Design and performance analysis of BLDC motor modeling

[1]Ch.N.Narasimha Rao, [2]P.Amrutha, [3]P.Vijay Paul
[1]Asst. Prof, EEE Dept, VFSTR (Deemed to be University), Guntur, A.P.
[2]Asst. Prof, EEE Dept, S.K.University, Ananthapur, A.P.
[3]Asst.Prof, EEE Dept, Samskruthi college of Engineering and Technology, Hyd.
cherukuri.narsi@gmail.com[1], pnamrutha.reddy@gmail.com[2],vijaypaul.my@gmail.com[3]

***ABSTRACT*:** Most of the applications needs the high performance BLDC motors. Modelling of Brushless Direct Current (BLDC) motor is a way to design for different applications. BLDC motor modeling can be done by using transfer function, equations and state space verification are required to design in simulation platform. Hall effect sensor based electronic commutation control of BLDC motor through a three phase inverter and controller. The BLDC motor with modeling can improve the current wave form. The performance of BLDC motor can improve with mathematical modeling. The Simulation of inverter modeling, PWM control, hall sensors are presented. The performance of closed loop control of BLDC motor with various BLDC modeling's presented in this paper. The speed, back emf and current waveforms of various models of BLDC are also presented in this paper.

Index Terms—BLDC, PWM, TRANSFER FUNCTION, STATE SPACE MODEL

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INTRODUCTION

The brushless dc motor has been widely utilized in day by day life and mechanical creation inferable from its predominance of basic construction, high productivity, and long life expectancy. The BLDC motor with low ripple in current results improved performance. Nonetheless, the BLDCM has force undulation during the running interaction, particularly the occasional recompense torque ripple, which turns into the fundamental factor influencing its smooth activity [1]-[5]. Simultaneously, torque ripple makes clamor and mechanical vibration, restricting its application in the high exactness field. Along these lines, decreasing torque undulation is a significant way to improve the exhibition of the BLDCM. Instant ON and OFF conditions are required for rotor position control at every point, so this is a challenge task to design BLDC motor [6]-[8]. An actuator should be design to reduce harmonic ripples and to improve dynamic performance. The design of BLDC model has been achieved from Simulink platform in MATLAB. To design an effective BLDC motor for an actuator MATLAB is an efficient and effective tool to achieve perfect electrical system, also attain desired performance[9]-[12]. The main advantages of this topology are more reliable, wide range of speed control and cost effective. Modelling of decoder, motor and inverter are the three sub-systems designed from transfer function; state transfer function and state space model are proposed in this paper.

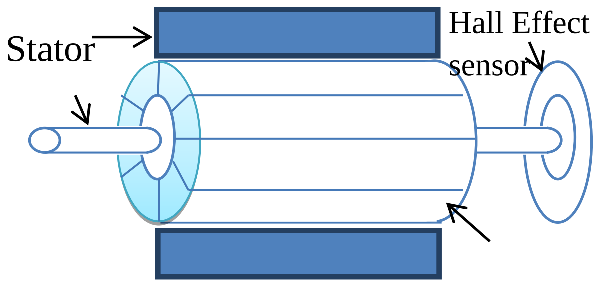

Fig. 1 Structure of BLDC motor

I. MODELING OF BLDC MOTOR

$$v_{ry} = R(i_r - i_y) + L\frac{d}{dt}(i_r - i_y) + e_r - e_y \qquad (1)$$

$$v_{yb} = R(i_y - i_b) + L\frac{d}{dt}(i_y - i_b) + e_y - e_b \qquad (2)$$

$$v_{br} = R(i_b - i_r) + L\frac{d}{dt}(i_b - i_r) + e_b - e_r \qquad (3)$$

$$e_r = \frac{k_e}{2}\omega_m F\theta_e \qquad (4)$$

$$e_y = \frac{k_e}{2}\omega_m F(\theta_e - 120) \qquad (5)$$

$$e_b = \frac{k_e}{2}\omega_m F(\theta_e - 240) \qquad (6)$$

The balancing of stator current is difficult, which is given as

$$I_a + I_b + I_c = 0 \qquad (7)$$

$$T_e = \frac{k_t}{2}\left[F(\theta_e)i_r + F(\theta_e - 120)i_y + F(\theta_e - 240)i_b\right] \qquad (8)$$

