Performance Analysis of BLDC Motor for Sinusoidal and Trapezoidal Back-Emf using MATLAB/SIMULINK Environment

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Abstract: The Brushless DC Motor find variety of applications in domestic and industrial applications. BLDC Motor has some important characteristics like low and high power density and ease of speed control. This paper presents a three phase inverter fed Brushless DC motor. The process considering the development of BLDC Motor Model in MATLAB/SIMULINK environment with sinusoidal and trapezoidal back-Emf waveform and also includes a comparison study for the harmonic analysis for sinusoidal and trapezoidal back-Emf models.

Key Words: BLDC Motor, Simulink Model, back-Emf

I.INTRODUCTION

Brushless DC Motor has the characteristics of DC motor but eliminates the need of commutator and brushes this reduces the losses in the machine and also improve the efficiency but increases the cost. Therefore BLDC Motor replaces the conventional DC Machine in high efficiency applications. The main reason for motor speed control is to account a signal for demanded speed and to drive the motor for that speed [1]. BLDC Motor uses DC voltage sources but the commutation is done electronically. BLDC Motor comes in variety of power ratings from low range to high range. It has some advantages over conventional DC motors like noiseless operations, higher efficiency, better speed and torque characteristics and longer life [2]. The selection of right BLDC motor for various applications is very important. The back-Emf is the most important factor which affects the torque produced in the BLDC Motor. Normally BLDC motor has trapezoidal back-Emf with rectangular waveform of stator current. It causes constant value torque but practically torque ripple exists due to current ripple, phase current commutations and non uniform back-Emf waveforms therefore always a difference exists between actual value and simulation results. The paper attempts to compare BLDC Motor performance for both sinusoidal and trapezoidal back-Emf waveforms.

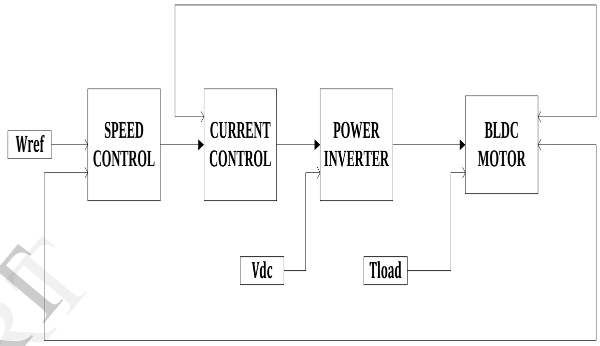


Fig.1 BLOCK DIAGRAM OF BLDC MOTOR CONTROL SYSTEM

Fig.1 shows block diagram of BLDC motor control system. Here hysteresis or PWM control is to be used for maintaining the actual current flowing into the motor as close as possible to the rectangular reference values [3]. The major disadvantage of BLDC Motor is its higher cost and high degree of complexity introduced by the six step inverter [4], [5].

II MATHEMATICAL MODELLING

Modeling of BLDC Motor can be done by considering it as a conventional three phase synchronous motor. It has three phase stator and permanent magnet rotor. The current induced in the rotor can be minimized by the high resistivity of both the magnet and stainless steel laminations. The BLDC Motor can be modeled in both d-q axis model and also abc phase model analysis. The important equations in modeling of BLDC Motor are as follows:

$$\mathrm{Vab} = \mathrm{R(ia - ib)} + \mathrm{L}\frac{d}{dt}\mathrm{(ia - ib)} + \mathrm{ea} - \mathrm{eb} \qquad [1]$$

$$\mathrm{Vbc} = \mathrm{R(ib - ic)} + \mathrm{L}\frac{d}{dt}\mathrm{(ib - ic)} + \mathrm{eb} - \mathrm{ec} \qquad [2]$$

$$\mathrm{Vca} = \mathrm{R(ic - ia)} + \mathrm{L}\frac{d}{dt}\mathrm{(ic - ia)} + \mathrm{ec} - \mathrm{ea} \qquad [3]$$

Where:

R= Per Phase Stator Resistance
L=Per Phase Stator Inductance
i_a,i_b,i_c=Instantaneous Stator Phase current
V_{ab},V_{bc},V_{ca}= Instantaneous Stator Line voltages
e_{ab},e_{bc},e_{ca} =Instantaneous phase back-Emf

