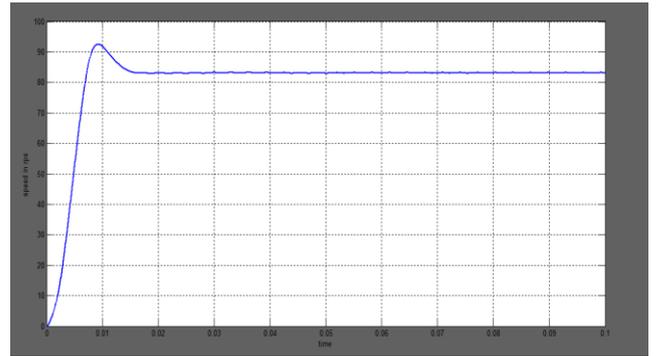
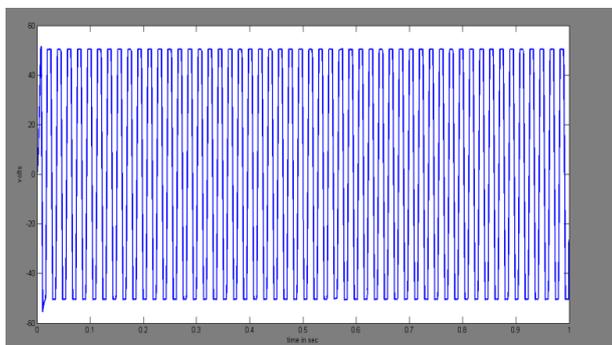
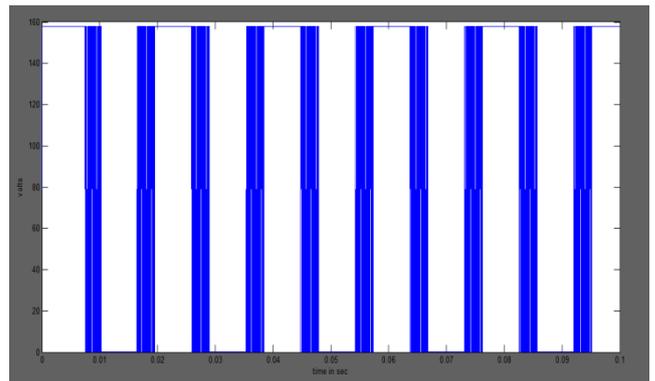


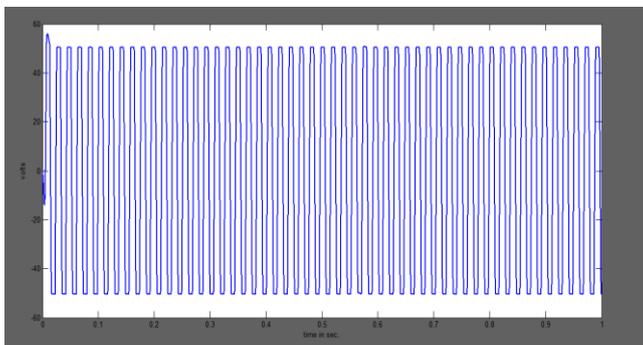
Fig.5 Speed



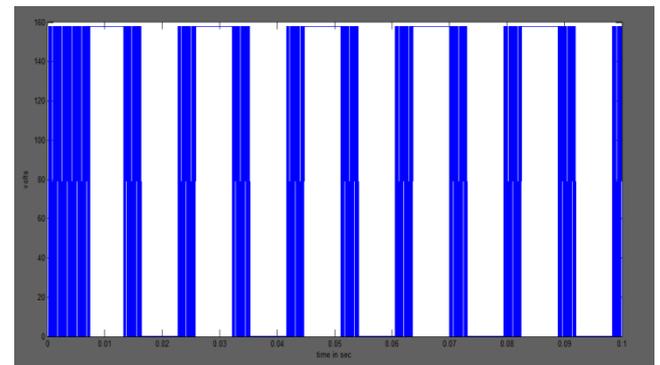
(a)



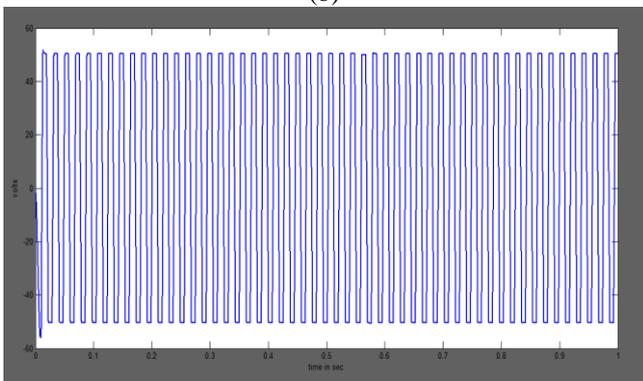
(a)