The back EMF in phases of permanent magnet BLDC motor is in the shape of trapezoidal which is shown in figure 3. The relation between the Back EMF and rotor position is expressed as

$$F(\theta_e) = \begin{cases} 1, \ 0 \le \theta_e \le 120 \\ 1 - \frac{6}{180}(\theta_e - 120) & 120 \le \theta_e < 180 \\ -1 & 180 \le \theta_e < 240 \\ -1 + \frac{6}{180} & 240 \le \theta_e < 360 \end{cases} \qquad (9)$$

$$T_e = k_f\omega_m + J\frac{d\omega_m}{dt} + T_L \qquad (10)$$

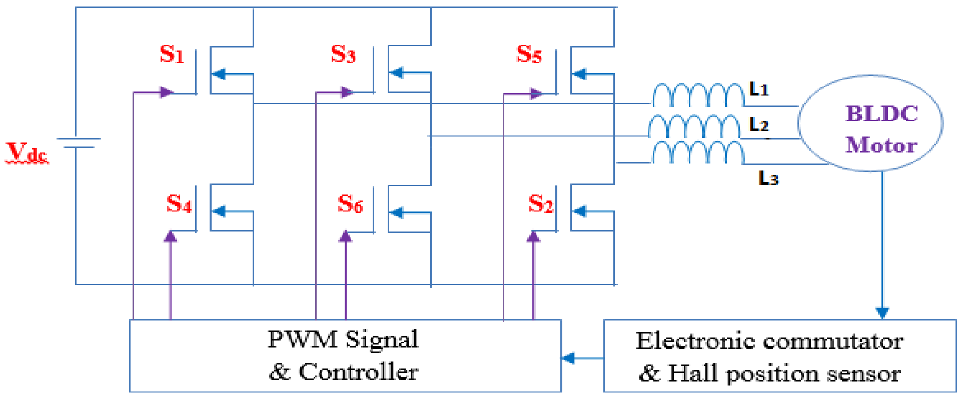

Figure.2 Brushless DC motor drive system

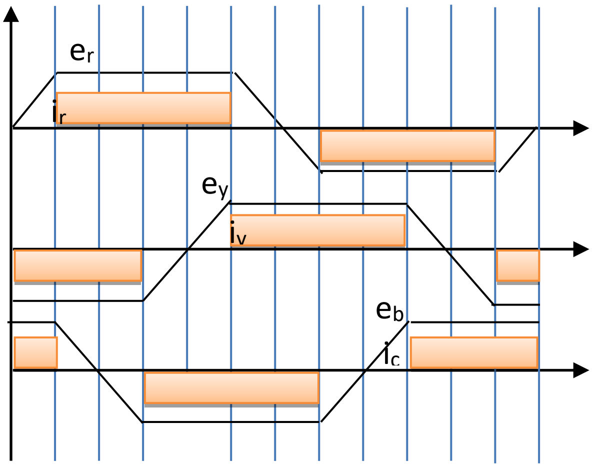

Figure.3 Trapezoidal back EMF and currents of three phase BLDC motor

A. Modelling Of Voltage Source Inverter

BLDC Motor inverter is implemented with MOSFET based power electronic device and switching PWM signals to drive BLDC motor. The rotor position can be detected by hall sensors and turn on the inverter switches to supply the BLDC motor and shown in fig.4.

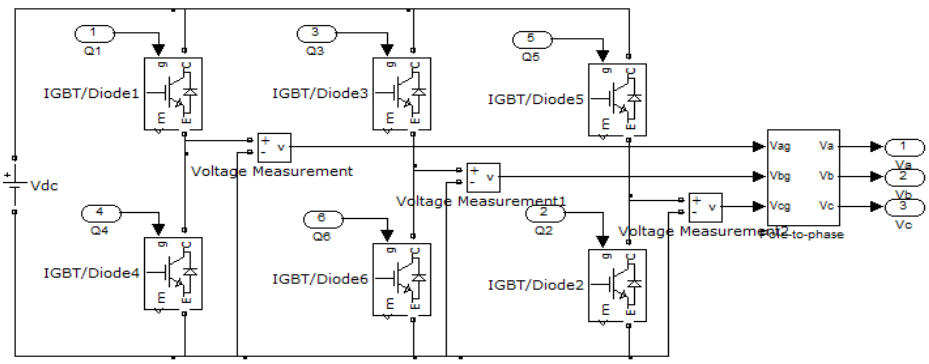

Figure.4 Mathematical modelling of inverter

The following table I shows the relation between the rotor position and inverter switches.

