Brushless DC Motor Speed Control System Simulink Simulation

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Abstract—**According to the mathematical model of a brushless DC motor, using MATLAB / Simulink to build various independent functional modules, and integrated into the simulation model of brushless DC motor control system. The system uses the double loop of control mode , including the inner current loop and the outer speed loop, to ensure that the motor is performance well in the high and low speed, and system has start fast, flexible control, robustness and other advantages. By conducting the two simulation experiments of tracking the speed and keeping the speed stability, we preliminarily verify the effectiveness and reasonable of the system modeling method and the feasibility of the control system design, simulation and setting parameters can also be made to optimize the actual controller control and commissioning reference.**

Keywords-BLDCM; speed control system; simulation and modeling

I. INTRODUCTION

Brushless DC motor (BLDCM) is a mechatronic control system, which is integrated closely by the motor, the modern electronic technology and micro-control technology. With the reducing cost of permanent magnetic materials and power semiconductors, the market continues to expand, more and more widely used in computer peripherals, office automation equipment, digital consumer electronics; industrial drives, servo control; automotive industry; medical equipment; household appliances; aerospace and other industries [1]. Thus the design requirements of BLDCM system gradually improves, and accurate simulation of its control system is particularly critical.

In this paper, we study the trapezoidal wave / square wave BLDCM having a series-wound DC motor starting characteristics and shunt DC motor speed characteristics. To be able to easily analysis its theoretical and verify various control programs and control algorithms, based on motor parameters and actual operating conditions, this paper establish BLDCM control system simulation model by MATLAB Simulink software module, and the simulation results as the actual system debugging data basis. The structure is organized as follows: Section 2 presents overall block diagram of the BLDCM control system, and describes the mathematical model of BLDCM. Section 3 establishes BLDCM simulation model by MATLAB/Simulink according to the motor theory. Finally, Section 4 conducts simulation experiments and comparative, moreover points out further work.

II. BLDCM CONTROL SYSTEM STRUCTURE AND MATHEMATICAL MODEL

A. *The Architecture of BLDCM Control System*

Brushless DC motor system block diagram is shown as Fig.1, mainly by the DC power supply, three-phase full-bridge inverter circuit, a motor body and a rotor position sensor, a controller composed of four parts.

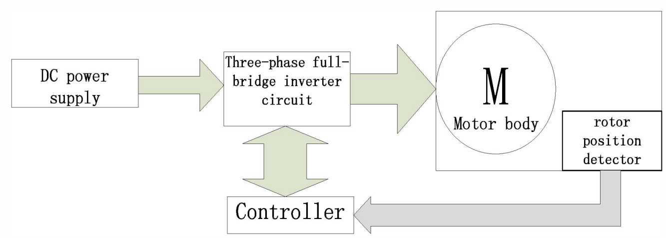

Figure 1. BLDCM system block diagram.

In short, the DC power driving BLDCM. According to the rotor position information provided by the Hall position sensor, the controller controls the three-phase full-bridge inverter circuit of six switches, so that the inverter circuit output needed current drive motor body [2].

B. *The Mathematical Model of BLDCM*

According to the motor phase variable, mathematical model is established using a-b-c coordinate system. The motor equivalent diagram is shown as Fig. 2. To simplify the analysis, we assume that the following conditions are true:

- three-phase windings 60° with the whole pitch concentrated winding, Y connection, completely symmetrical, evenly distributed in the smooth surface of the stator, no cogging;
- ignoring armature reaction, uniform distribution of air-gap magnetic field;
- an unsaturated magnetic circuit, ignoring eddy current and hysteresis losses;
- permanent magnet rotor without damping effect [3].

1) Voltage equation

By an equivalent circuit diagram of Fig. 2 can be obtained BLDCM three-phase voltage balance equation:

$$
\begin{bmatrix} u_U \\ u_V \\ u_W \end{bmatrix} = \begin{bmatrix} r & 0 & 0 \\ 0 & r & 0 \\ 0 & 0 & r \end{bmatrix} \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} + \begin{bmatrix} e_U \\ e_V \\ e_W \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} \tag{1}
$$

In formula (1), u_U 、 u_V and u_W represent three-phase winding voltage; r is the internal resistance of each phase winding; L is each phase winding inductance; M is winding each mutual sense.

