Simulation of PMSM Vector Control System Based on Matlab/Simulink

LIU Ting-ting, TAN Yu, WU Gang, WANG Shu-mao
Collage of Engineering
China Agriculture University, CAU
Beijing, China
liutingting817@163.com

Abstract—At the basis of analysis of the mathematical model of the permanent-magnet synchronous motor (PMSM) and the principle of field-orientated vector control, a novel method for modeling and simulink of PMSM system based on SVPWM is proposed. In Matlab/simulink, the simulation model of the whole system is built, two control loops are used, which are inner current-loop and the outer speed-loop. By simulating the specific motor, the waveforms are presented, which achieves the expected effect, and the reasonability and validity has been proved.

Keywords-PMSM; SVPWM; Matlab; vector control; modeling and simulation

I. INTRODUCTION

Along with the development of permanent magnetic materials and control technology, permanent magnet synchronous motor (PMSM), with its following merits: high torque/inertia ratio, high power density, high efficiency, reliable and easy for maintenance, is widely used in CNC machine tools, industrial robots and so on. Therefore, the establishment of the simulation model of PMSM and its control system is of great significance to the verification of a variety of control algorithms and the optimization of entire control system. This thesis is based on the analysis of mathematical model of PMSM, using the modular thought, with the powerful simulation modeling capabilities of Matlab/Simulink, the entire PMSM control system as a whole will be divided into several independent functional modules: PMSM body module, inverter module and coordinate transformation module and SVPWM production module and so on. Combine these modules organically, and we could build the simulation model of PMSM control system. Through the simulation of a specific motor, we analysis a variety of simulation waveforms, provide an effective means for the analysis and design of the PMSM control system.

II. THE MATHEMATICAL MODEL OF PMSM

The PMSM discussed in this paper is limited in the following cases: ignoring the core saturation and machine winding leakage inductance; supposing the magnetic potential in the air gap is in sine distribution; neglecting the higher harmonic wave in magnetic field. Under these assumptions, using the coordinate transformation principle, we could get PMSM's mathematical model in two-phase synchronous revolution coordinate system, the mathematical model is shown in formula (1).

$$\begin{cases} U_d = 2L_d \dfrac{di_d}{dt} - \omega_r L_q i_q + r_s i_d \\[2mm] U_q = \omega_r \psi_f + \omega_r L_d i_d + L_q \dfrac{di_q}{dt} + r_s i_q \\[2mm] T_e = \dfrac{3}{2} p_m \left[\psi_f i_q + (L_d - L_q) i_d i_q \right] \end{cases} \quad (1)$$

In this formula, U_d, U_q, i_d, i_q —voltage and current in axis d and axis q (V、A); r_s —the resistance of stator windings(Ω); L_d, L_q —the inductance in axis d and axis q (H); ψ_f —the main flux linkage of permanent magnet(Wb); ω_r —the rotor angular frequency(rad/s); p_m —number of pole-pairs of electric machine.

III. ROTOR FIELD-ORIENTED CONTROL PRINCIPLE OF PMSM

The basic idea of vector control is as follows: through the coordinate transformation, decompose the AC motor's s stator current I_s into two components: field current component I_{sd} and its vertical torque current component I_{sq}. According to PMSM's mathematical model $T_e = \dfrac{3}{2} p K_e i_q$, we could know that the relationship of electromagnetic torque T_e and i_q is linear, in speed regulating process, as long as we maintain the field current component I_{sd} invariable and control its torque component I_{sq}, we can obtain a good dynamic characteristic. In this thesis we adopt the i_d =0 rotor flux-oriented control, as long as we detect the rotor's space position accurately, by controlling the inverter can we locate the three-phase stator's combined current at axis q. Therefore, if the stator current's amplitude is determined, we could control the electromagnetic torque T_e.

IV. THE SIMULATION MODEL OF PMSM BASED ON MATLAB

In Matlab/Simulink environment, using the rich module library in SimPowerSystem, we build a double closed-loop

