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Simulation Research on Ship Shaft Power Generation System

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Abstract

In order to utilize the marginal power of the diesel engine, to save energy consumption and improve energy utilization.This paper mainly introduces the ship shaft power generation system of PMSM, the control method is SVPWM vector control, and finally the feasibility of the scheme is proved by the simulation of matlab/simulink.

Keywords

PMSM, Shaft generator, SVPWM, Matlab/simulink.

1. Introduction

As the price of crude oil continues to rise, the proportion of its cost consumption has reached more than half of the ship's operating costs, so energy conservation will inevitably become the focus of future ships. The use of shaft power generation system is an effective way to save fuel, so the research on shaft power generation technology has a long history. To some extent, the use of shaft power generation technology can save fuel consumption. This is because, on the one hand, the main engine of the ship uses low-quality heavy oil as the main fuel, which is cheaper and more economical.The development of marine shaft generator technology is based on this point. The generator is driven by the main engine of the ship, making full use of the 10% -15% power reserve of the main engine of the ship, so that the main engine operates in a state of high efficiency and low consumption[1]; another In terms of aspects, the electrical energy provided by the shaft power generation system can partially or completely replace the traditional diesel engine for power generation, thereby achieving the purpose of saving fuel. In addition, the shaft generator system can extend the maintenance cycle to reduce maintenance costs and simplify the operation and management of the ship. At the same time, it can reduce engine room noise and engine room temperature, thereby improving the engine room environment and also conducive to the layout of the engine room.Therefore, the shafting system is generally used in the PTI / PTO control method for ship boosting.

The shaft motor can work in PTO (Power Take Out) or PTI (Power Take In)and can be converted to each other[2,3]. It is no longer limited to shaft generator. PTO mode, that is, shaft generator mode, refers to the absorption of energy from the host to generate electricity, partially or completely replacing the traditional diesel generator set. PTI mode, that is, the motor mode, refers to a certain condition as a motor that absorbs energy from the power station to drive the propeller. Therefore, the shaft boost system is composed of a low-speed diesel engine and a shaft motor through a transmission device[4]. The specific energy flow diagram is shown in Figure 1 below:

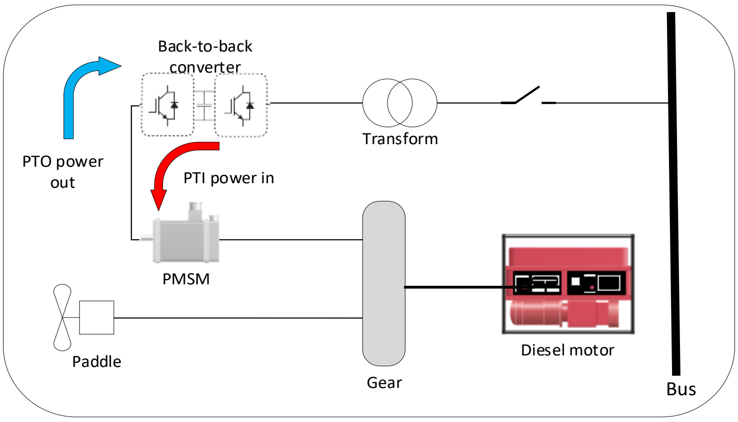

Figure 1 specific energy flow diagram

In permanent magnet generators, the magnetic field is directly generated by the permanent magnets on the rotor. This means that rotor pole winding or excitation devices are no longer required. Because there are no pole winding and associated losses, compared with electric excitation synchronous generators, permanent magnet generators have three major advantages: excellent efficiency, significantly reduced structural complexity, and low rotor inertia and weight[5,6].

2. Motor modeling and control method

2.1 Motor modeling

2.1.1 Motor theory

In order to simplify the analysis, it is assumed that the PMSM is an ideal motor and meets the following conditions:

(1)Ignore the saturation of the motor core;

(2)Excluding the eddy current and hysteresis loss in the motor;

(3)The current in the motor is a symmetrical phase sine wave current.