Table:I.The inverter voltages and rotor position

Theta	Switches ON	Van	Vbn	Vcn
0^0-60^0	S1 and S6	Vd/2	-Vd/2	0
60^0-120^0	S1and S2	Vd/2	0	-Vd/2
120^0-180^0	S2 and S3	0	Vd/2	-Vd/2
180^0-240^0	S3 and S4	-Vd/2	Vd/2	0
240^0-300^0	S4 and S5	-Vd/2	0	Vd/2
300^0-360^0	S5 and S6	0	-Vd/2	Vd/2

B. Modelling of Hall sensor

Hall sensor placed in rotor to know the rotor position, if it is placed in stator, it leads to be happen some misalignment. BLDC motor manufacture only decides the angle of rotor position, Table II explains the rotor position angles and its reference currents. The commutation sequences are based on the table II and the motor performances are also decided itself. The Hall sensors may be placed with 60º or 120º phase shift and MATLAB sub system model is as shown in fig.5.

TABLE.II Hall rotor position and reference current

θ_{ele}	I_{ar}	I_{br}	I_{cr}
0^0-60^0	0	I_s	- I_s
60^0-120^0	I_s	0	- I_s
120^0-180^0	I_s	- I_s	0
180^0-240^0	0	- I_s	I_s
240^0-300^0	- I_s	0	I_s
300^0-360^0	- I_s	I_s	0

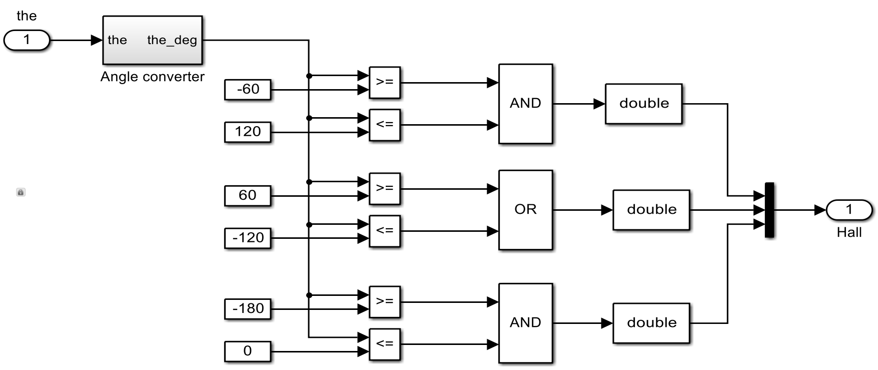

Figure.5 Simulink model of Hall Signal Generations

C. *Encoder Modelling*

A three phase Inverters which converters supply DC into three phase AC to energies stator winding. A decoder decodes the hall position signal to six switches is as shown in figure.6. Subsystem includes to changing pulse width as per duty cycle with modulating unit and direction changing logic. The switching frequency of MOSFET is 10 KHZ and its chopping rate also decided by the same frequency.

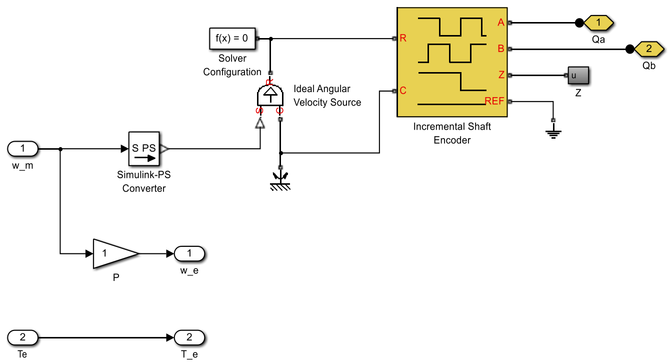

Figure.6 Simulink model of Encoder

The direction of rotation and motor speed positions equivalent pulse is computed by pulse decoder system [11]. Direction is multiplied with Pulse frequency which gets from speed parameter as per the equation 2.