The Phase currents can also be written as:

$$ia + ib + ic = 0$$

Thus the equation can be written as:

$$ic = -(ia + ib)$$

Thus the line voltage given by equations [1] and [2] can be written as:

$$Vab = R(ia - ib) + L\frac{d}{dt}(ia - ib) + ea - eb \qquad [4]$$

$$Vbc = R(ia + 2ib) + L\frac{d}{dt}(ia + 2ib) + eb - ec \qquad [5]$$

The flux of the permanent magnet rotor and speed of the rotor will influence the back-Emf as explained as follows:

$$ea = \frac{Ke\,\omega m}{2}F(\theta e) \qquad [5]$$

$$eb = \frac{Ke\,\omega m}{2}F[\theta e - \frac{2\Pi}{3}] \qquad [6]$$

$$ec = \frac{Ke\,\omega m}{2}F[\theta e - \frac{4\Pi}{3}] \qquad [7]$$

Thus the electromagnetic torque is given by:

$$Te = \frac{Ke}{2}F[\theta e]ia + \frac{Ke}{2}F\left[\theta e - \frac{2\Pi}{3}\right]ib + \frac{Ke}{2}F\left[\theta e - \frac{4\Pi}{3}\right]ic \qquad [8]$$

Where

$\theta_e = \frac{P}{2}\theta_m$ Electrical Angle ,degree
Wm=Rotor Speed in Rad/Sec.
Ke=back-Emf constane in volt/rad./sec.

The dynamics of the motor and load as follows:

$$To = KfWm + J\frac{d}{dt}(Wm) + TL \qquad [9]$$

$$To - TL = KfWm + J\frac{d}{dt}(Wm) \qquad [10]$$

$$J\frac{d}{dt}(Wm) = To - TL - KfWm \qquad [11]$$

$$Wm = -\frac{Kf}{J}Wm + \frac{1}{J}(To - TL) \qquad [12]$$

$$\theta = Wm$$

Where:

J=Moment of Inertia in Kg/m^2

K_f=friction constant in NM/Rad/Sec.

T_L=Load Torque in NM

III. SIMULINK MODEL

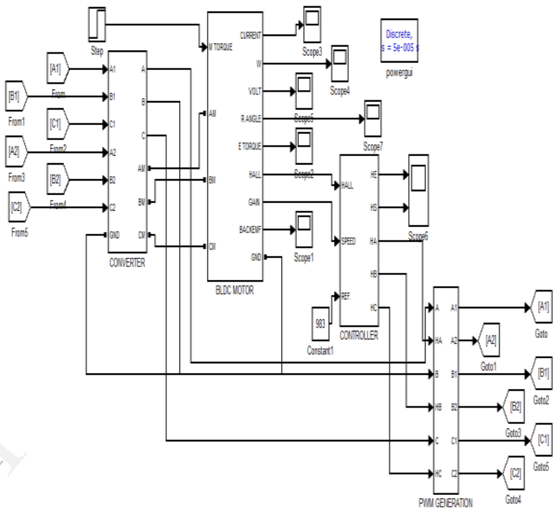


Fig.2 SIMULINK MODEL FOR PWM CONTROL OF BLDC MOTOR

The simulink model of BLDC Motor is as shown in the figure. In BLDC Motor the commutation is done electronically and the stator winding will be energized in a sequence and this makes rotor position information critical for successful commutation. The stator winding will be energized in proper sequence according to the information provided from the rotor sensors embedded into the stator. Normally Hall Effect sensors are used for sensing the position of rotor. In the presented model three hall sensors are used and this is the main disadvantage of the present model the sensors can also be minimized by using a different technique for PWM control of BLDC Motor [6]. If North Pole is passes through the hall sensor it will give active high signal and if South Pole passes through hall sensor it will give active low and thus this sequence will give commutation logic. PWM generation block will uses following equations for signal generation

$$Va = (T1)\frac{Vd}{2} - (T4)\frac{Vd}{2} \qquad [13]$$

$$Vb = (T3)\frac{Vd}{2} - (T6)\frac{Vd}{2} \qquad [14]$$

$$Vc = (T5)\frac{Vd}{2} - (T2)\frac{Vd}{2} \qquad [15]$$

Thus as explained by the above equations for every 60^0 electrical rotations the hall sensor will change its state and six steps will be taken to complete one electrical degree of rotation. It is not necessary that one electrical degree of rotation is equal to one mechanical degree of rotation.

