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PMSM Control Simulation Based on Pumping Unit

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Abstract

To study direct drive pumping unit of operating state, permanent magnet synchronous motor open-loop control system was used to model and simulate based on Matlab/Simulink software, and analyzed the waveforms change with different torque. The results indicate that permanent magnet synchronous motor can operate smoothly under low speed and high torque condition, and can meet work requirement of direct drive pumping unit with acceleration. The proposed Simulink simulation system can achieve stable control in actual operation, and its effectiveness was confirmed experimentally. Results of simulation analysis have some certain practical value for pumping unit driven by permanent magnet synchronous motor.

***Keywords**: PMSM, pumping unit, simulink, low speed*

1. Introduction

At present, most oil fields are low production and low permeation. In recent years, with continuous exploit to oil, some parts of oil well have become middle-later period. At the same time, pumping units have not high work efficiency, device magnify wastage, cause waste a large amount of electrical energy. Aiming at this kind of wells, in order to improve work efficiency and decrease unnecessary electrical energy waste, the more effective method is use permanent magnet synchronous motor (PMSM) to drive directly (as shown in Figure 1). Like this, efficiency of operations can be improved, maximum virtue of motor can be expressed, and can achieve function of low speed and high torque to meet requirement of most oil field. This paper uses Matlab/Simulink to build open-loop steady model and simulate, and analyze system control performance with simulation results of pumping unit operation.

Figure 1. Direct Drive Pumping Unit

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2. Research Method

The dq-rotor model equations used in the open-loop control of the PMSM are written [1]:

$$v_d = (R_s + L_s p)i_d - \omega_r L_s i_q$$
$$v_q = (R_s + L_s p)i_q + \omega_r L_s i_d + \omega_r \lambda_r \quad (1)$$

Where *p* is the derivative.

If the derivative terms are removed, the steady-state voltage equations in the rotor reference frame become [2]:

$$v_d = R_s i_d - \omega_r L_s i_q$$
$$v_q = R_s i_q + \omega_r L_s i_d + \omega_r \lambda_r \quad (2)$$

Figure 2 is the block diagram of the overall open-loop PMSM drive system designed in Matlab/Simulink. In this figure, transformations are in the following order from left to right: abc reference frame to dq-stationary reference frame transformation, dq-stationary reference frame to dq-rotor reference frame transformation and finally dq-rotor reference frame to abc-frame transformation [3].

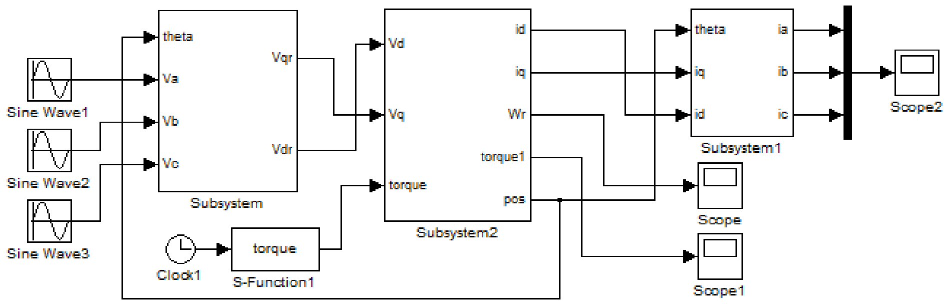

Figure 2. Overall Open-loop Control Block Diagram of PMSM in Simulink

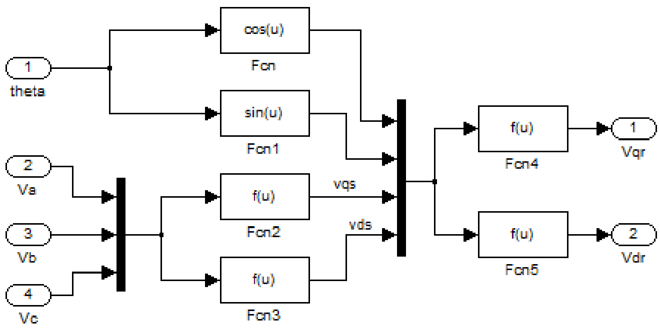

Figure 3. Abc to Stationary and Stationary to dq Rotor Reference Frame Transformation Block

Where v_{qs} and v_{ds} or v_α and v_β are the stationary reference frame voltages converted from the motors abc terminal voltages by using Clark's Transformation which are given by [4]:

$$v_\alpha = v_{qs} = \frac{(2v_a - v_b - v_c)}{3}$$
$$v_\beta = v_{ds} = \frac{(v_c - v_b)}{\sqrt{3}} \quad (3)$$

