SMALL CAPACITY SINGLE PHASE -THREE PHASE CONVERTER DRIVING MOTOR MANAGEMENT SYSTEM SIMULATION MODEL BASED ON SPWM AND SVPWM

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ABSTRACT: To develop single phase - three phase converter variable frequency speed regulation technology and to use three phase motor to replace single phase motor are the important way to improve the capacity and energy saving. This paper compares the application of single phase - three phase converter of two simulation models based on Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM), and the load that single phase – three phase matrix converter uses is permanent magnet synchronous motor (PMSM). The analysis results show that the performance in all aspects of SVPWM vector control using PMSM is superior to PMSM vector control system adopting SPWM..

KEY WORDS: single phase – three phase converter; SPWM; SVPWM; PMSM

1 INTRODUCTION

In recent years, the power electronics devices develop rapidly, and high-performance power electronic devices continue to emerge. In 1950s, the United States Ge Corp invented a thyristor; in the middle of 1980s, insulated gate bipolar transistor IGBT appeared, featured by high input impedance, voltage control, small drive power, and high switching speed (Brown, D. W., et al., 2012); in the later 1990s, the integrated gate com-mutated thyristor IGCT was known, the advantages of high voltage, large current, high switching frequency, high reliability, low loss and low cost. The rapid development of power electronic devices has promoted the development of converters.

According to whether there is the intermediate DC link, the single phase – three phase converter can be divided into two types: AC - DC - AC converter and AC - AC converter (Viitanen, T., & Niemi, E., 2009; Sato, S.,et al.,2006; Usui, H.,2010). AC - DC - AC converter has intermediate DC energy-storage link. According to the difference of original energy-storage, it can be divided into two types of voltage-type and current-type. At present, in the industrial and household occasions, what is widely used is AC - DC - AC converter. However, because of AC-DC- AC converter large capacitor or induct-or current energy-storage link, large volume and high weight result in the inconvenience of the installation and use. At the same time, a large electrolytic capacitor and volatile electrolyte will influence the converter service life, uneasy for maintenance.

The traditional type AC-AC converter, compared with AC-DC-AC, does not require DC link. Therefore, there is no AC-DC-AC converter problems. At the same time, it can realize four quadrant operation conveniently, and in low frequency output, the output waveform is close to the sinusoidal wave. Meanwhile, there are some disadvantages in this structure: the use of more thyristors, and the wiring is complex; the output frequency range can only be the frequency of 1/3~1/2; use phase control rectifier, the power factor is low.

The classification of matrix converter is based on the difference of the number of input phase and output phase, which is divided into three phase - three phase matrix converter, three phase - single-phase matrix converter, and single phase - three phase matrix converter. Single phase - three phase is one of the most important types, which is mainly used in the case of single-phase power supply, such as electricity for urban and rural residents.

Compared with the AC-DC-AC converter and traditional AC-AC converter, the matrix converter also requires no DC link, and there is no AC-DC-AC converter. At the same time, the power flow is bidirectional, able to realize the four quadrant operation; input current / output voltage is sinusoidal; arbitrary load power factor is 1. It can be said that the matrix converter is to make up for the shortage of AC - DC - AC converter and the traditional AC -AC converter. Single phase - three phase matrix converter, as an important class of matrix converter, has all the advantages of the above matrix converters.

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2 METHOD

2.1 Voltage transfer coefficient of single phase - three phase matrix converter based on SPWM and SVPWM modulation

The simulation model of single phase - three phase matrix converter with Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM) is established, respectively(Idris, Z.et al.,2005; Ryu, H. M.,2005).

When using SPWM modulation, power supply voltage is 100V, 50Hz, SPWM modulation ratio $M=1$, carrier to noise ratio $N=25$. Among them, the modulation ratio is $M=\frac{U_r}{V_c}$, U_r is the three-phase reference voltage amplitude, and V_C is the amplitude of the triangular carrier; carrier to noise ratio is $N=\frac{f_c}{f_r}$, and f_r is three phase reference voltage frequency. In addition to the fundamental frequency 1000Hz, in the frequency $|f_0-2f_i|$ and $|f_0+2f_i|$, the voltage components are relatively large. Among them, f_0 is the output voltage waveform, f_i is the power frequency, $f_0=1000Hz$, $f_i=50Hz$.

When using SVPWM for modulation, the power supply voltage is 100V, 50Hz, the switching frequency is 50kHz, and the sampling frequency is 50kHz. In addition to the fundamental frequency of 1000Hz, in the frequency $|f_0-2f_i|$ and $|f_0+2f_i|$, the voltage components are relatively large. Among them, f_0 is the output voltage waveform, f_i is the power frequency, $f_0=1000Hz$ and $f_i=50Hz$.

