# MATLAB / Simulink based Design and Control of Permanent Magnet Brushless DC Motor for Electric Power Steering Application

**Suhashini Shinde**[*1]
[*1]**Department of Electrical Engineering, C.U.K-585367, Karnataka, India**

*Abstract*— ***This paper presents a MATLAB / Simulink based design and simulation of Permanent Magnet Brushless DC (PMBLDC) Motor for Vehicular Applications. Nowadays for a vehicle design, electric power steering (EPS) is an advanced technology. A control scheme is presented in this paper based on the design of PMBLDC motor and requirements of EPS for assist motor. In this work, hysteresis current controller and rotor position sensors are designed to control the assist torque from the PMBLDC motor. The easy operation, accuracy of the system and implemented control schemes are validated by the MATLAB / Simulink based results.***

***Index Terms— Permanent Magnet Brushless DC (PMBLDC) motor, hysteresis control, current control, electric power steering (EPS), torque.***

## I. INTRODUCTION

Permanent Magnet Brushless DC (PMBLDC) Motor has significant importance because of inherent properties like high efficiency, low noise operation, maintenance free, etc.... These are widely used in many applications like automation, military, health sector, energy sector, home appliances and for many applications. Hence, it is important to design low cost and efficient speed controller for PMBLDC Motors [1-3].

One of the recent advancement in vehicle technologies is electric power steering (EPS) [3]. BMW vehicles upgraded to the EPS technology [4]. The EPS uses an electric motor to provide the steering assist. The EPS doesn't require fuel hence save in fuel cost, protecting environment and at any condition of operation, it can be easy to modify by changing the design of controller software to adjust the system's characteristic of power assistance [5]-[6].

Nowadays brush DC motors used in EPS has been gradually replaced by the PMBLDC motors because it uses the electronic commutation technology instead of mechanical commutation, high starting torque, high efficiency , simple in structure, wide speed range , reliable operation , etc.. [7]- [8].

Rest of this paper is organized as a brief introduction to role of Permanent Magnet Brush-Less DC (PMBLDC) Motor in advanced vehicle technology applications of electric power steering (EPS) is given in Section. I. Design and modeling aspects of PMBLDC Motor is discussed in Section. II. PMBLDC Motor based EPS control design and its MATLAB/Simulink based results are discussed given in Section.III. Finally conclusion is given in Section. IV.

## II. DESIGN AND MATHEMATICAL MODELING ASPECTS OF PMBLDC MOTOR

In PMBLDC Motor three stator phase windings are connected in a star manner. Fig.1. shows the equivalent circuit of a PMBLDC Motor.

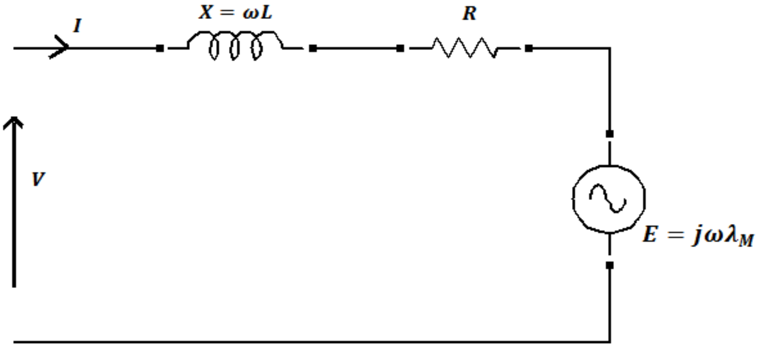


Fig.1. Equivalent circuit of a PMBLDC Motor

The windings of a PMBLDC Motor modelled are in a series combination of Resistance (R) and inductance (L). Speed of the BLDC motor depends on the voltage source, which is known as the back EMF (E) [4]. The three phase voltages are given by the equations (5), (6) & (7).

$$V_A = R_S . I_A + \frac{d}{dt} F_A + E_A \tag{5}$$

$$V_B = R_S.I_B + \frac{d}{dt}F_B + E_B \quad (6)$$

$$V_C = R_S.I_C + \frac{d}{dt}F_C + E_C \quad (7)$$

The relation between the back EMF waveform and the armature current (I) of an ideal BLDC motor is shown by the Fig.2. The shape of the currents should in rectangular waveform and must be in-phase with the corresponding phase back EMF [9]-[10].