The electrical and mechanical degree of rotation will be related as follows:

$$\theta e = \frac{P}{2}\theta m \qquad [16]$$

Where:
θ_e=Angle of rotation in electrical degree
θ_m=Angle of rotation in mechanical degree

IV. SIMULATION RESULTS

TABLE 1 BLDC MOTOR SPECIFICATION

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

SIMULATION RESULT FOR SINUSOIDAL WAVEFORM:

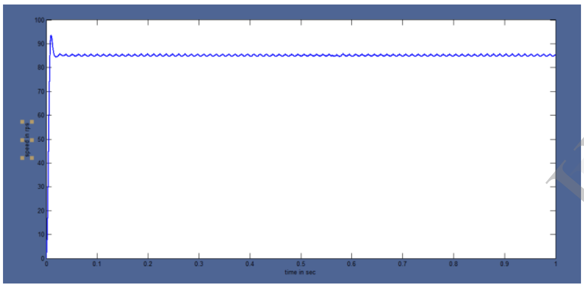
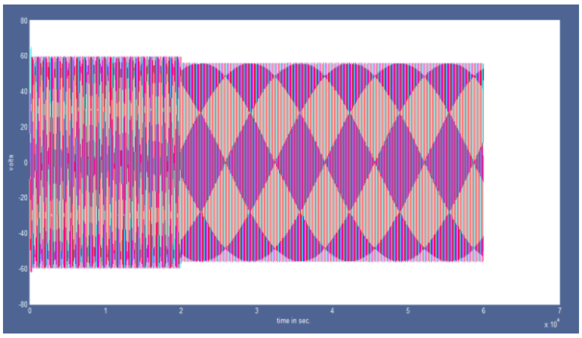