2) Torque equation and mechanical motion equation

From the perspective of energy conservation, the output power mostly through the electromagnetic torque to drive the rotor to do work, the BLDCM torque equation is:

$$
T_e = \frac{P_e}{\omega} = \frac{e_U i_U + e_V i_V + e_W i_W}{\omega} \tag{2}
$$

In formula (2), P_e is electromagnetic power; T_e is electromagnetic torque; ω is the rotor angular velocity.

Rotation of the rotor requires to overcome load torque and the other resistances (such as bearing friction, etc.), thus the motor equation of motion:

$$
T_e - T_L - B_d \omega = J \frac{d\omega}{dt} \tag{3}
$$

In formula (3), T_L is load torque; B_d is damping coefficient; J is rotor inertia.

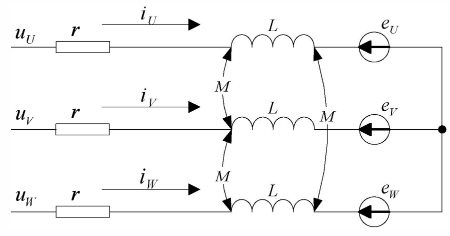

Figure 2. Motor equivalent diagram.

III. BASED ON MATLAB BLDCM SYSTEM MODELING

In the MATLAB / Simulink environment, using the built-in functions and M Systems model library SimPower, we establish the complete BLDCM system model, which is shown as Fig. 3.

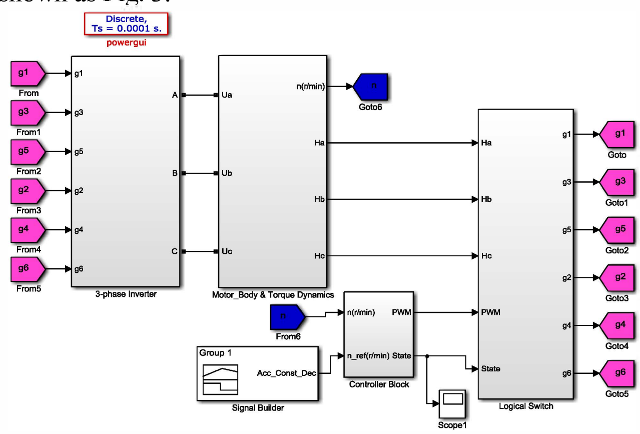

Figure 3. Overall control block diagram.

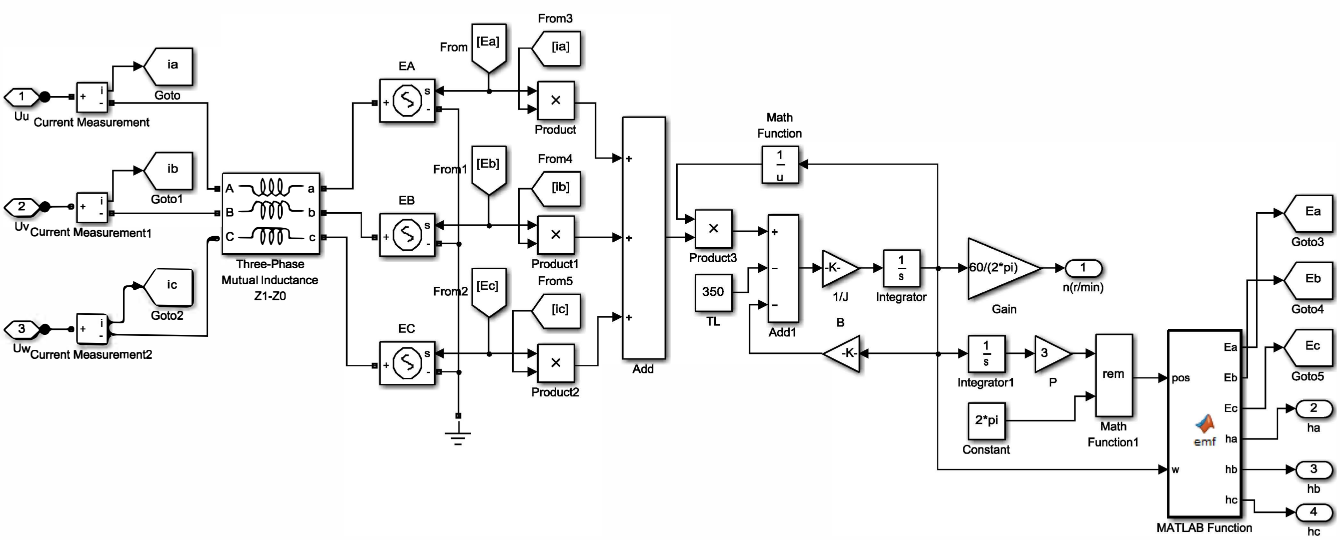

Figure 4. Motor body model.