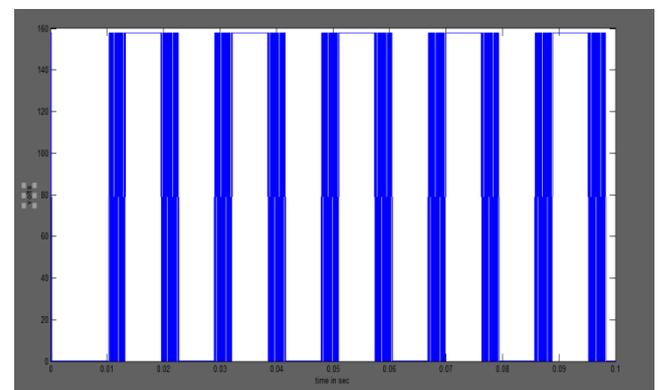
(b)



(b)



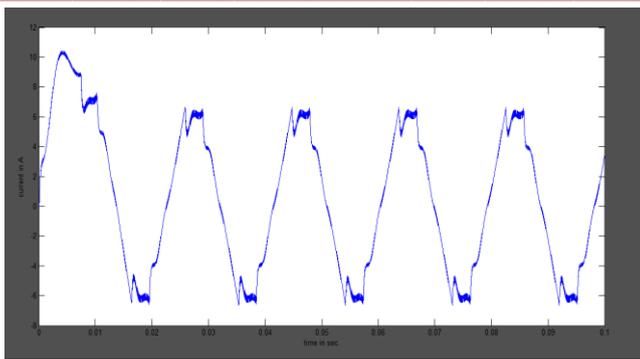
(c)



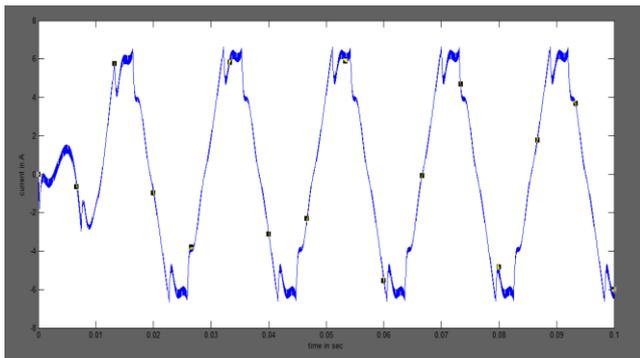
(c)

Fig.4 Back Emf (a) Phase A (b) Phase B (c) Phase C

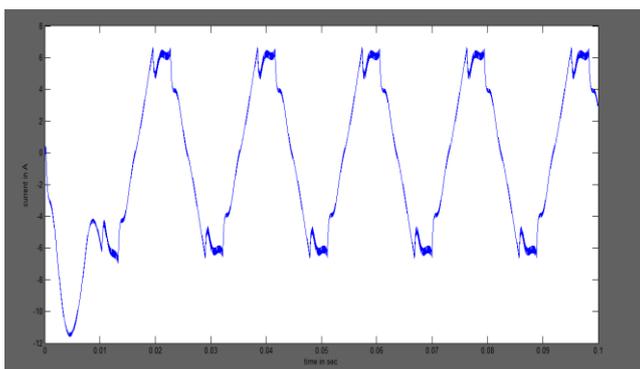
Fig.6 Line Voltage



(a)



(b)



(c)

Fig.7 Stator Current (a)Phase A (b) Phase B  
 (c) Phase C

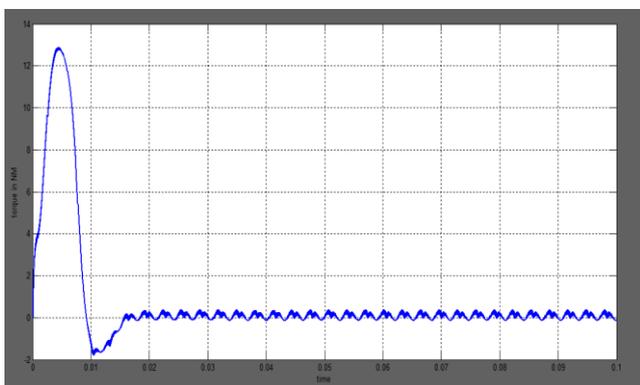


Fig.8 Electromagnetic Torque at no load

## V. Conclusions

The modeling of BLDC Motor using PWN Control presented in this paper. The feedback signal and commutation mechanism utilizes speed, position of the rotor and stator current. All the simulation results are of theoretical aspect and can be utilized for practical implementation. The simulation results show that speed oscillations are minimized by closed loop system.

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