MODELING OF BLDC MOTOR WITH IDEAL BACK-EMF FOR AUTOMOTIVE APPLICATIONS

Prof. D.N.Katole

Assistant prof. at
Department of Electrical Engineering
Priyadarshini J L college of institute of technology,Nagpur.

Puja Kurrewar

UG student
Department of Electrical Engineering
Priyadarshini J L college of institute of technology ,Nagpur.

Sumedha Pachghare

UG student
Department of Electrical Engineering
Priyadarshini J L college of institute of technology, Nagpur.

Nisha Itankar

UG student
Department of Electrical Engineering
Priyadarshini J L college of institute of technology, Nagpur.

Nikita Gawande

UG student
Department of Electrical Engineering
Priyadarshini J L college of institute of technology, Nagpur..

Anirudha Hastak

UG student
Department of Electrical Engineering
Priyadarshini J L college of institute of technology, Nagpur .

ABSTRACT

Automotive Industry is targeting sustainable transportation in near future. Therefore hybrid and electric vehicles are going to be popular due to their sustainability, energy saving and zero emission. Electric motors play a significant role in Electrical Vehicles. In wheel motor technology is being used in modern electric vehicles to improve efficiency, safety, and controllability of vehicle nowadays. BLDC motor has been demanding as an in-wheel motor in electric vehicles because of high efficiency, desired torque versus speed characteristics, high power density and low maintenance cost. In this paper, BLDC motor with ideal back-EMF is modeled and simulated in MATLAB / SIMULINK.

Keywords- *Simulation of BLDC Motor, In-wheel Motor, Electric Vehicle.*

I. INTRODUCTION

BLDC motor are becoming more popular in our common daily different applications such as industrial automation, automotive, aerospace instrumentation and appliances since 1970's.They help electronic devices to be more reliable and durable. BLDC motor is a novel type of DC motor which commutation is done electronically instead of using brushes. Therefore it needs less maintenance. Also its noise susceptibility is less, looking forward to have integral motor. Electronic commutation technique and permanent magnet rotor cause BLDC to have immediate advantages over brushed DC motor and induction motor in electric vehicle application. In-wheel technology is using a separate motor mounted inside tire for each wheel instead of one central drive train propelling two or all four wheels in conventional electric vehicles. It increases controllability of vehicle and decreases chassis weight. With using in wheel and by-wire technologies instead of mechanical, hydraulic and pneumatic control systems; idea of an Intelligent Fully Electronically Controlled Vehicle (IFECV) approaches to reality. Two wheel drive train system of a commercial IFECV. BLDC has more complex control algorithm compare to other motor types due to electronically commutation. Therefore accurate model of motor is required to have complete and precise control scheme of BLDC. To design of BLDC motor drive system, it is necessary to have motor model gives precise value of torque which is related to current and back-EMF. Different simulation model have been presented to analyze performance of BLDC motor. Lots of various modeling techniques according to different applications of BLDC motor have been used. Although all the previous works made a great contribution to modeling BLDC motor, but there is no simple model. BLDC motor is more

advantageous as compared to brushed DC motor and induction motor in electric vehicle application because of its electronic commutation technique and permanent magnet rotor.
appropriate for in-wheel motor application. Hence in this paper model of 3 phases, 4 poles, Y connected, trapezoidal back-EMF type of BLDC motor for automotive industry application is modeled and simulated in MATLAB / SIMULINK.

WORKING AND OPERATION

In a BLDC motor the stator and the rotor flux maintain a constant angle although both are rotating in space. This is similar to the DC motor, but in the DC motor, both the armature and the field flux are stationary in space. There are two types of BLDC with respect to back-EMF signal of motor; sinusoidal and trapezoidal. There are also two types of BLDC according to have sensors for detecting rotor position or not. Normally Hall Effect sensors were being used for low cost, low resolution requirements and optical encoder for high resolution requirements. Sensor signals are using to adjust PWM sequence of 3-phase bridge inverter. In sensor less control back-EMF sensing, back- EMF integration, flux linkage-based, freewheeling diode conduction and speed independent position function techniques are using for electronic commutation. In this model, Hall Effect signals are produced according to rotor position for commutation. Also a 3-phase inverter using MOSFETs is used as voltage source. Different control techniques can be applied to the model. Hence control techniques of BLDC are not objective of used in loop control algorithm to control speed. Schematic system of BLDC motor drive. simulation model is consisting of three parts. Each part is simulated separately and integrated in overall simulation model. For decoding Hall Effect signals in PWM generator, MATLAB code is written. In this paper a 3 phases, 4 poles, Y connected trapezoidal back-EMF type BLDC is modeled. Trapezoidal back-EMF is referring that mutual inductance between stator and rotor has trapezoidal shape .
Therefore ABC phase variable model is more applicable than d-q axis. With the intention of simplifying equations and overall model the following assumptions are made:

- Magnetic circuit saturation is ignored.
- Stator resistance, self and mutual inductance of all phases are equal and constant.
- Hysteresis and eddy current losses are eliminated.
- All semiconductor switches are ideal

The electrical and mechanical mathematical equations of BLDC are:

$V_a = Ri_a + (L\text{-}M)\, di_a/dt + E_a$ (1)

$V_b = Ri_b + (L\text{-}M)\, di_b/dt + E_b$ (2)

$V_c = Ri_c + (L\text{-}M)\, di_c/dt + E_c$ (3)

$E_a = K_e\omega_m F(\theta_e)$

$E_b = K_e\omega_m F(\theta_e - 2\pi/3)$ (4)

$E_c = K_e\omega_m F(\theta_e + 2\pi/3)$

$T_a = K_t i_a F(\theta_e)$

$T_b = k_t i_b F(\theta_e - 2\pi/3)$ (5)

$T_e = T_a + T_b + T_c$ **(6)**

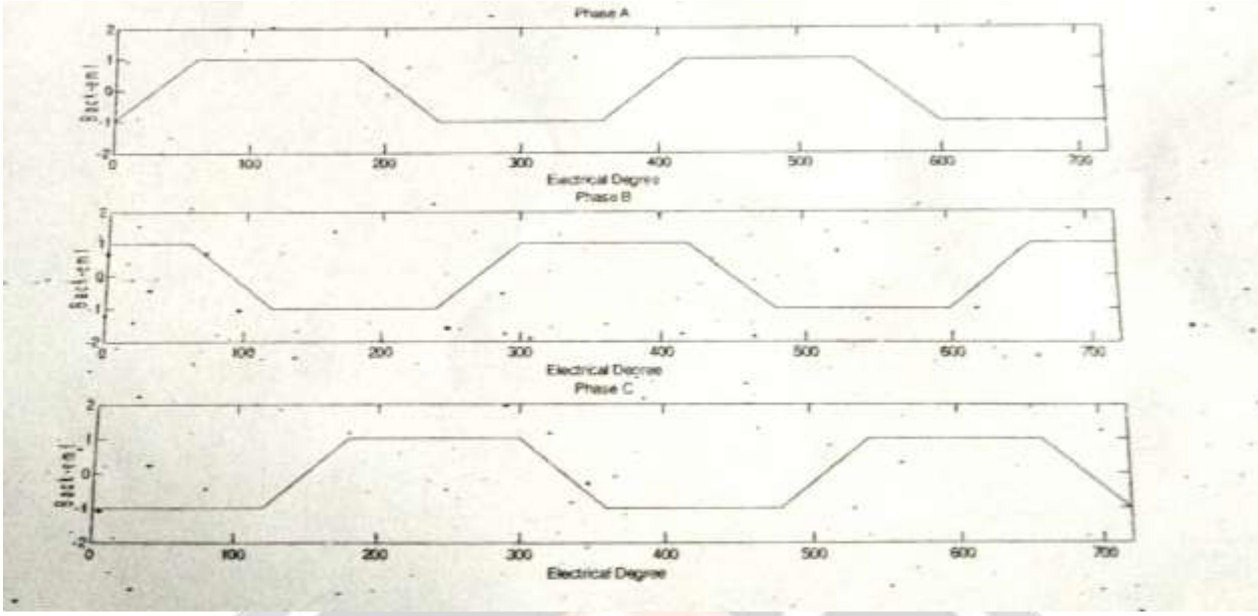
$T_e - T_l = Jd^2\theta_m/dt^2 + \beta d\theta_m/dt$ (7)

$\theta_e = P/2\, \theta_m$ (8)

$\omega m = d\, \theta_m/dt$ (9)

Where k= a, b, c
V_k : kth Phase voltage applied from inverter to BLDC
I_k : kth Phase current
R : Resistance of each phase of BLDC
L : Inductance of each phase of BLDC
M : Mutual inductance
$\boldsymbol{E_k}$: kth phase back- EMF constant
$\boldsymbol{T_k}$: Electric torque produced by kth phase
$\mathbf{T_e}$: Electric torque produced by BLDC
$\mathbf{K_e}$: Back-EMF constant
$\boldsymbol{K_t}$: Torque constant
$\boldsymbol{\omega m}$: Angular speed of rotor
$\boldsymbol{\theta m}$: Mechanical angle of rotor

θe : Electrical angle of rotor
F(θe) : Back- EMF reference as function of rotor position.