$$N_a = \left(\frac{60}{2000}\right) \times f_{Qa} \qquad (11)$$

N_a - Motor speed in rpm

f_{Qa} - Frequency of QEP signal $Q_a$in Hz

D. *PWM Current Controller*

The PWM current controller for switch on power switches to inverter shown in fig.7 a MATLAB-SIMULINK model.

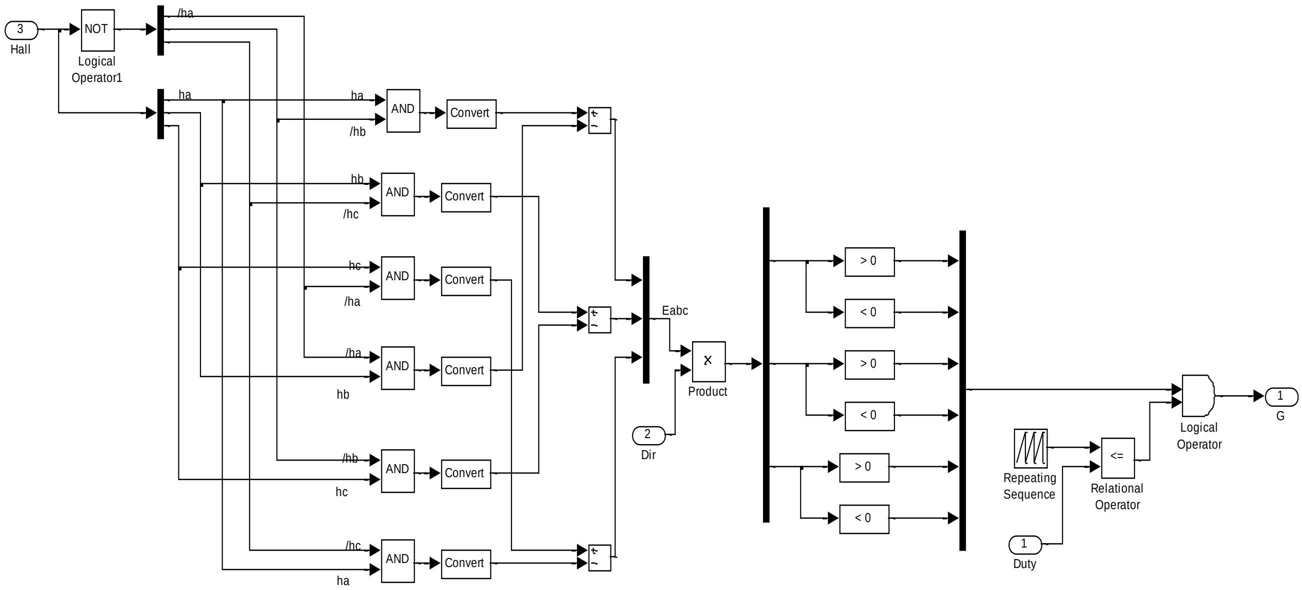

Figure.7 PWM current controller

II. MATLAB/SIMULINK MODELING OF BLDC MOTOR

E. Modeling of BLDC Motor In Transfer Function

The modelling of BLDC motor by using transfer function as shown in fig 8.