Fig.3 Speed



Current

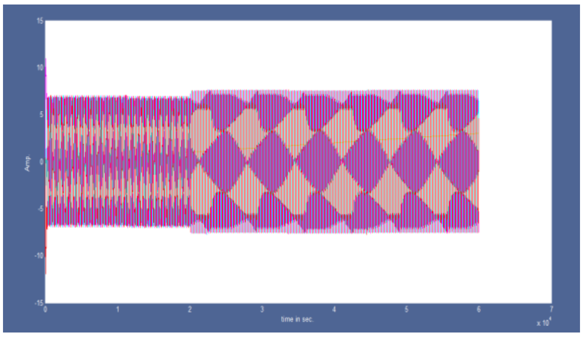


Fig.4 Back Emf

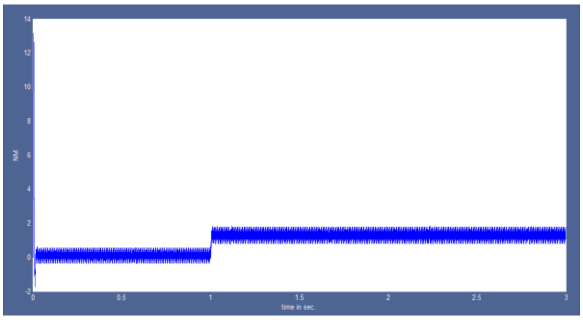


Fig. 4 Torque

FFT ANALYSIS FOR SINUSOIDAL WAVEFORM

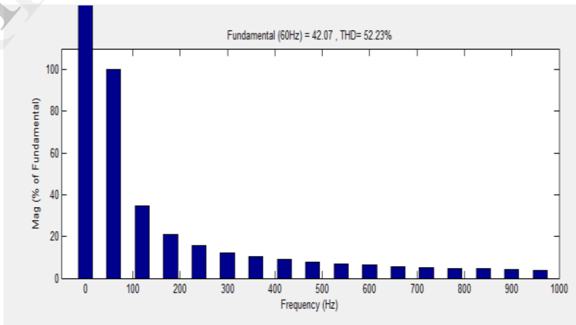


Fig.5 FFT Analysis for Speed

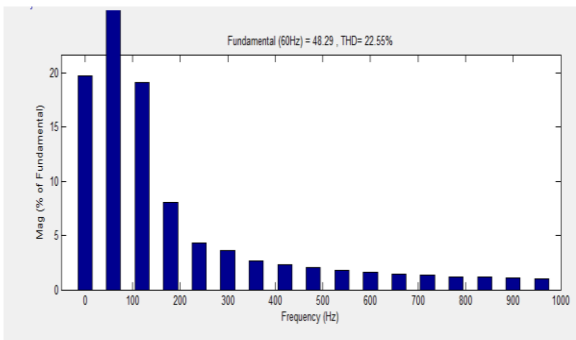


Fig.6 FFT Analysis for Back-Emf

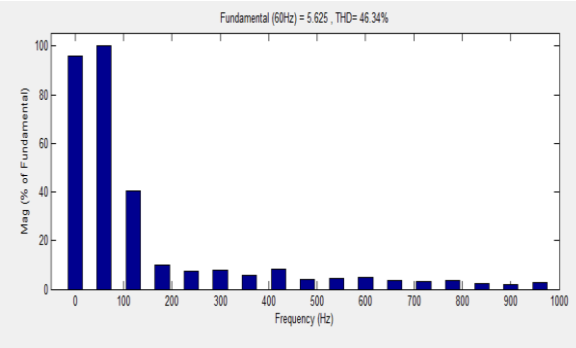


Fig.7 FFT Analysis for Current

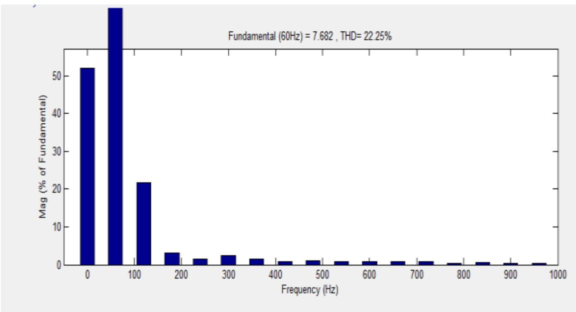


Fig.8 FFT Analysis for Torque

SIMULATION RESULT FOR TRAPEZOIDAL WAVEFORM:

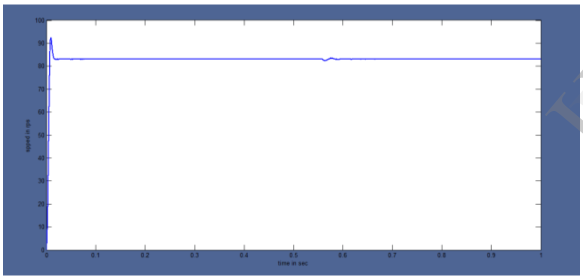


Fig.9 Speed

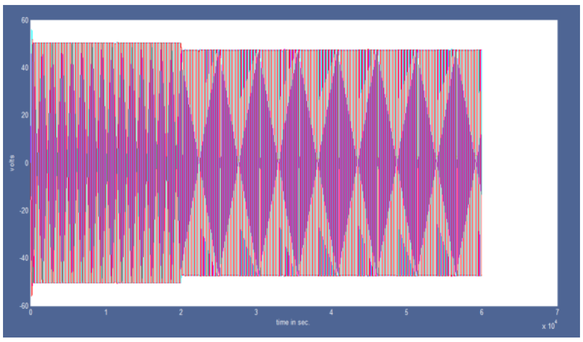


Fig.10Back-Emf

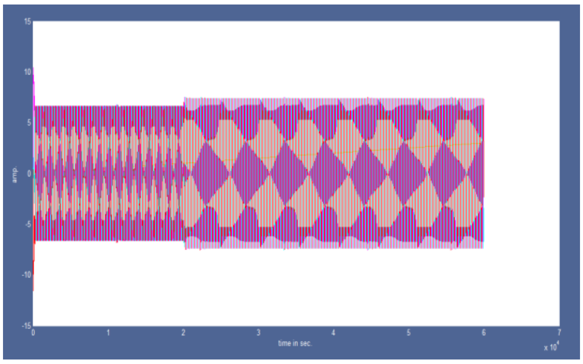


Fig. 11Current

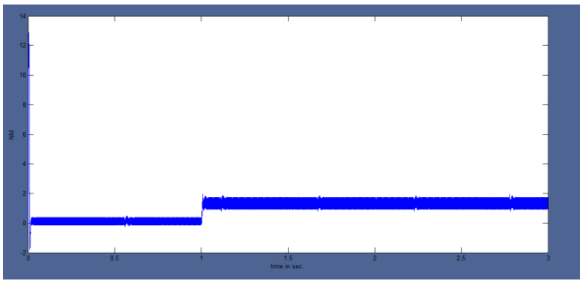


Fig. 12 Torque

FFT ANALYSIS FOR TRAPEZOIDAL WAVEFORM

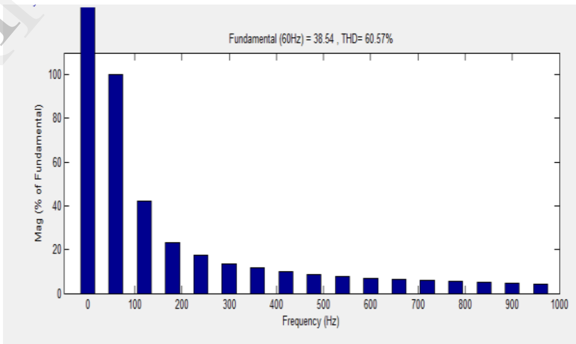


Fig. 13 FFT Analysis for Speed

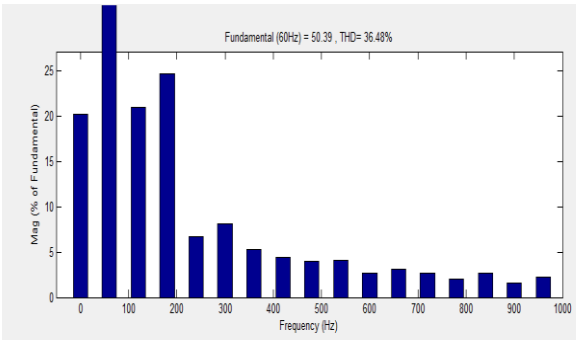


Fig.14 FFT Analysis for back-Emf

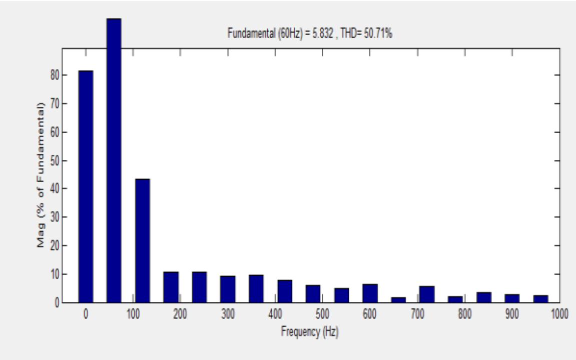


Fig.15FFT Analysis for Current

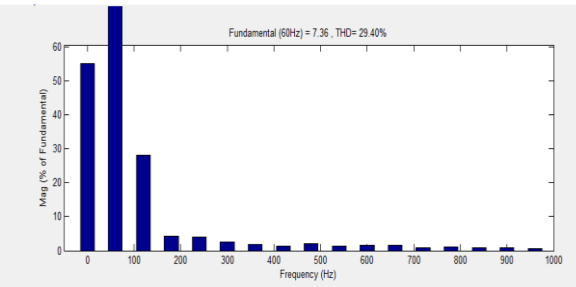


Fig. 16 FFT Analysis for Torque

Comparison of Sinusoidal and Trapezoidal waveform for speed and torque

Type of waveform	Speed			Torque		
	Ripple	Peak value	THD	Ripple	PEAK VALUE	THD
Sinusoidal	0.2	93.5	52.2	0	13.6	22.25
Trapezoidal	0.05	92.5	60.5	0	12.8	29.40

Comparison of Sinusoidal and Trapezoidal waveform for stator current

Type of waveform	Current				
	Ripple	Peak Value			THD
		Ia	Ib	Ic	
Sinusoidal	0	7.6	7.6	7.5	46.34
Trapezoidal	0	7.4	7.4	7.5	50.71

\Comparison of Sinusoidal and Trapezoidal waveform for Back-Emf

Type of waveform	Back-Emf				
	Ripple	Peak Value			THD
		Ea	Eb	Ec	
Sinusoidal	0	55.8	55.8	55.8	22.57
Trapezoidal	0	47.5	47.5	47.5	36.48

IV. REFERENCE

[1]"Application characteristics of permanent magnet synchronous and brushless dc motors for servo drives," presented at the IEEE IAS Annual Meeting, Atlanta, 1987.

[2]M. Lajoie-Mazenc, C. Villanueva, and J. Hector, "Study and implementation of a hysteresis controlled inverter on a permanent.

[3] T. M. Jahns, "Torque production in permanent magnet synchronous motor drives with rectangular current excitation," IEEE Trans. Ind. Appl., vol. IA-20, no. 4, pp. 803-813, July/Aug. 1984.

[4] A. A. Aboulnaga, P. C. Desai, F. Rodriguez, T. R. Cooke, and A. Emadi, "A novel low-cost high-performance single-phase adjustable-speed motor drive using PM brushless DC machines: IIT's design for 2003 future energy challenge," in Proc. 19th Annu. IEEE Applied Power Electron. Conf., Anaheim, CA, Feb. 2004, pp. 1595–1603.

[5] C. W. Lu, "Torque controller for brushless DC motors," IEEE Trans. Ind. Electron., vol. 46, no. 2, pp. 471–473, Apr. 1999.

[6] S. Anand, M. Nikola, J.Young and K. Mahesh "An FPGA Based Novel Digital PWM Control Scheme for BLDC Motor Drives" IEEE Trans. On Ind. Electron., Vol. 56, No.8, Aug. 2009.