Hence it is assumed that phase zones are distributed symmetrically to different phase windings; back-EMF signals have 120 degree phase shift with respect to each Other. For convenient implementation of equation in MATLAB / SIMULINK, most of references are used state space equations. Hence most of motor manufacturers do not wire motor neural point, phase to phase voltage equations are used like in State space form of equations (1), (2), (3) and (7) can be derived as

$V_{ab} = R(i_a-i_b) + (L-M)\, d/dt\, (i_a-i_b) + E_{ab}$ (10)

$V_{bc} = R(i_b-i_c) + (L-M)\, d/dt\, (i_b-i_c) + E_{bc}$ (11)

Where ia +ib +ic =0 therefore after modifying equations (10) and (11) and neglecting mutual inductance,

$di_a/dt = -R/Li_a+2/3L(V_{ab}-E_{ab})+1/3L(V_{bc}-E_{bc})$ (12)

$di_b/dt = -R/Li_b-1/3L(V_{ab}-E_{ab})=1/3L(V_{bc}-E_{bc})$ (13)

$$\begin{bmatrix} \dot{i}_a \\ \dot{i}_b \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{\beta}{J} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ \omega_m \end{bmatrix} + \begin{bmatrix} \frac{2}{3L} & \frac{1}{3L} & 0 \\ -\frac{1}{3L} & \frac{1}{3L} & 0 \\ 0 & 0 & \frac{1}{J} \end{bmatrix} \begin{bmatrix} V_{ab} - E_{ab} \\ V_{bc} - E_{bc} \\ T_e - T_l \end{bmatrix}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \\ \omega_m \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ \omega_m \end{bmatrix}$$

Then state space model of BLDC motor is Implementing of above final state space equation will make model more complex. Although neutral point of motor is not accessible but virtually is possible to estimate it with zero crossing point of back EMF. Also for linear and zero initial condition systems, State space to Laplace transform and vice versa can be written. Therefore final state space equation is divided to two simple and separate electrical and mechanical Laplace equations applied by phase to neutral voltages. It makes the BLDC model more simple and convenient for various control techniques implementation. Ideal reference back-EMF signal of motor also is produced according electrical rotation of rotor in each phase separately and applied as negative feedback to phase voltage. BLDC motor model is shown in fig.1

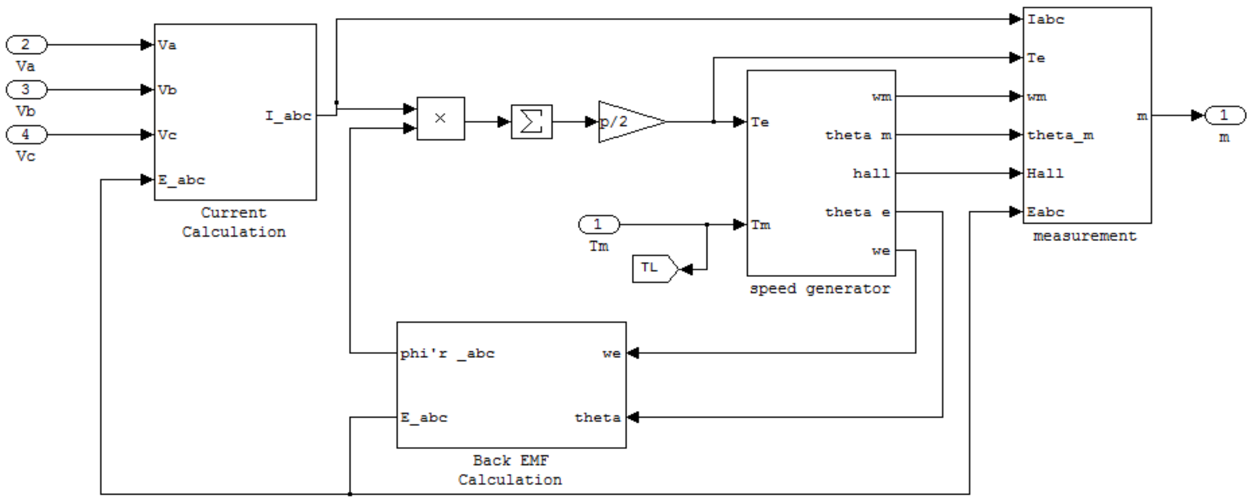
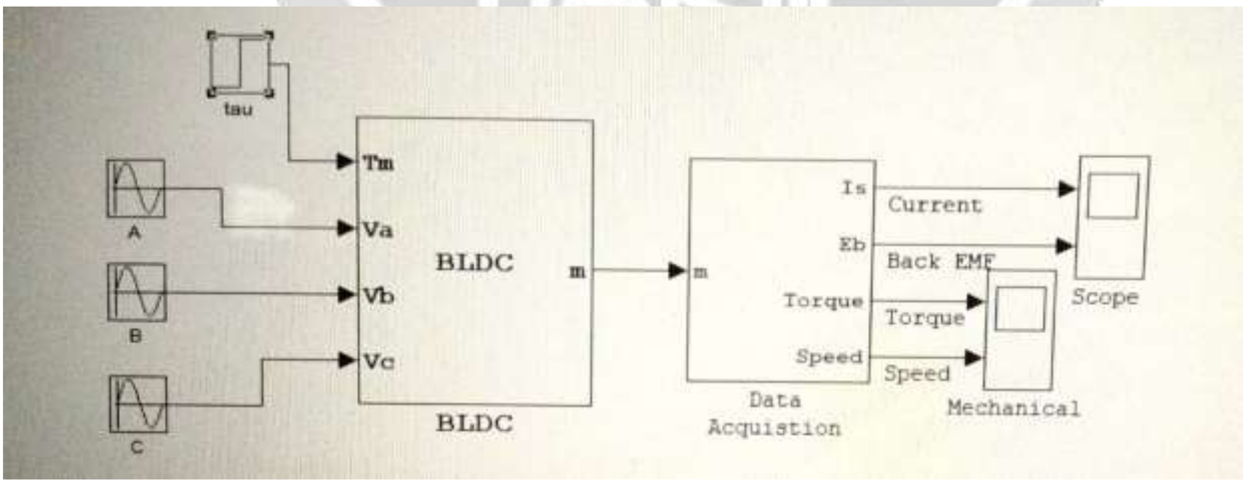


