Vector Control of PMSM Applied in Ship Electric Propulsion System based on dsPIC

Junfeng Qin [1, a], Hongfen Bai [2, b] and Xiaojun Zhang [1, c]

[1] Maritime College, Qinzhou University, Qinzhou 535000, China

[2] Marine Engineering College, Dalian Maritime University, Dalian 510000, China

[a]20878653@qq.com, [b]bdunbhf@163.com, [c]xjzhang01@163.com

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Abstract. Taking the three-phase permanent magnet synchronous motor (PMSM) applied in ship electric propulsion system as an example, this paper discusses the mathematical model of the PMSM and the vector control principle and describes the algorithm of the space vector pulse width modulation (SVPWM). Finally, the SVPWM control model for PMSM is established in Matlab/Simulink and the experimental setup is built using dsPIC. The simulation and experimental results both verify the correctness and effectiveness of the proposed method.

1. Introduction

Recently, all-electric and hybrid electric ship propulsion system has become the development trend of future ship power plant with the development of power electronic technology and the increasingly sophistication of high-power AC motor frequency technology[1]. The permanent magnet synchronous motors (PMSM) with the advantages of high efficiency, high power density and fast dynamic response are commonly used as the propulsion motor in the electric ship propulsion system. In the vector control of PMSM, the control method of space vector pulse width modulation (SVPWM) has characters of high voltage utilization, low harmonic components, fewer control power transistor switch, small power consumption and easy digital implementation, which is one of the most popular PWM methods. In [2], the PMSM vector control system of the PMSM based on SVPWM was simulated, but the load in the simulation system was not based on the propulsion propeller characteristic. The features of the propeller were taken into consideration in [3].The dsPIC30f4011 is adopted as core of the control system in this paper. The chip integrates a lot of peripheral modules and the quadrature encoder module, PWM module and AD conversion module were used to provide an ideal solution for the drive applications of the PMSM [4].Therefore, this paper studies the vector control system for the PMSM of the electric propulsion ship based on SVPWM techniques and verifies the correctness of the strategy in the simulation and experimental setup based on dsPIC30f4011.

2. Vector Control System of the PMSM Based on SVPWM

2.1 The vector control mode of PMSM.

The main idea of vector control is to convert the model of AC motors into the model of DC motors, and its purpose is to make the control effect of AC motors equal to that of DC motors. The mathematical model of PMSM will not be repeated here now. The control strategy of id=0 is used and the torque equation T_e was written as:

$$T_e = \frac{3}{2} n_p \left(\Psi_d i_q - \Psi_q i_d \right) = \frac{3}{2} n_p [\psi_f i_q + (L_d - L_q) i_d i_q] = \frac{3}{2} n_p \psi_f i_q \tag{1}$$

Where, ψ_f is the amplitude of the flux, i_d , i_q represents d, q axis currents respectively; n_p is the number pole pairs and T_e is proportional to i_q . This control strategy is easy to implement. Figure 1 shows the vector control system of PMSM drive of ship propulsion system based on SVPWM technique [5].

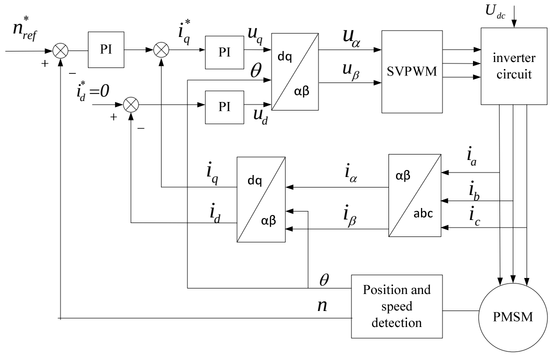


Fig.1 Vector control system structure diagram of the PMSM drive

2.2 Principle of SVPWM techniques.

The aim of vector control strategy based on SVPWM technique is to obtain a circular magnetic field through the combination of different width voltage pulse squences[6]. Figure 2 shows the voltage vectors of SVPWM techniques.

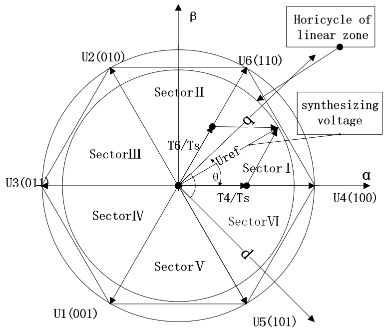


Fig.2 Voltage vectors of SVPWM techniques

In order to determine the sector of reference voltage, the equation (2) is defined as follows.

$$\begin{cases} U_1 = \dfrac{\sqrt{3}U_\beta}{U_{dc}} \\ U_2 = \dfrac{\sqrt{3}}{2U_{dc}}(\sqrt{3}U_\alpha - U_\beta) \\ U_3 = -\dfrac{\sqrt{3}}{2U_{dc}}(\sqrt{3}U_\alpha - U_\beta) \end{cases} \tag{2}$$

Wherein, U_α , U_β repersent the components of reference voltage vector U_{out} on α , β axis.