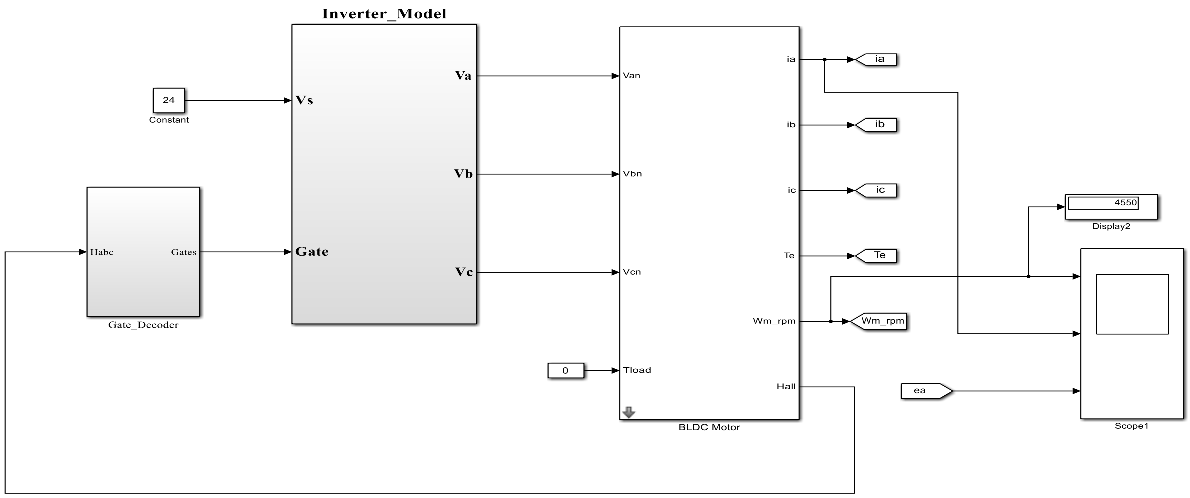

Figure.8 BLDC motor modelling in transfer function

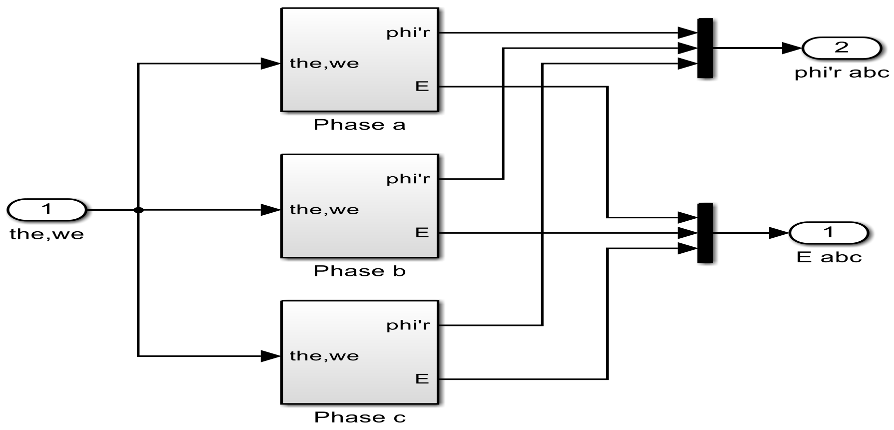

Figure.9 phase currents and Back EMF generation of simulink blocks

F. *Modeling of BLDC motor in transfer Equations*

With the help of transfer equations, the complete MATLAB/Simulink model of modelling of BLDC motor as shown in fig 10.