Fig.1. BLDC Motor Model

Table 1

ELECTRICAL DEGREE	HALL 1	HALL 2	HALL 3
0-60	1	0	1
60-120	0	0	1
120-180	0	1	1
180-240	0	1	0
240-300	1	1	0
300-360	1	0	0



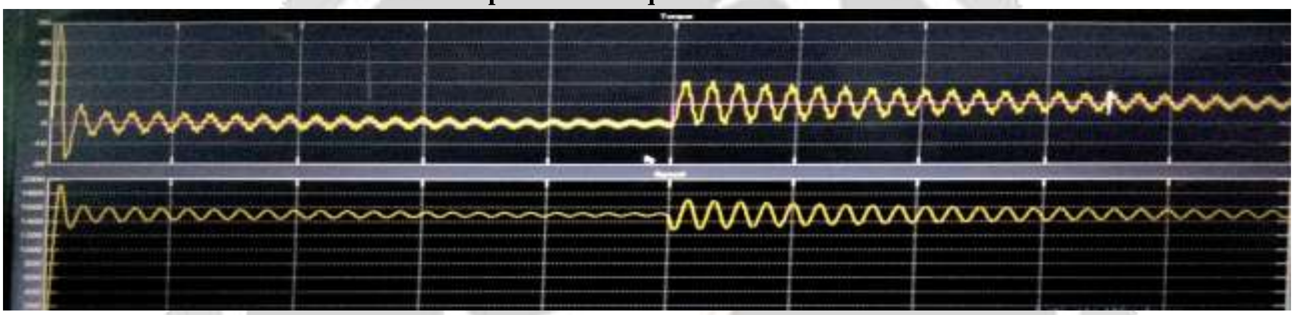
SIMULATION RESULTS

Simulation results of BLDC motor under no load and load conditions are shown. As it can be seen in Fig. 3, dynamic response of BLDC due to its permanent magnet (low inertia) rotor is high. Pulsating torque of BLDC is shown in Fig. 4. Fig. 5. shows back-EMF produced in phase A of motor. Hall Effect signals of all three phase are shown in Fig. 6. according to table I. Table II shows BLDC motor specification to investigate performance of advanced model.