Define variables A, B, C. If $U_a > 0$, then $A = 1$; otherwise $A = 0$. If $U_b > 0$, then $B = 1$; otherwise $B = 0$. If $U_c > 0$, then $C = 1$, otherwise $C = 0$. According to three binary codes A, B, C , the value in the decimal can represent sector thougu the expression $N = 4C + 2B + A$, as shown in Table1.

To calculate the action times of voltage space vector in different sectors, define the variables *X*, *Y*, *Z*:

$$\begin{cases} X = \dfrac{T}{\sqrt{2}U_d}u_\beta \\ Y = \dfrac{T}{2\sqrt{2}U_d}(\sqrt{3}u_\alpha + u_\beta) \\ Z = \dfrac{T}{2\sqrt{2}U_d}(-\sqrt{3}u_\alpha + u_\beta) \end{cases} \tag{3}$$

Action time according to the PWM pulse width from wide to narrow can be denoted as T_a, T_b, T_c:

$$\begin{cases} T_a = \dfrac{T\text{-}T_1\text{-}T_2}{4} \\ T_b = T_a + \dfrac{T_1}{2} \\ T_c = T_b + \dfrac{T_2}{2} \end{cases} \tag{4}$$

The relationship of sector number, calculation time and action time of three phases in different sectors is shown in Table 1. Sector is the number of sector area; N is calculated by the binary value of the corresponding reference voltage components; *A*, *B* and *C* are the switching time of phase A,B and C respectively in different sectors.

Table 1 The relationship of sector number, calculating time

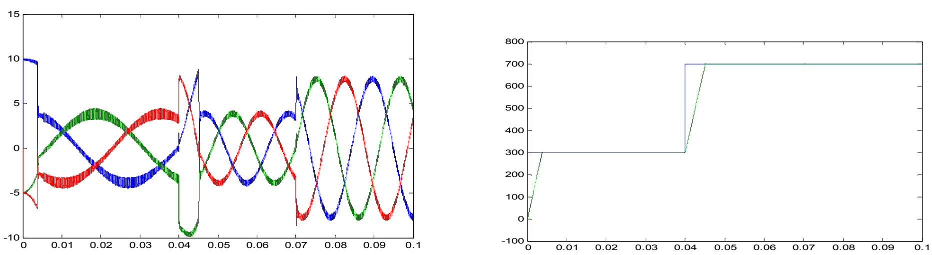
N	T_1	T_2	T_0	sector	A	B	C
3	$T_1=\left\|\frac{T_4}{T_s}\right\|=\|U_2\|$	$T_2=\left\|\frac{T_6}{T_s}\right\|=\|U_1\|$	$T_0=(1\text{-}T_1\text{-}T_2)/2$	I	T_a	T_b	T_c
1	$T_1=\left\|\frac{T_2}{T_s}\right\|=\|U_2\|$	$T_2=\left\|\frac{T_6}{T_s}\right\|=\|U_3\|$	$T_0=(1\text{-}T_1\text{-}T_2)/2$	II	T_b	T_a	T_c
5	$T_1=\left\|\frac{T_2}{T_s}\right\|=\|U_1\|$	$T_2=\left\|\frac{T_3}{T_s}\right\|=\|U_3\|$	$T_0=(1\text{-}T_1\text{-}T_2)/2$	III	T_c	T_a	T_b
4	$T_1=\left\|\frac{T_1}{T_s}\right\|=\|U_1\|$	$T_2=\left\|\frac{T_3}{T_s}\right\|=\|U_2\|$	$T_0=(1\text{-}T_1\text{-}T_2)/2$	IV	T_c	T_b	T_a
6	$T_1=\left\|\frac{T_1}{T_s}\right\|=\|U_3\|$	$T_2=\left\|\frac{T_5}{T_s}\right\|=\|U_2\|$	$T_0=(1\text{-}T_1\text{-}T_2)/2$	V	T_b	T_c	T_a
2	$T_1=\left\|\frac{T_4}{T_s}\right\|=\|U_3\|$	$T_2=\left\|\frac{T_5}{T_s}\right\|=\|U_1\|$	$T_0=(1\text{-}T_1\text{-}T_2)/2$	VI	T_a	T_c	T_b

3. Simulations

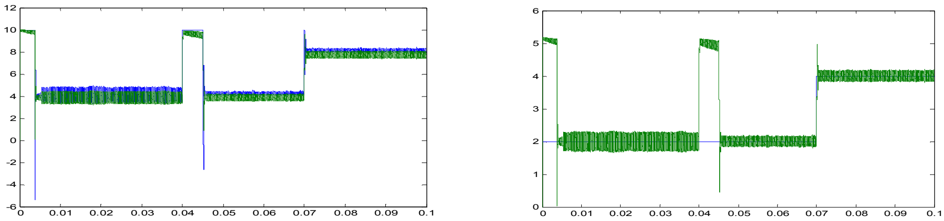
In order to verify the correctness and feasibility of the proposed method, this model of the control system was established in Matlab/Simulink. The parameters of PMSM in simulation are shown in Table 2.