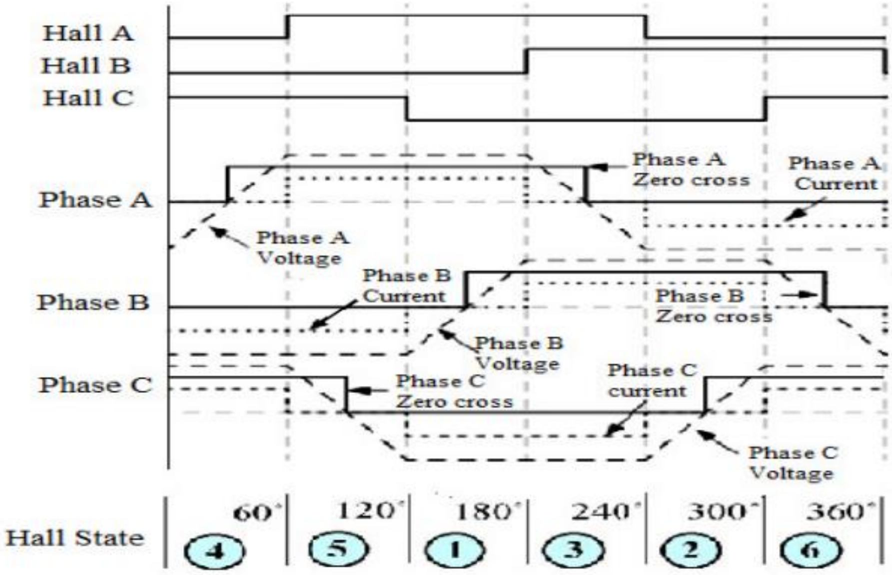


Fig.2. Waveform of back EMF and phase current with respect to hall-sensor position

If the self and mutual inductance around the air gap are consider to be constant, then there will be a direct relation between the applied source voltage of the phase terminals (V) and the induced back EMF (E) is given by equation (8) and the electromagnetic torque (Te ) in N.M is given by equation (9)

$$E \propto V \quad (8)$$

$$T_e = \frac{(E_A.I_A + E_B.I_B + E_C.I_C)}{\omega_r} \quad (9)$$

Where, $\omega_r$ = Rotor mechanical speed
, $V_A$= Phase "A" voltage
$V_B$= Phase "B" voltage
$V_C$= Phase "C" voltage
$I_A$ = Phase "A" current
$I_B$ = Phase "B" current
$I_C$ = Phase "C" current
$R_S$ = Stator resistance
$F_A$= Phase "A" stator flux linkages
$F_B$= Phase "B" stator flux linkages
$F_C$= Phase "C" stator flux linkages
$E_A$ = Phase "A" back EMF
$E_B$ = Phase "B" back EMF
$E_C$ = Phase "C" back EMF

## III. MATLAB/SIMULINK RESULTS OF PM BLDC MOTOR BASED EPS CONTROL SYSTEM

In this work, current control strategy is adopted for the PMBLDC motor of EPS. This control strategy requires only torque signal of wheel and speed signal of vehicle. The control scheme of the proposed PMBLDC motor based EPS system is shown in Fig. 3 [11]. Calculated specifications of the overall system is given by the Table.1 and according to the related formulations and specifications simulation model has developed and is shown by the Fig.4.

Fig.5. Shows the MATLAB/Simulink based resultant torque response of proposed systems. It's clear, with the sudden increase of the load; the torque has a greater pulse, which is mainly caused by the current commutation and frequent switching of the current hysteretic controller.

Fig.6. shows the MATLAB/Simulink based resultant speed response waveform. It's clear that whatever the time at 0.25s or 0.4s, when the load suddenly increases or reduced, the speed response reached steady-state is fast. Hence the system has smooth and quick response.

