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Modeling and Simulation of BLDCM Using MATLAB/SIMULINK

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Abstract: The aim of this study was to modeling of three phases Brushless DC Motor (BLDCM) with MATLAB/SIMULINK package program. Brushless DC motors (BLDCM) have important advantages according to brushed DC motors and induction motors. They have better speed/torque characteristics, high efficiency, high dynamic response, small size construction and so on. The design and analysis of complex power electronic systems such as motor drives is usually done using a modern simulation software, such as MATLAB/SIMULINK, SPICE, EMTP, SABER, SPECTRE, SIMPLORER, etc., which can provide accurate predictions of the systems behavior in reality.

Key words: MATLAB/SIMULINK, brushless DC motor, simulation techniques, modeling

INTRODUCTION

During the last decade, classical and modern control system design methods, involving advanced mathematical techniques and time-consuming calculations have been greatly aided by software packages such as MATLAB/SIMULINK, SPICE, EMTP, SABER, SPECTRE, SIMPLORER, etc., which can provide accurate predictions of the systems behaviour in reality. In recent years, BLDCM has become a popular choice in industry applications such as automotive, aerospace, consumer, medical, instrumentation. BLDCM have advantages over brushed DC motors and induction motors. They have better speed versus torque characteristics, high efficiency, high dynamic response and so on. Also, torque delivered to the motor size is higher, making it useful in applications where space and weight are critical factors. However, BLDCM need position information for torque producing. The position information is usually obtained via measurement using device such as position encoder, resolver or Hall Effect sensors. These devices increase machine size, cost and rotor inertia, additionally also make the drive system complex and mechanically robustness[1,2].

A three phase BLDCM has three phase windings on the stator and permanent magnet rotor. The difference between this machine and the Permanent Magnet Synchronous Motor (PMSM) is that the machine back EMF is trapezoidal[3]. Some confusion exists as to the correct models that should be used in each case. The BLDCM is very similar to the standard wound rotor synchronous machine except that the BLDCM has no damper windings and excitation is provided by a permanent magnet instead of a field winding[4,5].

MATHEMATICAL MODEL OF BLDCM

Figure 1 shows a dynamic equivalent circuit of the BLDCM. In simulation, the common "y" connection of stator windings, three phase balanced system and airgap uniform are assumed[5].

For this model, the stator phase voltage equations in the stator reference frame of the BLDCM are as Eq. 1;

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_a & L_{ab} & L_{ac} \\ L_{ba} & L_b & L_{bc} \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

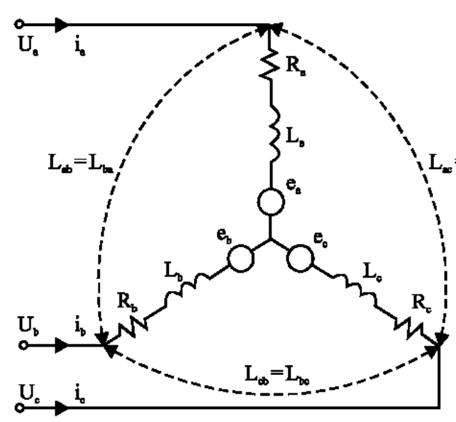

Fig. 1: Equivalent circuit of BLDCM

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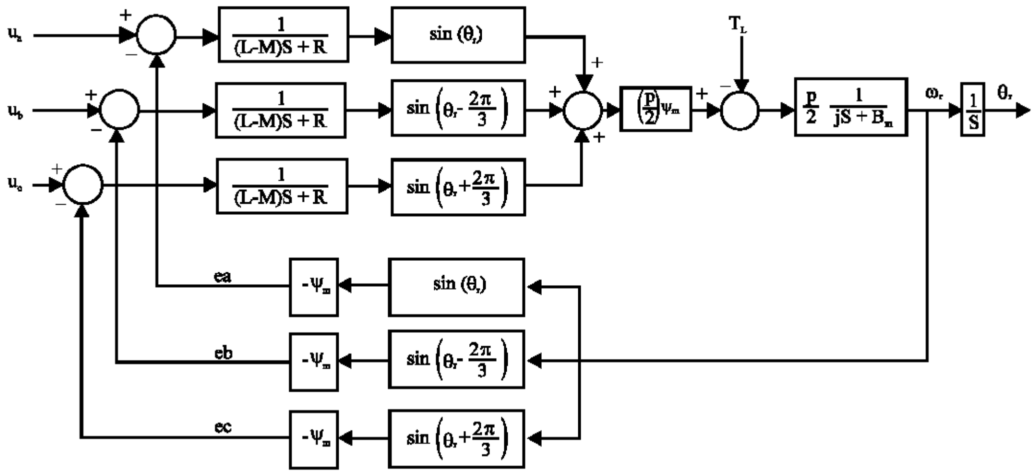

Fig. 2: Block diagram of BLDCM

In here, back EMF is depend to magnetic flux in rotor because of permanent magnet with speed of rotor Eq. 2.