From Figure 3, the stationary to rotor reference frame voltage equations corresponding to the Park's Transformation under the assumption that the rotor angle representation is chosen between the rotor q-axis and the stationary q-axis, as shown in Figure 4, are given by [5]:

$$
\begin{aligned}
v_d &= v_q{}^s \sin\theta_r + v_d{}^s \cos\theta_r \\
v_q &= v_q{}^s \cos\theta_r - v_d{}^s \sin\theta_r
\end{aligned}
\tag{4}
$$

The coordinate representation of the stationary reference frame is shown in Figure 4 [6].

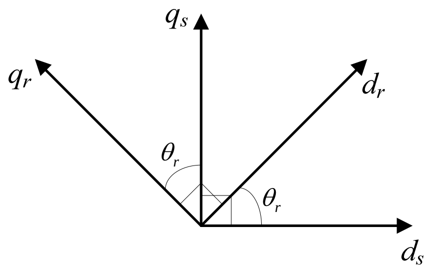

Figure 4. Rotor Reference Frame and Stationary Reference Frame Coordinate Representation

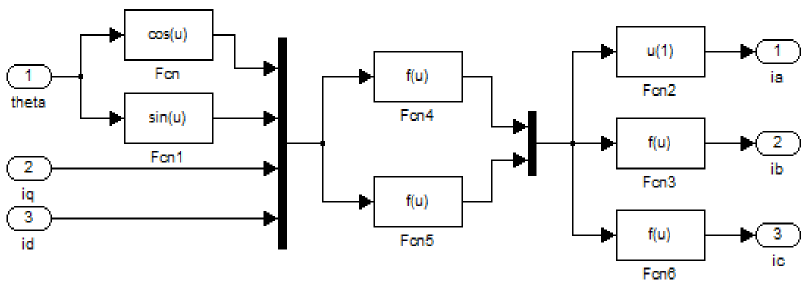

Figure 5. Dq Rotor Reference Frame to Stationary and Stationary to abc Transformation Block

From Figure 5, the rotor frame to stationary frame current equations corresponding to the inverse Park's Transformation, under the assumption that the rotor angle representation is chosen as between the rotor q-axis and the stationary q-axis as shown in Figure 4, are given by [7, 8]:

$$
\begin{aligned}
i_d{}^s &= i_d \cos\theta_r - i_q \sin\theta_r \\
i_q{}^s &= i_q \cos\theta_r + i_d \sin\theta_r
\end{aligned}
\tag{5}
$$

Again from Figure 5, the stationary frame to the abc frame current transformation corresponding to the inverse Clark's Transformation can be expressed as [9]:

$$
\begin{aligned}
i_a &= i_{qs} \\
i_b &= -\frac{1}{2} i_{qs} - \frac{\sqrt{3}}{2} i_{ds} \\
i_c &= -\frac{1}{2} i_{qs} + \frac{\sqrt{3}}{2} i_{ds}
\end{aligned}
\tag{6}
$$

From Figure 2, the inside of the PMSM model is presented in Figure 6.

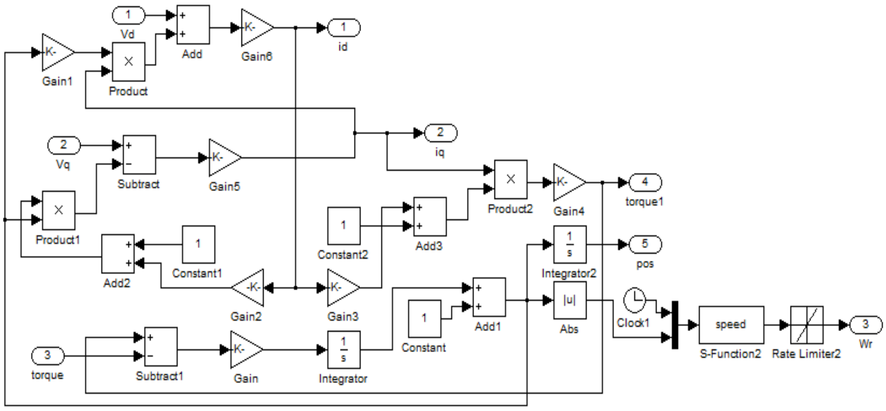

Figure 6. Steady State dq-axis Rotor Reference Frame Motor Model

Equations for Figure 6 can be summarized as [10, 11]:

$$
\begin{aligned}
v_d &= R_s i_d - \omega_r L_q i_q \\
v_q &= R_s i_q + \omega_r L_d i_d + \omega_r \lambda_r \\
T_{em} &= \frac{3}{2}\frac{P}{2}\left(\lambda_i i_q + \left(L_d - L_q\right) i_q i_d\right) \\
T_{em} + T_{mech} - T_{damp} &= \frac{2J}{P}\frac{d\left(\omega_r(t) - \omega_e\right)}{dt} = J\frac{\omega_{rm}(t)}{dt}
\end{aligned}
\tag{7}
$$