In this way, the PMSM phase voltage equation in the natural coordinate system is:

$$u_{3s} = Ri_{3s} + \frac{d}{dt}\psi_{3s} \tag{1}$$

The flux linkage equation is

$$\psi_{3s} = L_{3s}i_{3s} + \varphi_f \cdot F_{3s}(\theta_e) \tag{2}$$

among them: ψ_{3s} is Flux linkage of three-phase winding; u_{3s} 、 R 、 i_{3s} are respectively the phase voltage, resistance and current of the three-phase winding; L_{3s} is the inductance of the three-phase winding; $F_{3s}(\theta_e)$ is the flux linkage of the three-phase winding, and satisfies

$$i_{3s} = \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix}, R_{3s} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}, \psi_{3s} = \begin{bmatrix} \varphi_A \\ \varphi_B \\ \varphi_C \end{bmatrix}$$

$$u_{3s} = \begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix}, F_{3s}(\theta_{3s}) = \begin{bmatrix} \sin\theta_e \\ \sin(\theta_e - 2\pi/3) \\ \sin(\theta_e + 2\pi/3) \end{bmatrix}$$

$$L_{3s} = L_{m3}\begin{bmatrix} 1 & \cos 2\pi/3 & \cos 4\pi/3 \\ \cos 2\pi/3 & 1 & \cos 2\pi/3 \\ \cos 4\pi/3 & \cos 2\pi/3 & 1 \end{bmatrix} + L_{l3}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

In which, L_{m3} is stator mutual inductance; L_{l3} is stator leakage inductance.

According to the principle of electromechanical energy conversion, the derivation of electromagnetic torque T_e in the magnetic field energy storage to the displacement of the mechanical angle θ_m ,therefore:

$$T_e = \frac{1}{2} p_n \frac{\partial}{\partial \theta_m} \left({i_{3s}}^T \cdot \psi_{3s} \right) \tag{3}$$

Where: P_n is the number of pole pairs of PMSM.

In addition, the mechanical motion equation of the motor is:

$$J \frac{d\omega_m}{dt} = T_e - T_L - B\omega_m \tag{4}$$

Where: ω_m is the mechanical angular velocity of the motor; J is the moment of inertia; B is the damping coefficient; T_L is the load torque.

2.1.2 Three-phase PMSM dq axis modeling

In order to simplify the mathematical model of PMSM in the natural coordinate system, the coordinate transformations used usually include static coordinate transformation (Clark transformation) and synchronous rotation coordinate transformation (Park transformation)[7].

Clark transformation : Transform the natural coordinate system ABC to the stationary coordinate system α-β ,as follows:

$$T_{3s/2r} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \tag{5}$$

Park transformation : The coordinate transformation that transforms the stationary coordinate system α-β to the synchronized rotating coordinate system d-q is called Park transformation,as follows:

$$T_{2r/3s} = \begin{bmatrix} \cos\theta_e & -\sin\theta_e & 1/2 \\ \cos(\theta_e - 2\pi/3) & -\sin(\theta_e - 2\pi/3) & 1/2 \\ \cos(\theta_e + 2\pi/3) & -\sin(\theta_e + 2\pi/3) & 1/2 \end{bmatrix} \tag{6}$$

2.1.3 Mathematical modeling in synchronous rotating coordinate system

In order to facilitate the design of the later controller, the mathematical model of the synchronous rotating coordinate system d-q is usually selected, and its stator voltage equation can be expressed as:

$$\begin{cases} u_d = Ri_d + \frac{d}{dt}\varphi_d - \omega_e \varphi_q \\ u_q = Ri_q + \frac{d}{dt}\varphi_q - \omega_e \varphi_d \end{cases} \tag{7}$$

The stator flux equation is:

$$\begin{cases} \varphi_d = L_d i_d + \varphi_f \\ \varphi_q = L_q i_q \end{cases} \tag{8}$$

The available stator voltage equation is :

$$\begin{cases} u_d = Ri_d + L_d \dfrac{d}{dt} i_d - \omega_e L_q i_q \\ u_q = Ri_q + L_q \dfrac{d}{dt} i_q + \omega_e \left(L_d i_d + \varphi_f \right) \end{cases} \tag{9}$$

The electromagnetic torque equation can be written as:

$$T_e = \frac{3}{2} p_n i_q \left[i_d \left(L_d - L_q \right) + \varphi_f \right] \tag{10}$$

2.2 SVPWM vector control

At present, the common methods of traditional vector control are $i_d = 0$ control and maximum torque current ratio control[8,9],Figure 2 shows the PMSM vector control block diagram using the $i_d = 0$ control method. It can be seen from the figure that the PMSM quantity control mainly includes two parts: speed loop PI controller, current loop PI regulator and SVPWM algorithm, etc.