simulation model based on $i_d = 0$, which is shown in Fig.1, the current loop and the speed loop are both composed of PI regulator. The PMSM control system mainly includes: PMSM body module, three-phase voltage inverter module, coordinate transformation module and SVPWM production module. In this thesis we mainly discuss the building process of coordinate transformation module and SVPWM module.
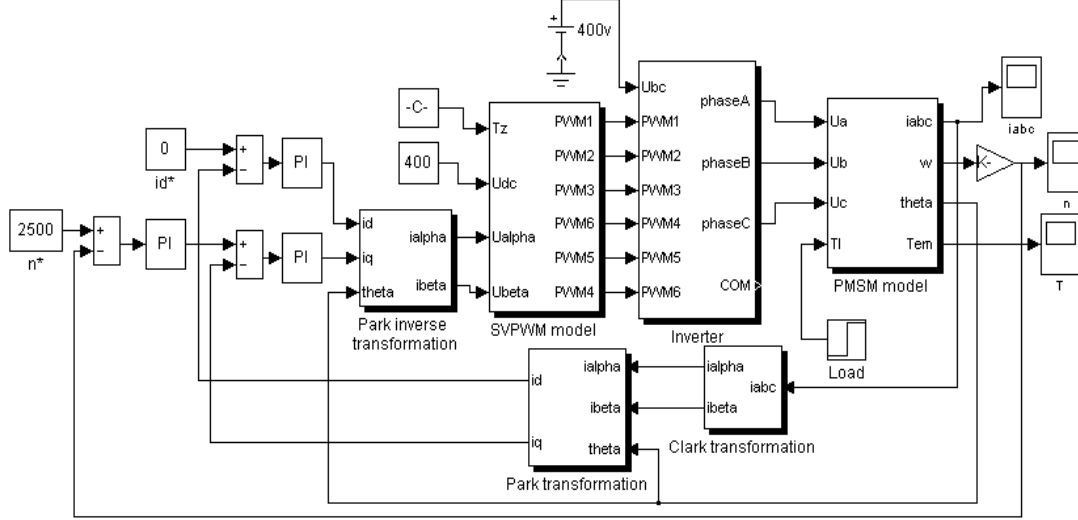

Figure 1. Simulation block of PMSM Control System

A. Coordinate transformation's Simulink realization

Coordinate transformation module's function is to transform motor's stator three phase current into the corresponding current in synchronized revolving *dq* coordinate, compared with the reference input i_q^*, take the bias obtained as the current regulator(PI) 's input. The coordinate transformation used in vector control: Park inverse transformation, Clark transformation and Park transformation. Its transformation matrix is as follows:

Park inverse transformation:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

(2)

Clark transformation:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

(3)

Park transformation:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

(4)

Take the Clark inverse transformation as an example, its simulation model is shown in Fig.2.
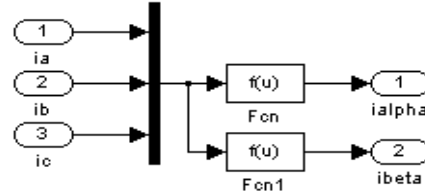

Figure 2. Simulation block of Park inverse transformation
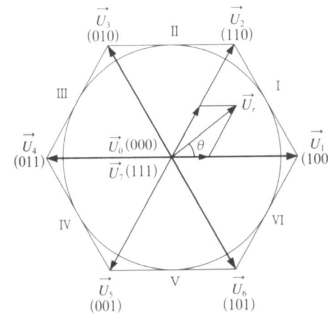
B. SVPWM module's Simulink realization

Figure 3. Basic space voltage vector

Space vector pulse-width modulation (SVPWM) technology's main idea is as follows: take the ideal flux path as a benchmark, when AC motor is powered by three-phase sine wave voltage, approach the benchmark flux circle with the actual flux produced by inverter's 8 switch mode, and the motor could obtain a constant amplitude circular magnetic field (sine magnetic field), so as to achieve high performance. Using the SVPWM method, we select 2

adjacent effective vectors and the vector zero from these 8, and form the space voltage vector U_r that needed according to their respective response time, the principle shown in Fig.3.

1) The sector judgment: According to the relationship of each sectors U_α, U_β and U_r, the judgment is as follows: when $U_\beta > 0$, A=1, else A=0; when $\sqrt{3}U_\alpha - U_\beta > 0$, makes B=1, else B=0; when $-\sqrt{3}U_\alpha - U_\beta > 0$, makes C=1, else C=0. Set three auxiliary variables U_{r1}, U_{r2} and U_{r3}, the determination of current sector N=A+2B+4C can be obtained from the following algorithm.

$$\begin{cases} U_{r1} = U_\beta \\ U_{r2} = \sqrt{3}U_\alpha - U_\beta \\ U_{r3} = -\sqrt{3}U_\alpha - U_\beta \\ N = sign(U_{r1}) + 2sign(U_{r2}) + 4sign(U_{r3}) \end{cases} \quad (5)$$