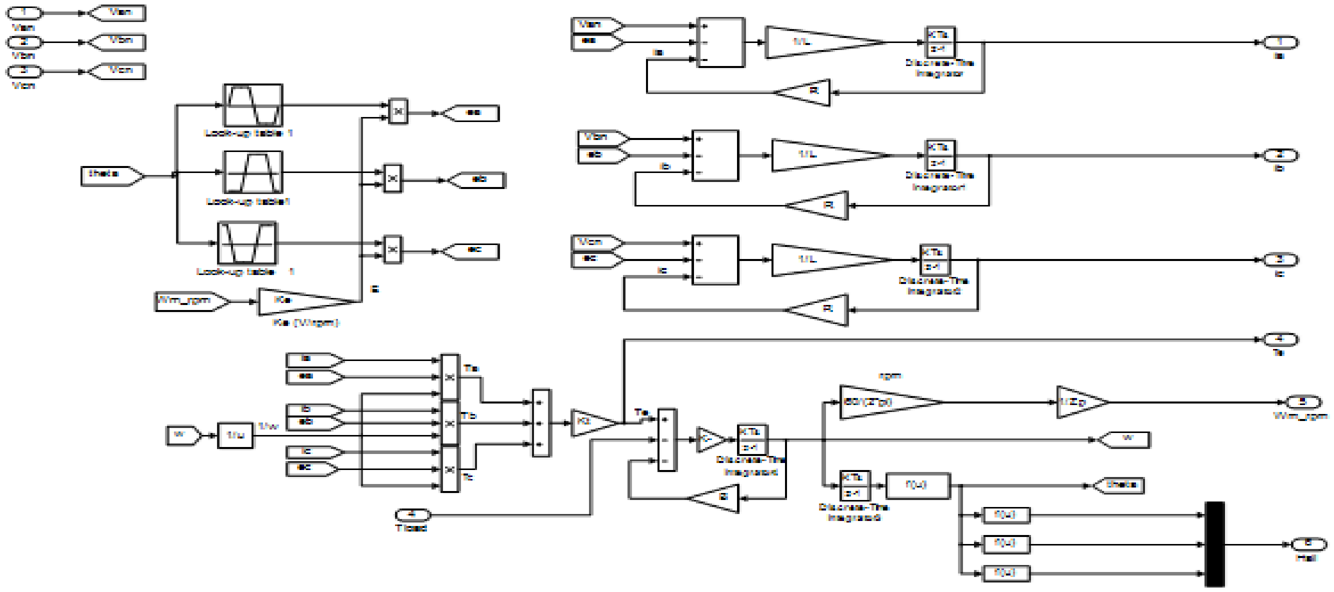

Figure.10 Modelling of BLDC Motor in Transfer Equations

G. *Modeling of BLDC Motor in State Space*

The modeling of BLDC motor with state space equations by using MATLAB/simulink as shown in fig. 11

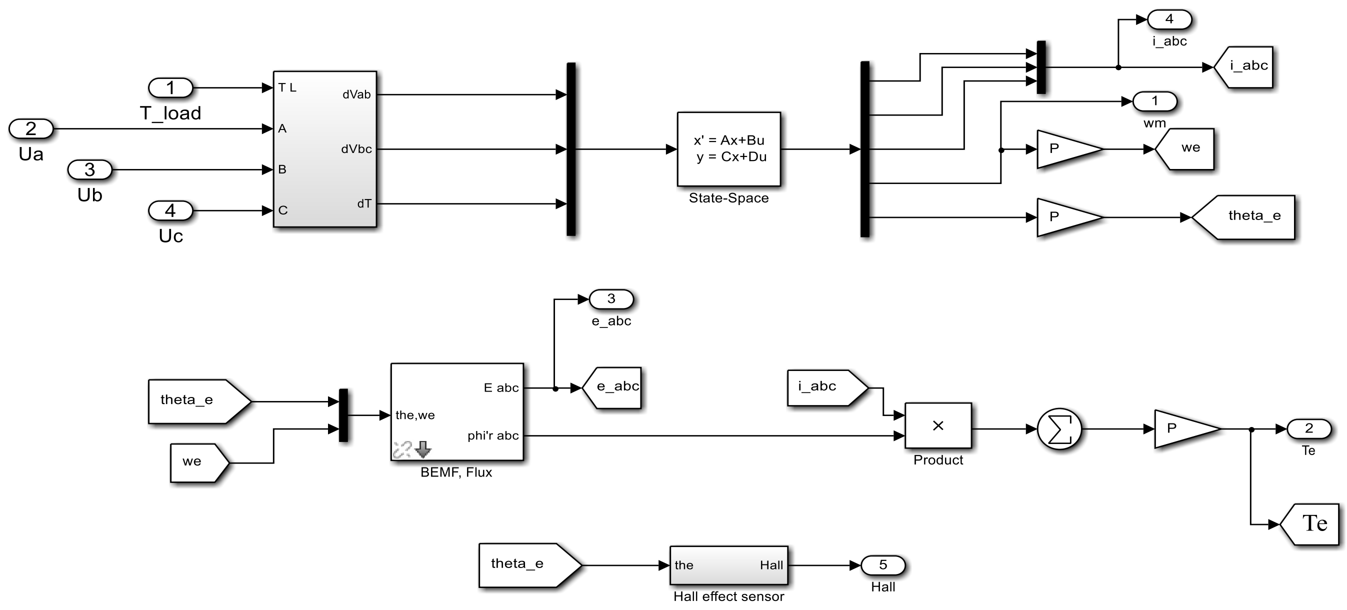

Figure.11 Modelling of BLDC motor in state space

III. Simulation Results and discussion

A PWM controlled closed loop operation of BLDC motor is simulated with by using equations, transfer functions and state space modeling. The simulation results of these models are presented and compared.