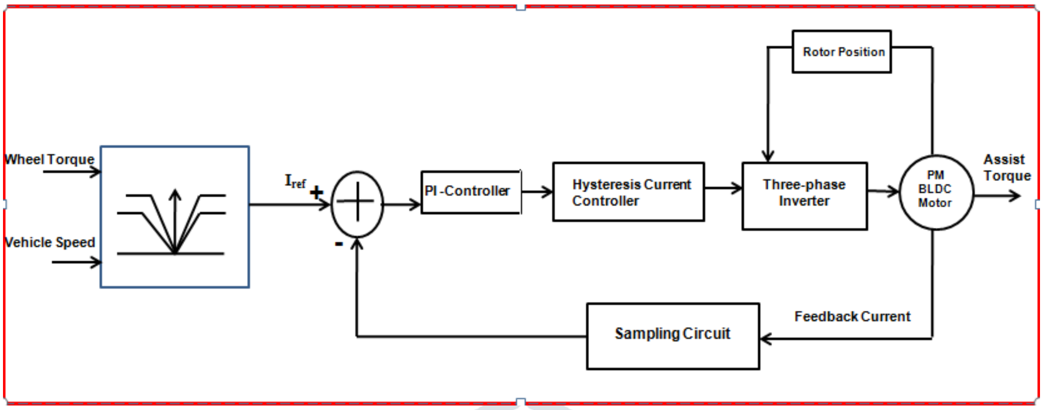


Fig.3. Block diagram of control scheme of PMBLDC motor system in EPS

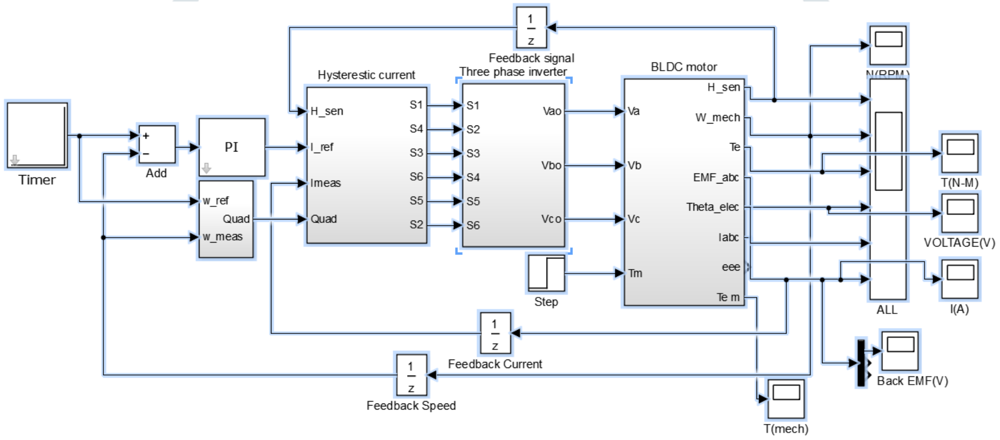


Fig.4. MATLAB/Simulink experimental diagram of control scheme of PMBLDC motor system in EPS with masked blocks

TABLE I
SPECIFICATIONS OF THE PMBLDC MOTOR BASED EPS SYSTEM

| Sl. No | Name of the parameter | Rating of the parameter |
|---|---|---|
| 1 | Rated speed in r/min | 1000 |
| 2 | Stator phase winding resistance in Ω | 0.1 |
| 3 | Self-inductance of stator winding in mH | 1 |
| 4 | Mutual inductance in mH | 0.5 |
| 5 | Motor inertia in kg.m$^2$ | 0.002 |