Where damping torque, T_{damp}, is assumed to be zero.

3. Simulation Results and Analysis

From top dead center to bottom dead center, pumping rod operates 3sec: accelerate 1sec from 0rpm to 40rpm, then constant speed 1sec, and decelerate 1sec from 40rpm to 0rpm. Then at bottom dead centre, rod continues to upstroke operation. Because of the load of rod itself, during simulation, it need load torque 100N·m. Meanwhile, loads torque to 400N·m at upstroke operation for pumping oil weight, which operates 6 seconds simulation at a time.

Table 1. Experimental System Parameters

Pole Pairs	16
Flux Linkage (V·s)	0.08
Stator Phase Resistance (Ω)	0.0063
Moment of Inertia (kg·m^2)	51.4753
Inductances (H)	0.032
Voltage (V)	380

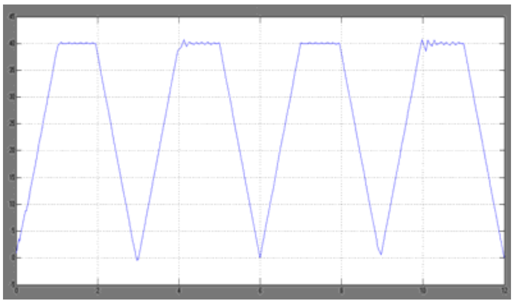

Figure 7. Dynamic Speed Response

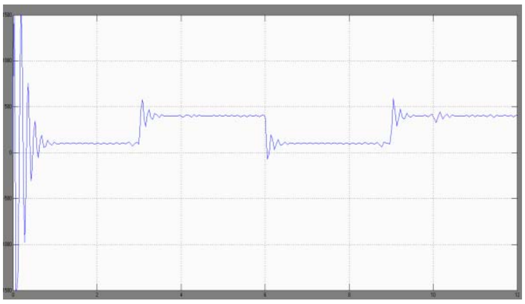

Figure 8. Torque Response of PMSM

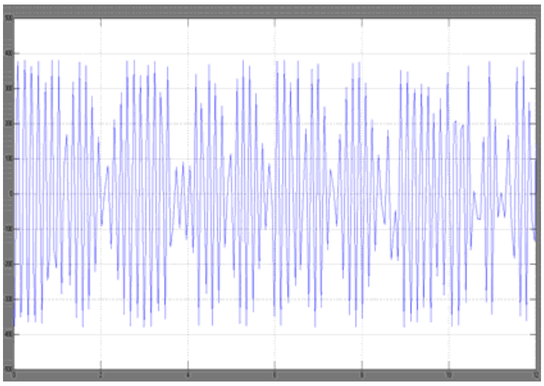

Figure 9. A Phase Voltage Source

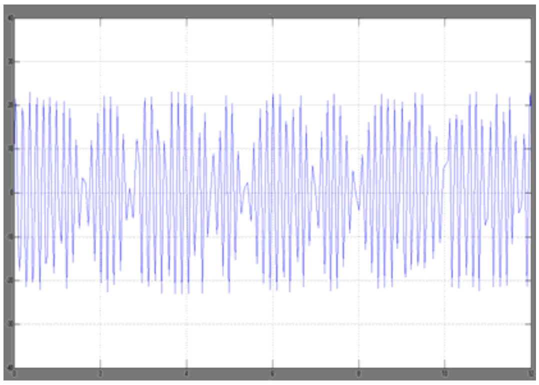

Figure 10. Simulated a Phase Motor Currents

4. Conclusion

According to above results of simulation, the control of PMSM can be estimated relative stable totally. Although have a little instability at launch phase, it can adjust rapidly and meet apply requirement of PMSM with different torque and acceleration. Simulation of PMSM can provide the judgment of PMSM actual control means of direct drive pumping units, and lay a solid basis for the next step work.

Acknowledgements

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