The simulation model that identifying the sector number as shown in Fig.4. The corresponding relationships between the value of N and the sector number can be settled by the Look-Up Table module, the input value is [1 2 3 4 5 6], the output value is [2 6 1 4 3 5].
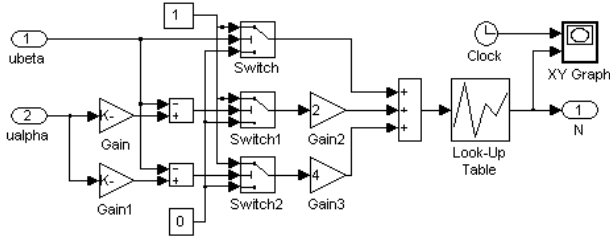

Figure 4.   Simulation model of sector judgment

2) The calculation of X, Y, Z and T_1, T_2: T_1 means the main vector's operating time in current work sector, T_2 means vice-vector's operating time, in different sector, the operating time T_1 and T_2 can be calculated as follows.

$$X = \frac{2U_\alpha}{\sqrt{2}U_{dc}}t_z$$

$$Y = \frac{(\sqrt{3}U_\alpha + U_\beta)}{\sqrt{2}U_{dc}}t_z,$$

$$Z = \frac{(\sqrt{3}U_\alpha - U_\beta)}{\sqrt{2}U_{dc}}t_z$$

When $T_1 + T_2 - t_z > 0$, t_z is switching period, calculate the new value of T_1、 T_2, $T_1 = T_1t_z/(T_1+T_2)$;

$T_2 = T_2t_z/(T_1+T_2)$. To different sectors, T_1 and T_2 's evaluations can be derived from Table 1. Fig.5 shows the simulation model.

TABLE I.   EVALUATION OF T_1,T_2

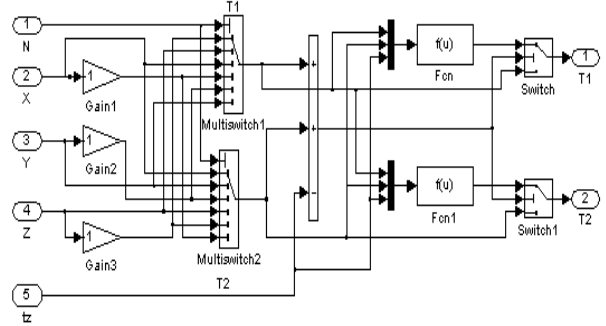| Sector number	I	II	III	IV	V	VI
T_1	$-Z$	Y	Z	$-X$	X	$-Y$
T_2	Y	$-X$	X	$-Z$	$-Y$	Z

Figure 5.   Simulation model of T_1,T_2

3) The detrmination of vector switching points T_{cm1},T_{cm2},T_{cm3}

$$\begin{cases} T_a = 0.25(T - T_1 - T_2) \\ T_b = T_a + 0.5T_1 \\ T_c = T_b + 0.5T_2 \end{cases} \quad (6)$$

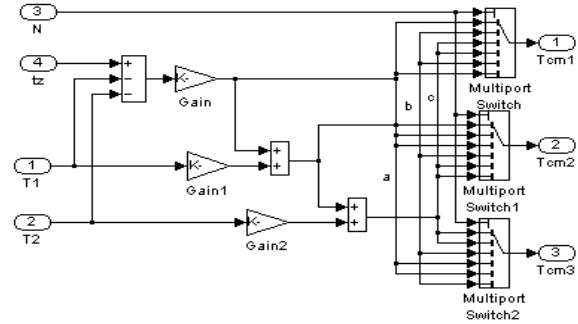Fig.6 shows the simulation model of vector's switching points T_{cm1},T_{cm2},T_{cm3}.