Fig.12 shows the speed, back emf and current waveforms of BLDC motor model with transfer functions.

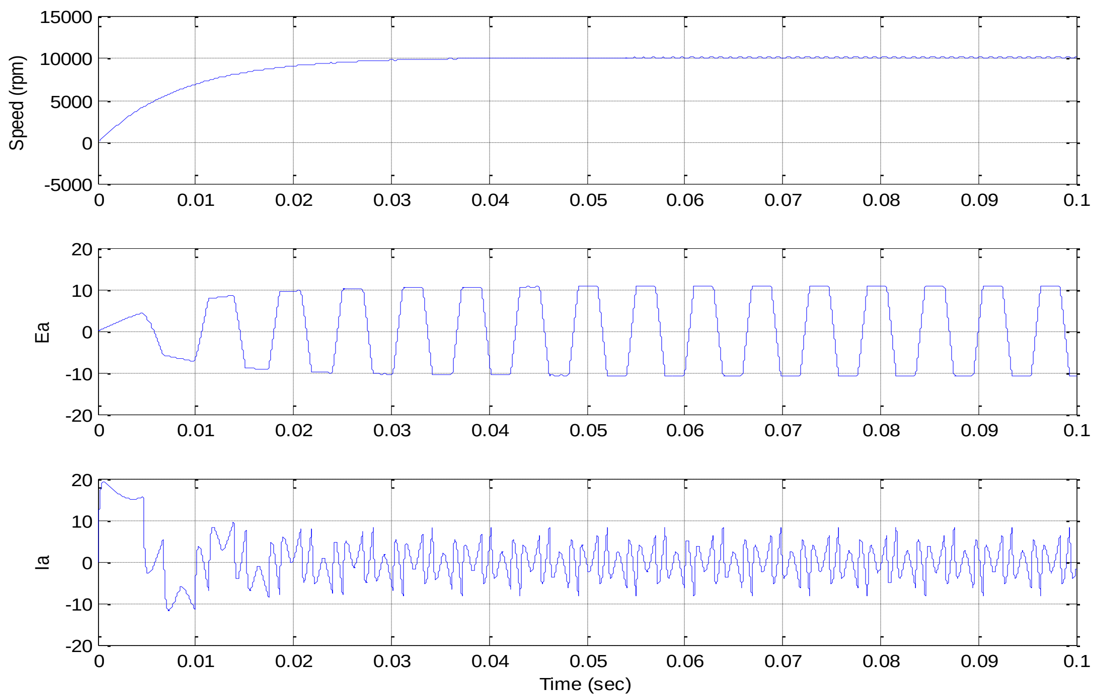

Figure.12 Output waveform of BLDC motor model in Transfer functions

Fig.13 shows the speed, back emf and current waveforms of BLDC motor model with transfer equations.