Based on the idea of modular modeling, the model is divided into the following sub-modules: Motor_Body & Torque Dynamics, 3-phase Inverter, Logical Switch and Controller Block, wherein the Logical Switch is part of the controller unit.

A. *Motor_Body Model and Torque Dynamics*

Motor body's mathematical model is to describe the working principle of BLDCM, including stator winding speed and torque calculated, as shown in Fig. 4. The mechanical angle of the motor turn rotor can be obtained by the integrating operation of the angular velocity ω, multiplied by the number of pole pairs p to get motor angle, and then carry out the electrical angle of 2π remainder operation, that was the rotor position signal pos, which is the input of M function block.

BLDCM directly detectable hall signals to determine the position of its rotor, in accordance with the rotor position, a motor operating cycle is divided into six segments, each can be used to obtain the value of the counter electromotive force by solving the linear segments, Table I shows the rotor electrical angle different the output signals at M function[4].

TABLE I. M—FUNCTION OUTPUT SIGNALS OF ROTOR AT DIFFERENT ELECTRICAL ANGLES

Rotor position	Ha Hb Hc	Conduction phase	Counter electromotive force of each phase winding
0° ~60°	1 1 0	UV	$Ea=k_e\omega$ $Eb=-k_e\omega$ $Ec=k_e\omega(1-pos/(\pi/6))$
60° ~120°	0 1 0	UW	$Ea=k_e\omega$ $Eb=k_e\omega((pos-\pi/3)/(\pi/6)-1)$ $Ec=-k_e\omega$
120° ~180°	0 1 1	VW	$Ea=k_e\omega((2\pi/3-pos)/(\pi/6)+1)$ $Eb=k_e\omega$ $Ec=-k_e\omega$
180° ~240°	0 0 1	VU	$Ea=-k_e\omega$ $Eb=k_e\omega$ $Ec=k_e\omega((pos-\pi)/(\pi/6)-1)$
240° ~300°	1 0 1	WU	$Ea=-k_e\omega$ $Eb=k_e\omega((4\pi/3-pos)/(\pi/6)+1)$ $Ec=k_e\omega$
300° ~360°	1 0 0	WV	$Ea=k_e\omega((pos-5\pi/3)/(\pi/6)-1)$ $Eb=-k_e\omega$ $Ec=k_e\omega$

B. *Three-Phase Full-Bridge Inverter Circuit*

Three-phase full-bridge inverter circuit model is shown as Fig. 5, which uses an integrated unit IGBT and diode in parallel.

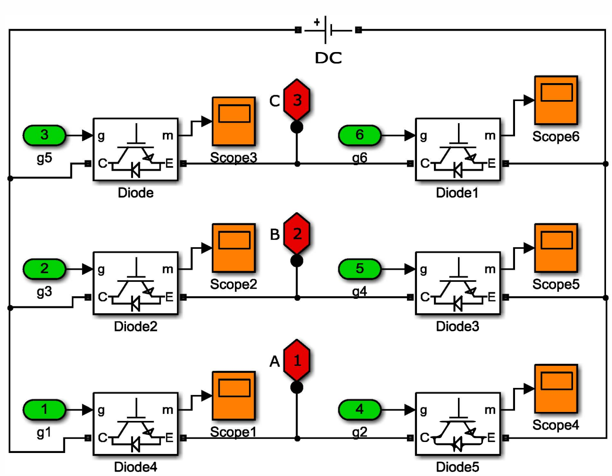

Figure 5. Model of 3-phase inverter.