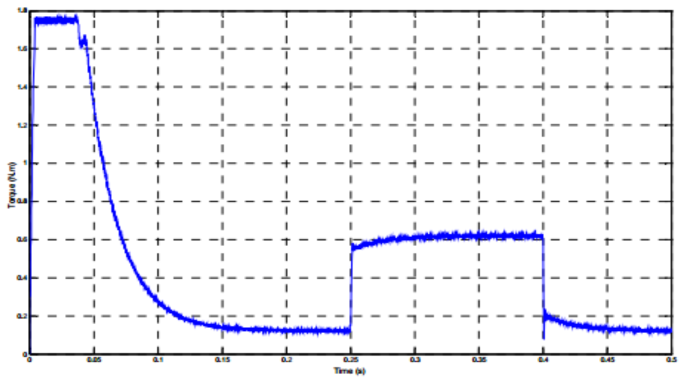

Fig.5 Torque response waveform of the proposed system

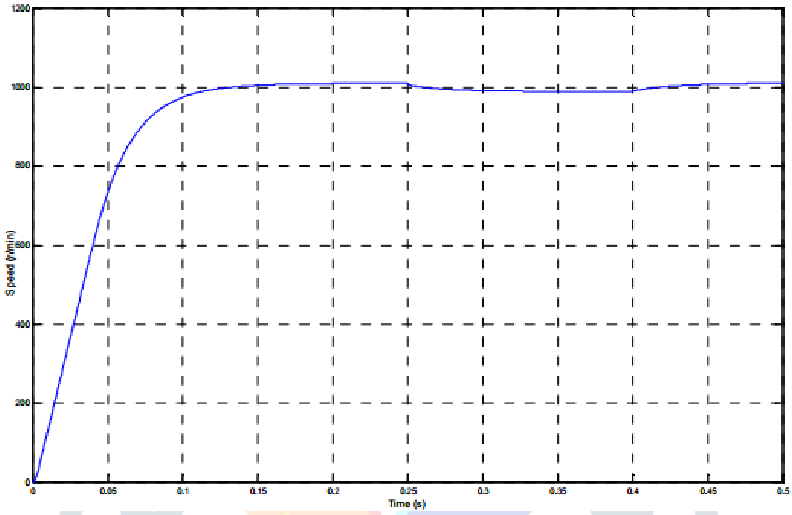


Fig.6. Speed response waveform of the proposed system

## IV. CONCLUSION

Thus, in this paper modelling and control of PMBLDC motor in EPS vehicular application has simulated in MATLAB/Simulink gui environment. The simulation results prove that the developed control strategy of the PMBLDC motor is in the acceptable range. For further research on the EPS control strategies an Artificial Intelligence (AI) based fuzzy logic control (FLC) techniques, optimization technique methods can be adapted.

## REFERENCES

[1] P. Pillay, R. Krishnan, “Modeling, simulation, and analysis of permanent magnet motor drives. I. The permanent-magnet synchronous motor drive”, IEEE Trans. Ind. Appl. 25 (2) (1989) pp.265–273.

[2] Wenxin Liu, Li Liu Il-Yop Chung David A. and Cartes Wei Zhang, “Modeling and detecting the stator winding fault of permanent magnet synchronous motors”, Elsevier Publications, Simulation Modelling Practice and Theory 27 (2012) pp.1–16.

[3] Dr. B. Singh, Prof B P Singh and C. L. Putta Swamy, “Modeling of Variable Structure Controlled Permanent Magnet Brushless dc Motor”, *IE(I)* Journal-EL, Vol.75, February 1995.

[4] Nunney, Malcolm James, “Light and Heavy Vehicle Technology”, Elsevier Science. p. 521. ISBN 978-0-7506-8037-0. Retrieved 18 June 2010.

[5] [Online available]: https://en.wikipedia.org/wiki/Power_steering.

[6] Mandy Concepcion, “BMW Automotive Technologies”, Edition: 2, ISBN: 14849-33532, May 10 2013.

[7] Wu Jie, Wang Yun-Yan, “A New Technique for Reducing Cogging Torque in EPS Permanent Magnet Brushless DC Motor[C]”, Hubei University of Technology. Proceeding of International Conference on Electrical Machines and Systems 2007, Oct. 8~11, Seoul, Korea, pp. 789-791.

[8] Emilia Silva , Eric Backx, Theo Hofman , Henk Voets and Maarten Steinbuch , “Design of Power Steering Systems for Heavy-Duty Long-Haul Vehicles”, Proceedings of the 19th World Congress The International Federation of Automatic Control Cape Town, South Africa. August 24-29, 2014, pp. 3930- 3935.

[9] W. Yuanxi, Yu Yali, Z. Guosheng, S. Xiaoliang, "Fuzzy Auto- adjust PID Controller Design of Brushless DC Motor", Elsevier International conference on medical physics and biomedical engineering, pp. 1553-1559, 2012.
[10] Bhim A. Rajan, R. Raj, S. Vasantharathna, "Fuzzy Based Reconfigurable Controller for BLDC Motor", IEEE, International conference on computing, communication and networking technologies, 2010.
[11] Yan Wei-Sheng, Lin Hai, Li Hong,Yan Wei, "Sensorless Direct Torque Controlled Drive of Brushless DC Motor based on Fuzzy Logic", IEEE Trans. on Ind. Elec. and Appl., Vol.23, No.4, July 2009.