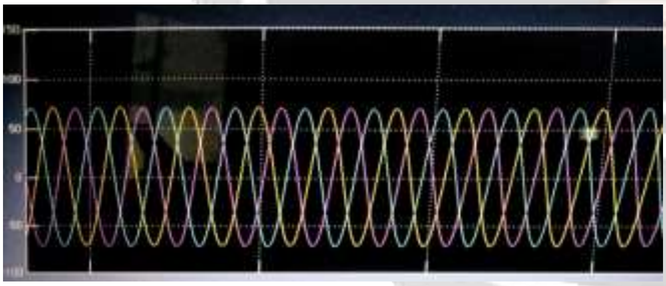
Table 2
BLDC MOTOR SPECIFICATION

DESCRIPTION	VALUE	UNIT
POWER	10	KW
DC VOLTAGE	240	V
PHASE RESISTANCE(R)	1	Ohm
PHASE INDUCTANCE(L)	0.25	m-H
INERTIA(J)	15.17e-6	Kg-m2
DAMPING RATIO	0.001	N-s/m
POLES	4	-

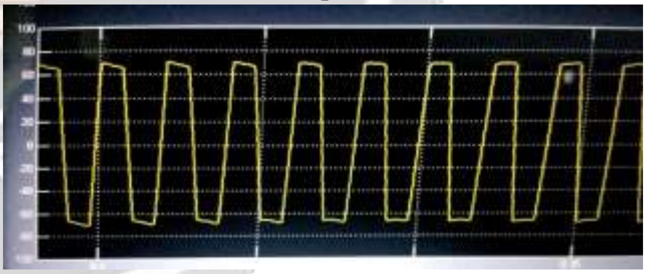
Speed and Torque characteristics

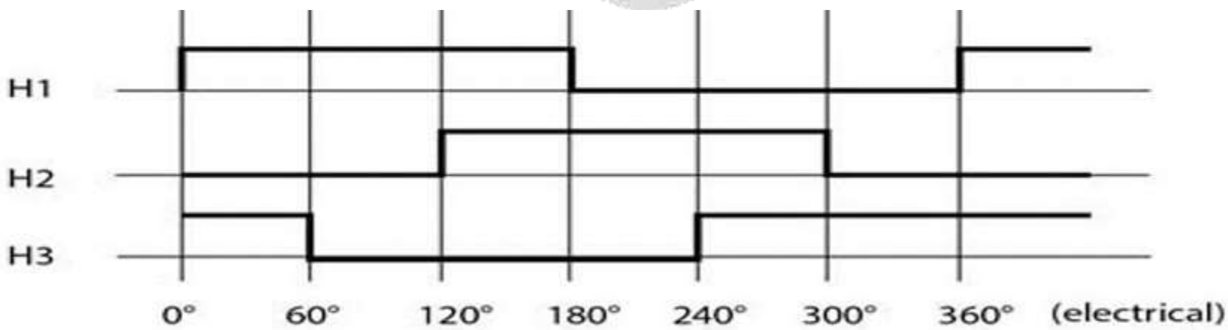


Current Characteristics



Back EMF of phase





Hall effect signals

ADVANTAGES:

- Noise susceptibility is less.
- Less maintenance.
- High efficiency.

CONCLUSION

In this paper it is shown that BLDC motor is a good choice in automotive industry due to higher efficiency, higher power density and higher speed ranges compare to other motor types. BLDC motor model with ideal back-EMF is presented in this paper. The proposed model is simulated in MATLAB / SIMULINK. Simulation results under no load and load conditions are showing proper performance of model. Output characteristics and simplicity of model make it effectively useful in design of BLDC motor drives with different control algorithms in different applications.

REFERENCES

[1] A. Tashakori, M. Ektesabi and N. Hosseinzadeh, "Characteristic of suitable drive train for electric vehicle", 2010 3rd International Conference on Power Electronic and Intelligent Transportation System (PEITS), 20-21 Nov 2010, Shenzhen

[2] Y. S. Jeon, H. S. Mok, G. H. Choe, D. K. Kim and J. S. Ryu, "A new simulation model of BLDC motor with real back EMF waveform", IEEE CNF. On Computer and Power Electronics, 2000. COMPEL 2000. Pp.217- 220, July 2000.

[3] S. Vinatha, S. Pola, K.P. Vittal, "Simulation of four quadrant operation & speed control of BLDC motor on matlab / simulink", TENCON 2008- 2008 IEEE Region 10 Conference, 19- 21 Nov 2008, Hyderabad, India.

[4] Congzhao Cai, Hui Zhang, Jinhong Liu, Yongjun Gao, "Modelling and simulation of BLDC motor in electric power steering", Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific, 28-31 March 2010, Chengdu, China.

[5] Wonbok Hong, Wootaik Lee, Byoung-Kuk Lee, "Dynamic simulation of brushless DC motor drives considering phase commutation for automotive applications", Electric Machines & Drives Conference, 2007. IEMDC '07. IEEE International, 3-5 May 2007, Antalya