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = -\omega_r \psi_m \begin{bmatrix} \sin(\theta_r) \\ \sin\left(\theta_r - \frac{2\pi}{3}\right) \\ \sin\left(\theta_r - \frac{4\pi}{3}\right) \end{bmatrix} \tag{2}$$

Motor equations can be expressed in state-space form as Eq. 3

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{1}{(L-M)}\left\{ \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \psi_m \omega_r \begin{bmatrix} \sin(\theta_r) \\ \sin(\theta_r - \frac{2\pi}{3}) \\ \sin(\theta_r - \frac{4\pi}{3}) \end{bmatrix} \right\} \tag{3}$$

Electrical exist power of motor can be calculated using Eq. 4.

$$P = e_a i_a + e_b i_b + e_c i_c \tag{4}$$

Electromagnetic torque can be calculated as Eq. 5.

$$T_e = \frac{P}{\omega_m} \tag{5}$$

Electromagnetic torque to be motor dynamic equations can be expressed as Eq. 6.

$$T_e = j\left(\frac{2}{p}\right)\frac{d}{dt}\omega_r + B_m\left(\frac{2}{p}\right)\omega_r + T_L \tag{6}$$

Equation 6 can be arranged as Eq. 7 in state-space form (2).

$$\frac{d}{dt}\omega_r = \left(\frac{p}{2j}\right)\left[T_e - B_m\left(\frac{2}{p}\right)\omega_r - T_L\right] \tag{7}$$

Speed of motor is proportional position of rotor Eq. 8.

$$\frac{d}{dt}\theta_r = \omega_r \tag{8}$$

Figure 2 shows block diagram of mathematical model in three phases BLDCM.

SIMULATION OF THE BLDCM

The model of MATLAB/SIMULINK was shown in Fig. 3 according to rotor reference frame of the BLDCM for simulation of motor using equations which have been given above. Parameters which have been belong to motor used simulation are as below;

R = 11.05 ohm, L = 0.0215 henri, P = 6, J = 0.0001, B = 0.001 φ = 0.11weber, M = 0.002 henri, T_L = 0.1 Newton, V = 2*10/π

i_a, i_b, i_c currents in the result of simulation has been given in Fig. 4.

Speed of the BLDCM in the result of simulation has been given in Fig. 5.

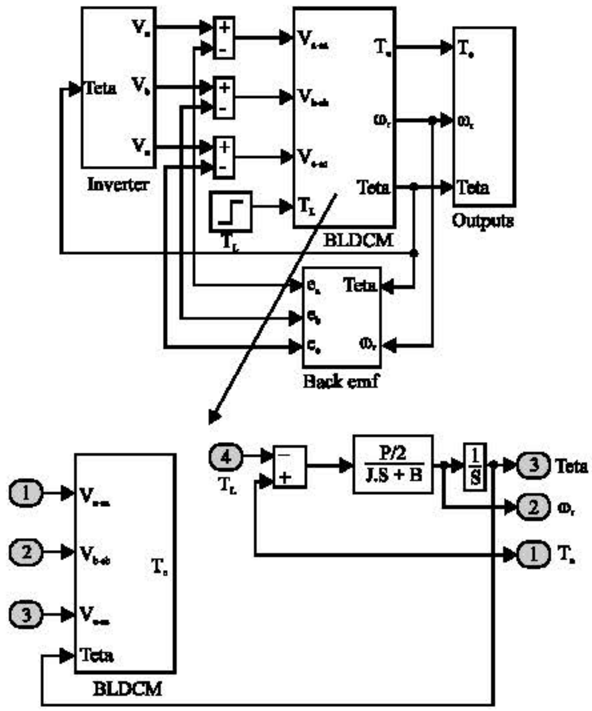

Fig. 3: MATLAB/SIMULINK model of the BLDCM

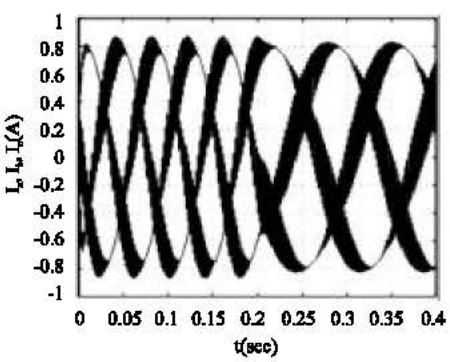

Fig. 4: i_a, i_b, i_c motor phase currents

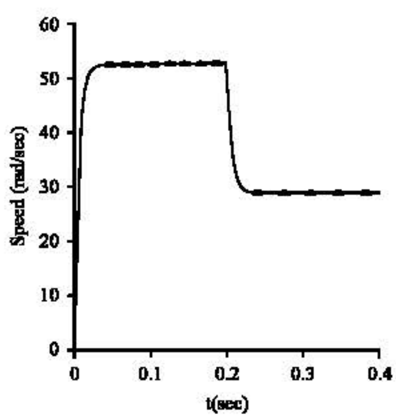

Fig. 5: Speed of the BLDCM

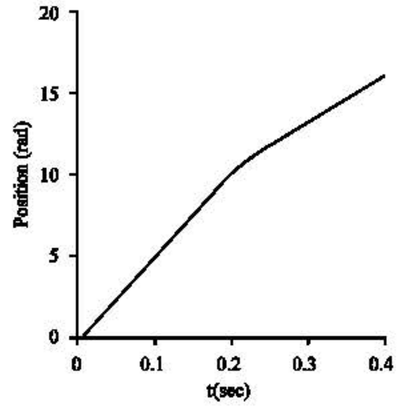

Fig. 6: Position of the BLDCM

Position of the BLDCM in the result of simulation has been given in Fig. 6.

CONCLUSIONS

In this study, MATLAB/SIMULINK based modeling and simulation of the BLDCM is presented. This model can be provide a guide in the modeling of the BLDCM for investigators. This model has a flexible structure and enables to users to change motor parameters easily.

NOMENCLATURE

B	Friction constant, N/rad/s
i_a, i_b, i_c	Motor phase currents, A
J	Moment of inertia, kg m^2
L	Inductances, H
M	Mutual inductance, H
P	Number of pole pairs
R	Stator resistance, Ω
T_e	Electric torque, Nm
T_y	Load torque, Nm
U_a, U_b, U_c	Phase voltages, V
ω_r	Rotor speed, Rad/s
θ_r	Angle between stator and rotor, rad

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