C. *Logical Switch*

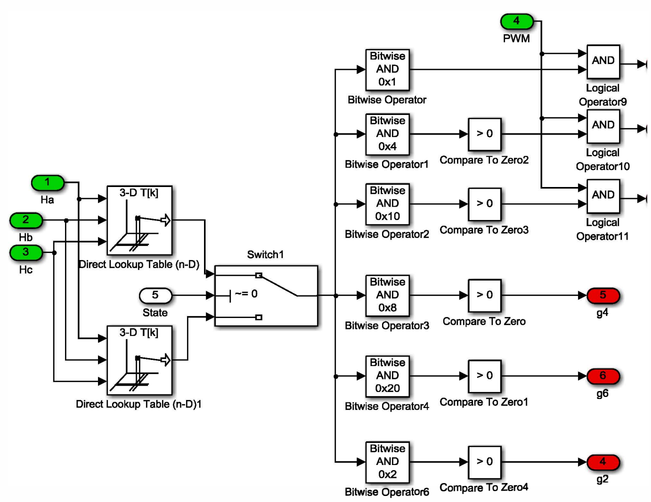

Figure 6. Block diagram of logical switch.

The current state signal (electric or power), three hall position signal and the PWM signal as the input signal of logic switch, and we use direct lookup table to control the six IGBT of full-bridge inverter circuit turn-off. Wherein, g1, g3, g5 control upside transistor opening and closing, and g2, g4, g6 control underside transistor opening and closing. The drive circuit uses tube modulation mode, in other words, the upside transistor using pulse width modulation, and the underside transistor full-on. Logic switch unit internal block diagram is shown as Fig. 6.

D. *Controller Block*

The control module uses the double loop control of current loop and speed loop. Wherein, the speed loop's input is the difference between the reference speed and the actual speed, through speed PI regulator, which output is reference current. The difference between the reference current and real-time winding current value as a current loop input, through current PI regulator, its output is the voltage control signal[5]. The signal is then compare with triangular wave to generate the PWM signal. The specific model is shown as Fig. 7.

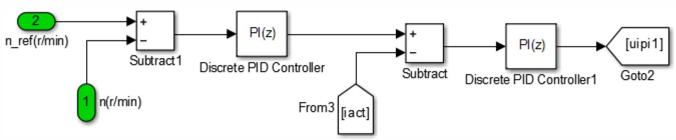

Figure 7. Double-loop PI regulator block diagram.

Motor operation switcher block diagram is shown as Fig. 8. Once the actual speed off the target speed is too large, and more than a certain threshold value, it is determined whether the state work properly. If correct, switching operation.

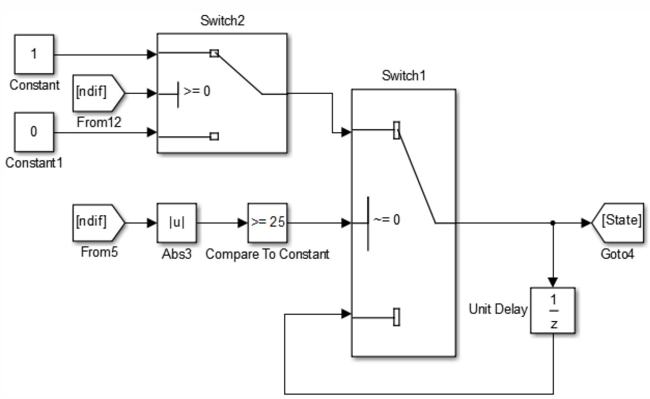

Figure 8. Block diagram of operating state shift.

IV. SIMULATION AND ANALYSIS

We conducted two simulations: one is that we keep the load torque constant and change the target speed, then observe the case of the actual speed tracking target rotation speed; another is that the target rotational speed keep constant and the load torque is constantly changing[6], then observe the stability of the actual speed.

Simulation motor parameters is shown as Table II:

From the figure, blue, green and red curves of the upper window represent the target speed, actual speed and the difference between them; square wave of the bottom window reflects changes in the operation mode of motor, 1 represents electric, 0 represents regenerative braking power.

TABLE II. MOTOR PARAMETERS

Power	37KW	DC supply voltage	513V
Rated speed	900r / min	Full speed	1100 r / min
winding inductance	4.1e-5H	mutual inductance	4.4e-6H
resistance	8.3e-3Ω		

In speed tracking experiment (constant load torque, target speed changes), we will load torque is set to 350N • m. The results shown in Fig.9.