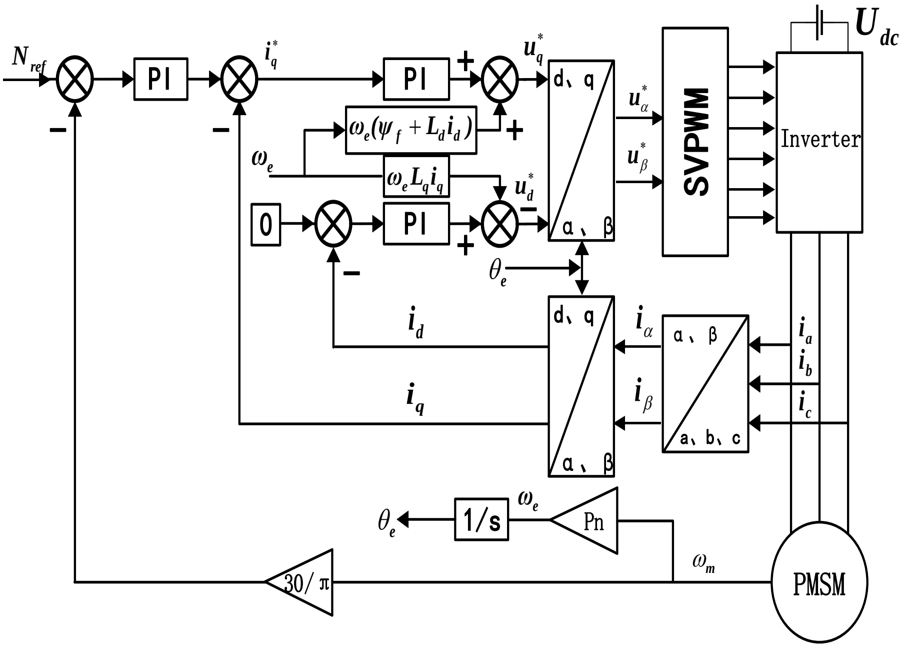

Figure 2 Three-phase PMSM vector control block diagram

3. System simulation model

Build system simulation model through matlab platform.The simulation model of the shaft generator system of the permanent magnet synchronous motor is shown in the figure 3 below.

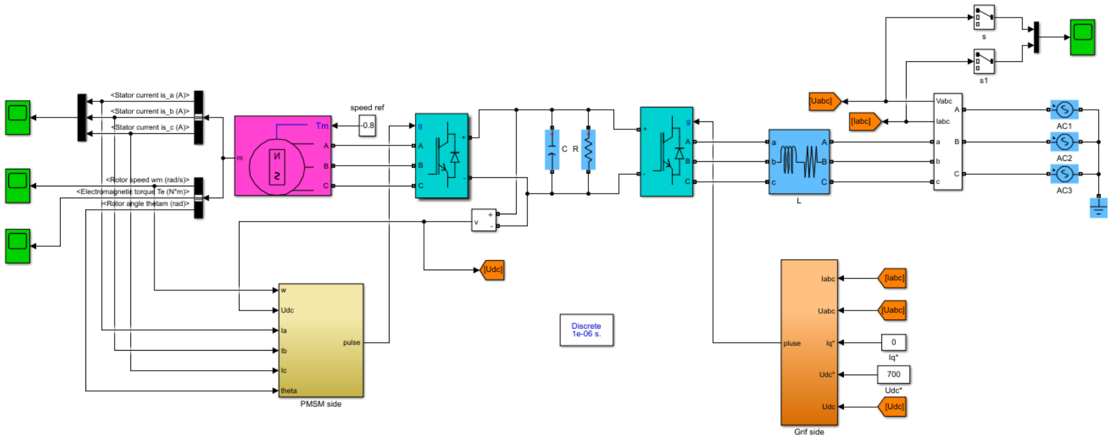

figure 3 System simulation model

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The stator three-phase current simulation results are shown in Figure 4 below.