Figure 6.   Simulation model of T_{cm1},T_{cm2},T_{cm3}

Compare the isosceles triangular wave with T_{cm1},T_{cm2},T_{cm3} (isosceles triangular wave is produced by integrating the pulse generator), we can get the symmetric space vector PWM waveform, carry on ANAD operation to PWM1、PWM3、PWM5, and produce PWM2、PWM4、PWM6. Connect these models above to produce SVPWM model as shown in Fig.7.
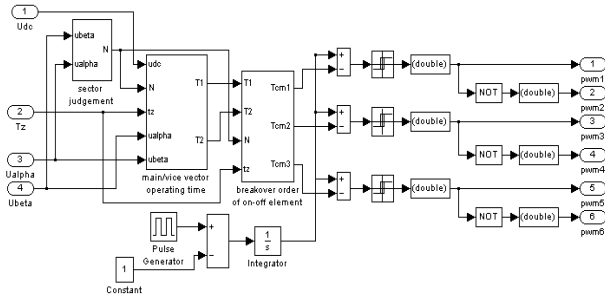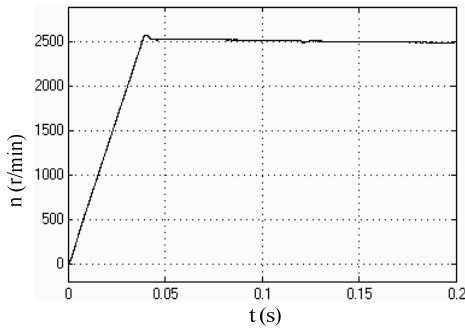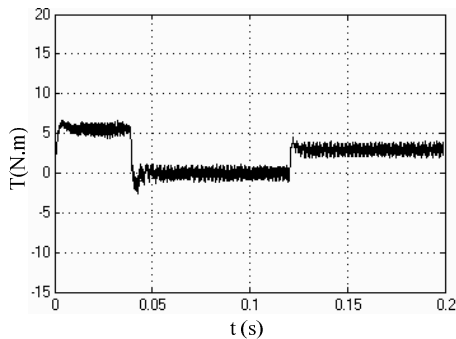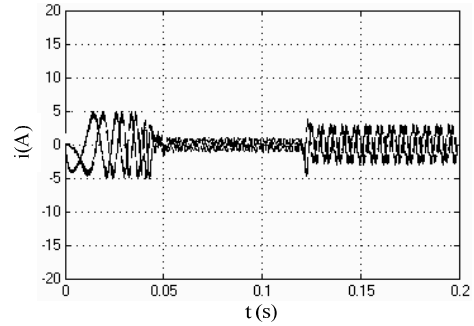
Figure 7.   Simulation model of SVPWM

V.   THE SIMULATION RESULT

Carry on the simulation testing to the PMSM control system. The parameters of PMSM is as follows: $p = 4$, $L_d = L_q = 0.0085H$, $R_s = 2.875\Omega$, $J = 0.0008kgm^2$, $\psi_f = 0.175Wb$, IGBT's switching frequency is 10KHz. The given speed is 2500r/min, no-load start; we can get the speed, three-phase current and torque curves as shown in Fig.8. As seen in Fig.8, the speed achieves the setting value in 0.04 second, the maximum speed overshoot 3%, in 0.12 second, load torque changes from 0 to 4, the current becomes small immediately, the electromagnetic torque reduces correspondingly, but, this did not cause obvious changes in speed, it shows that the system has good anti-disturbance capacity to load changes.

（a）Rotational speed

（b）Torque

（c）Three-phase current

Figure 8.   Simulation waveforms

VI.   CONCLUSIONS

Based on the rotor field oriented control of permanent magnet synchronous motor, we establish the simulation model of PMSM control system using Simulink toolbox of Matlab. The simulation results show that the system can run smoothly and still has perfect dynamic and static characteristics under 2500r/min high-speed, it has provides a train of thought for the actual PMSM system's design and debugging.

REFERENCES

[1] Irfan Guney, Yuksetoguz, Fusun Serteller."Dynamic behavior model of permanent magnet synchronous motor fed by PWM inverter and fuzzy logic controller for stator phase current, flux and torque control of PMSM". IEEE Proceeding from Electric Machines and Drives Conference , VOL.12, NO.17, 2001, pp. 479-485.

[2] Changjiang Zhan, Vigna Kumaran Ramachan-daramurthy."Dynamic Voltage Restorer Based on Voltage-Space-Vector PWM Control". IEEE Transactions on IndustryTrans on Industry Applications, VOL.37, NO.6, 2001, pp.1885-1863.

[3] Habetler T G, Profumo F, Pastorelli M. "Direct Torque Control of Induction Motor Machines Using Space Vector Modulation". IEEE Trans on Industry Applications, VOL.28, 1992, pp.1045-1053.

[4] Mizutani R, Takeshita T, Mat sui N."Current Model Based Sensorless Drive of Salientpole PMSM at Low Speed and Standstill". IEEE Trans on Ind Appl, VOL.36, NO.6, 2000, pp. 1598-1603.

[5] Takahashi I, Noguchi T. "A New Quick Response and High Efficiency Control Strategy of an Induction Motor". IEEE Trans on Industrial Applications, VOL.22, NO.5, 1986, pp.821-827.