Table 2 Simulation parameters of PMSM

Parameters	Values	Comments
p	4	the number of pole pairs
R	0.62 Ω	resistance of the stator windings
L_d	0.002075H	d-axis stator inductance
L_q	0.002075H	q-axis stator inductance
J	9.444×10^{-5}kg.m^2	rotor moment of inertia
B	0	damping coefficient
n_{ref}	1000r/min	rated speed
T_e	2Nm	given load torque



(a) A, B, C Winding currents (b) Speed waveforms



(c) Waveforms of q-axis currents (d) Torque waveforms

Fig.3 Simulation waveforms

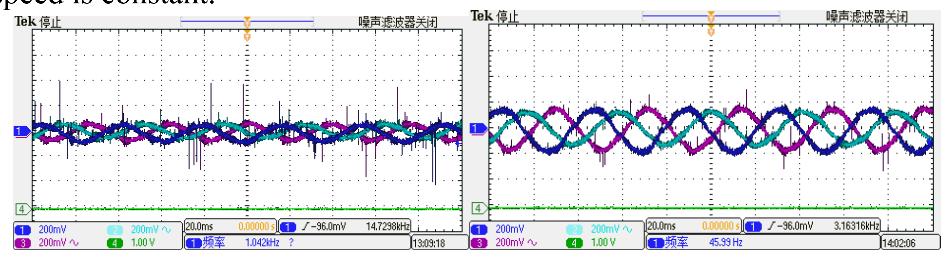
The simulation time is 0.1s. The motor drive is started with full load T_e=2Nm and the initially given speed is n=300r/min. Until t=0.04s the speed is shifted to 700r/min 错误!未找到引用源。and the torque is shifted to 4Nm at t=0.07s. Simulation waveforms are shown in Fig.3.

The simulation results show that the vector control system of the PMSM drive has good dynamic and static performances. And the q-axis currents will increase with the growth of the torque.

4. Experimental demonstrations

To further verify the correctness of the algorithm of SVPWM, the experimental setup of vector control system based on SVPWM for the PMSM drive was built. And dspic30f4011 was used as the digital controller which is a specialized chip in the motor and power control embedded DSP kernel with abilities in high-speed data processing. In the experiment, the parameters of PMSM are same as Table 1.The experimental results are as follows.

Fig.4 (a) is phase current waveforms without load at the speed of 400r/min and we can see that effective value of currents is 0.57A. The phase current waveforms with load at the speed of 360r/min are shown in Fig.4 (b).The real effective value of currents is 1.4A. After loading, the current will increase because it is proportional to the torque, and the frequency of currents will not change because the speed is constant.



(a) Without load (b) With load

Fig.4 Phase current waveforms

Then the experiments at other speeds were conducted and the comparison results between the real speed and given speed are shown in table 3.From table 3, the given speed can follow the real speed well.

Table 3 Given speed and real speed

Numble	Given speed (r/min)	Real speed (r/min)	error(r/min)
1	150	149	1
2	250	251	1
3	350	352	2
4	450	448	2
5	550	550	0
6	650	651	1
7	750	750	0
8	800	800	0
9	850	851	1

5. Summary

Propulsion motor is an important part of ship electric propulsion system and PMSM is often used as propulsion motor because of its advantages. On the base of theoretical analysis and mathematical model of PMSM, this paper investigated the SVPWM vector control system of PMSM using the control strategy of i_d=0. The simulation and experiment results proved the validity of proposed theory, which has important practical significance for the further study of ship electric propulsion system.

References

[1]. Junjie Ren,Yancheng Liu,Ning Wang,et al.Sensorless control of ship propulsion interior permanent magnet synchronous motor based on a new sliding mode observer.ISA Transactions. Vol.54(2015),p.15-26.

[2]. Tingting Liu,Tan Yu, Gang Wu,et al.Simulation of PMSM vector control system based on Matlab/Simulink, International Conference on Measuring Technology and Mechatronics Automation, Hunan, China, April11-12, 2009, p. 343-346.

[3]. Junjie Ren, Hui Feng, Hongying Ren,et al.Simulation of PMSM vector control system based on propeller Load characteristic. International Conference on Intelligent Control and Information Processing. Dalian,China,August 13-15, 2010, p.735-737.

[4]. Raees A. Siddiqui, Roger I. Grosvenor, et al. dsPIC-based advanced data acquisition system for monitoring, Control and Security Applications.Proceedings of 12th International Bhurban Conference on Applied Sciences & Technology. Islamabad, Pakistan, January13-17, 2015, p. 293-298.

[5]. Shuanghe Yu, Zhenqiang Yang, Shuang Liu,et al. Analysis and implementation of digitalized vector control for PMSM with switching control. 2010 3rd International Symposium on Systems and Control in Aeronautics and Astronautics. Harbin, China, June 8-10,2010,p.912-917.

[6]. Swathy T.V. Abhilash T.V R.I.T, Kottayam. High performance vector control of PMSM with dead-Time compensation.2012 IEEE International Conference on Power Electronics, Drives and Energy Systems. Bengaluru, India, December16-19, 2012, p.1-6.