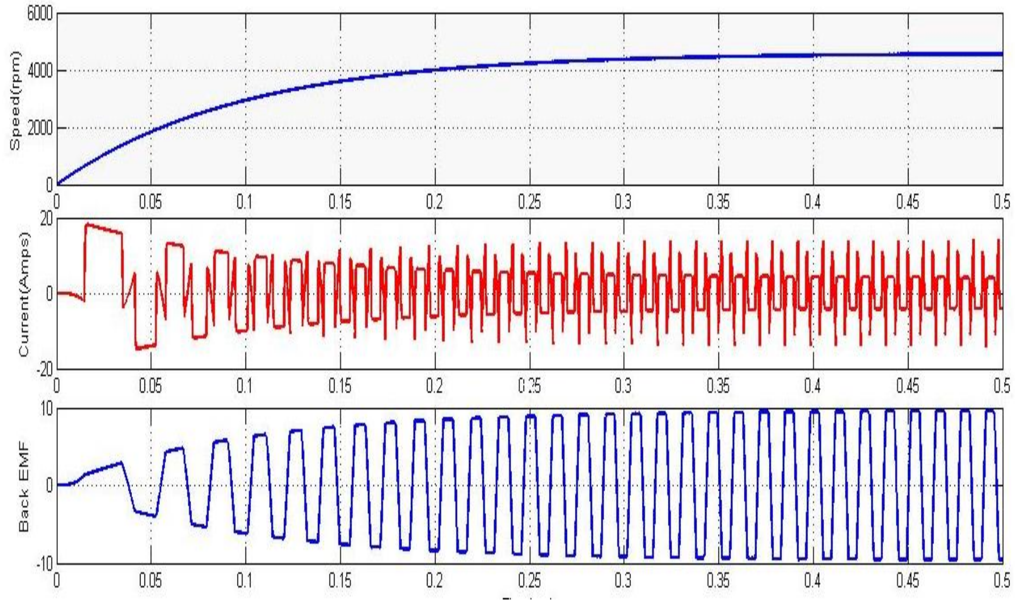

Figure.13 Output waveform of BLDC motor model in transfer equations

Fig.13 shows the speed, back emf and current waveforms of BLDC motor model with state space model.

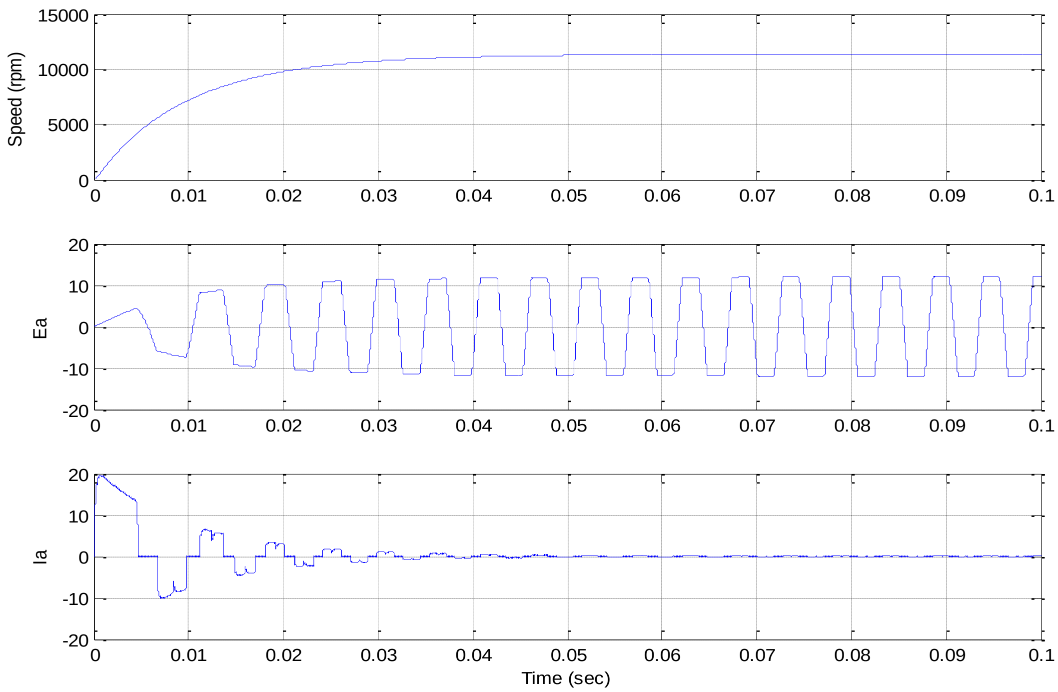

Figure.14 output waveforms of BLDC motor model in state space model

IV. CONCLUSION

Obtained the modeling of BLDC motor with transfer function, transfer equations and state space models by using required equations and Simulink models. Obtained the simulation and results of closed loop control of BLDC motor with PWM control. The required models are also simulated and verified the results of speed, back emf and current waveforms of different BLDC motor modelings. All methods are has their advantages and drawbacks. In the state space model of BLDC motor, the current ripples also reduced, so that the performance can be improved with this model. State space model of BLDC form has the more advantages in many actuating applications.

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