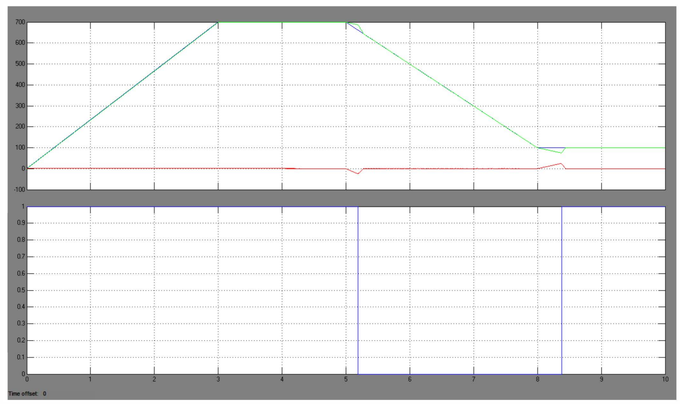

Figure 9. Result of speed tracing experiment.

In the stability test speed (constant target speed, load torque changes), we set the target rotation speed to 800 r / min. The result is shown as Fig. 10.

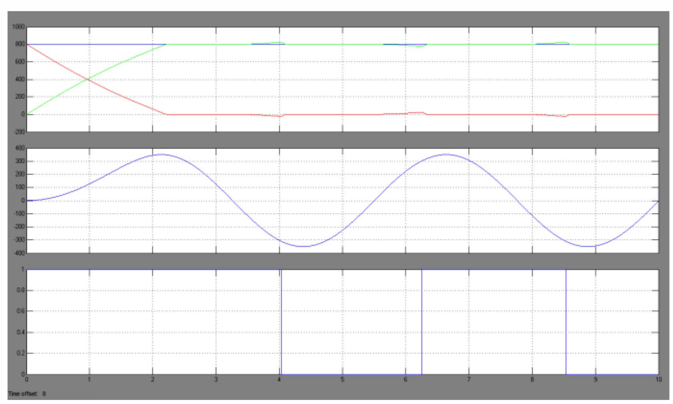

Figure 10. Result of speed stability experiment.

From the figure, blue, green and red curves of the upper window represent the target speed, actual speed and the difference between them. In the middle of the window, curve represents the applied load. The square wave of lower window reflects the motor operation mode Variety.

As it can be seen from the simulation results of two experiments, fast dynamic response, speed error in addition to switching motor operation at a larger (but in the design allowable range), and the remaining time is almost zero, the system controls to good effect.

When the motor is running at a constant speed, the phase current waveform and the counter electromotive force waveform are shown as Fig. 11.

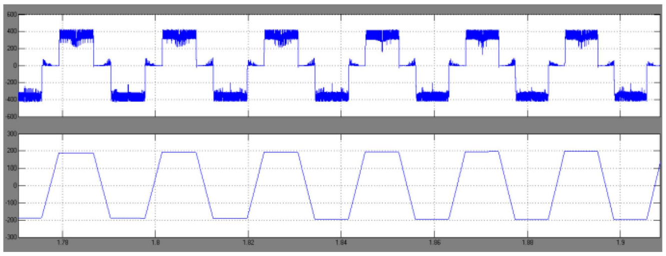

Figure 11. Waveform of phase current and CEMF.

As can be seen from the figure above, counter electromotive force waveform is consistent with the theory; due to the PWM modulation, the top of phase current waveform appear larger disturbance.

Six-way IGBT control signals shown in the inverter circuit is turned off as shown in Fig. 12.

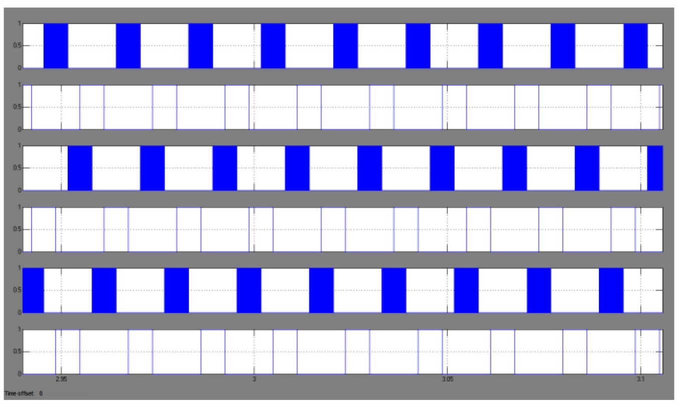

Figure 12. Control signals of six IGBTs.

In the figure, top-down control signal of IGBT were g1, g2, g3, g4, g5, g6 (refer to Fig.5). Visiblely, in the corresponding conduction phase, g1, g3, g5 participate PWM modulation, g2, g4, g6 keep open normally.

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