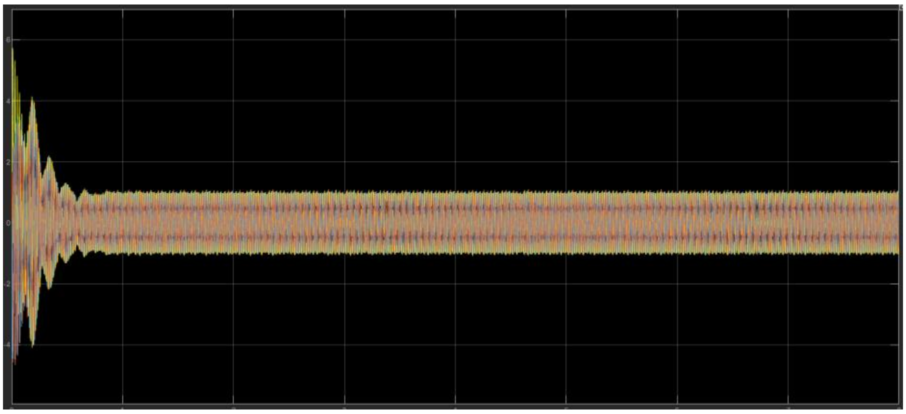

Figure 4 stator three-phase current

The output three-phase voltage simulation results are shown in Figure 5 below.

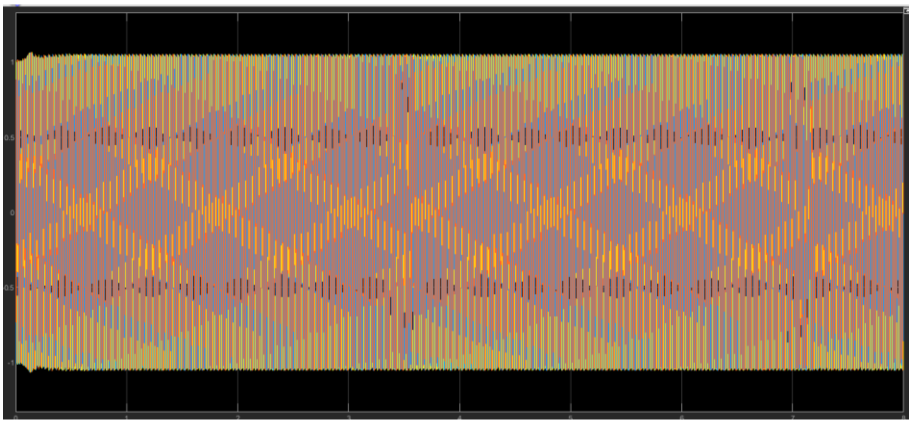

Figure 5 three-phase voltage simulation

The output active power and reactive power are shown in Figure 6 below.

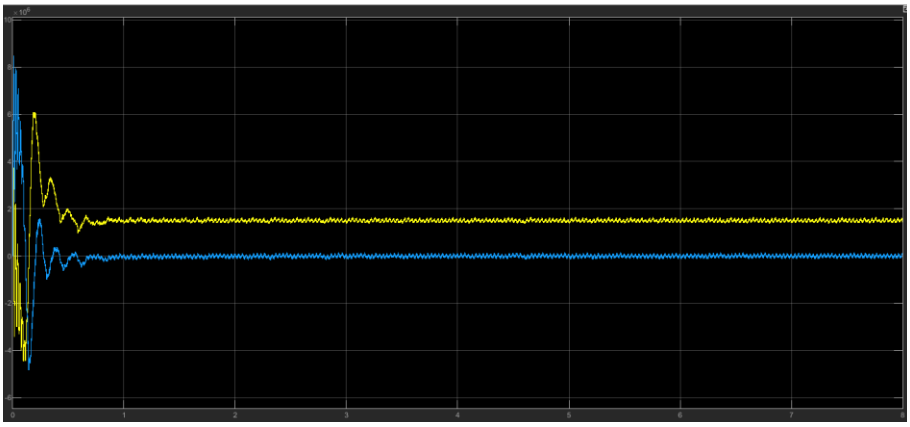

Figure 6 active power and reactive power

4. Conclusion

The marine shaft power generation system can bring about the effective use of energy. The model of the marine shaft power generation system is built through matlab. The simulation results show the load power system grid specifications. The simulation model proves the reliability of the scheme.

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