Define the voltage transmission ratio as the ratio of motor input phase voltage to the power supply voltage, namely $G=\frac{U_{\varphi m}}{U_{sm}}$.

For SPWM, when the output frequency is 1000HZ, the voltage transmission ratio is: $G=\frac{31.25}{100}=0.3125$;

For SVPWM, when the output frequency is 1000HZ, the voltage transmission ratio is: $G=\frac{34.65}{100}=0.3465$.

The voltage transfer coefficient obtained by SVPWM is higher than that obtained by SPWM, which is decided by the advantage of SVPWM itself.

2.2 Control strategy of PMSM control system

The load of single phase - three phase matrix converter is PMSM, and the performance difference of the converter drive motor under different control strategies is discussed mainly (Rahman, M. F.et al.,2011).The mathematical model of permanent magnet synchronous motor is introduced in the following. Vector control $i_d=0$ is used in this paper.

2.2.1 PMSM mathematical model

In the three-phase static abc coordinate system, the rotor circuit and magnetic circuit of the permanent magnet synchronous motor (PMSM) are asymmetric. The motor equations are a set of nonlinear time-varying equations related to the rotor position. In the static two-phase $\alpha\beta 0$ coordinate system, the motor equation is still a set of nonlinear time-varying equations related to the rotor position although simplified. In the rotating two-phase $dq0$ coordinate system, the equation of the motor is transformed through the coordinate. The voltage, current, and flux linkage equation are the constant coefficient equations, beneficial for analysis and control.

Taking the counter clockwise direction as the positive direction of the speed, the d-q coordinate system of the permanent magnet synchronous motor (PMSM) is shown in figure 1. ϕ_f is the magnetic field axis, and the space position coincides with magnetic pole magnetic field axis. d axis coincides with magnetic pole magnetic field axis, d and q axis are located on the rotor, and q axis exceeds the d axis of 90 degrees. The angle between the d axis and the reference axis - stator a phase axis is θ_r (electrical angle).

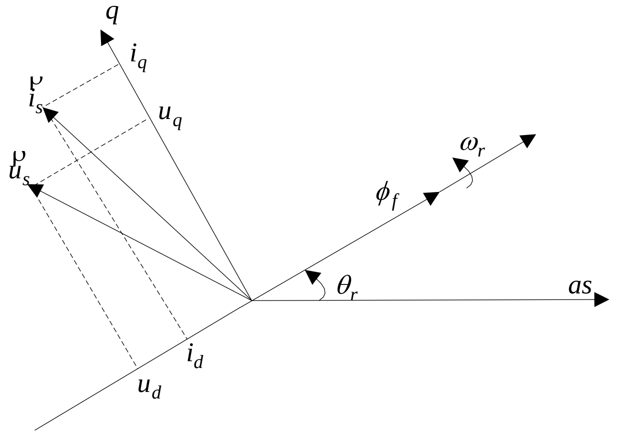


Figure 1. d-q coordinate system of permanent magnet synchronous motor

The stator voltage equation of the three-phase permanent magnet synchronous motor in the d-q axis coordinate system is:

$$u_d = Ri_d + \frac{d\phi_d}{dt} - \omega_r \phi_q \tag{1}$$

$$u_q = Ri_q + \frac{d\phi_q}{dt} - \omega_r \phi_d \tag{2}$$

Stator flux equation:

$$\phi_d = L_d i_d + \phi_f \tag{3}$$

$$\phi_q = L_q i_q \tag{4}$$

Electromagnetic torque equation:

$$T_e = \frac{3}{2} p\left(\phi_d i_q - \phi_q i_d\right) = \frac{3}{2} p\left(\phi_f i_q + \left(L_d - L_q\right) i_d i_q\right) \tag{5}$$

Mechanical motion equation:

$$J \frac{d\omega_m}{dt} = T_e - T_L - B\omega_m \tag{6}$$

In (1)- (6), u_d and u_q--Stator voltagedq axis component

i_d and i_q --Stator currentdq axis component

ϕ_d and ϕ_q --Stator fluxdq axis component

L_d and L_q --Stator windingdq axis component

R-- Stator resistance

ϕ_f -- Rotor permanent magnet flux linkage

p -- Motor rotor pole pairs

T_e --Motor electromagnetic torque

T_L --Load torque

J—Moment of inertia

B--Friction coefficient

ω_m --Rotor mechanical angular velocity

$\omega_r = p\omega_m$ --Rotor electric angular velocity

2.2.2 $i_d = 0$ vector control

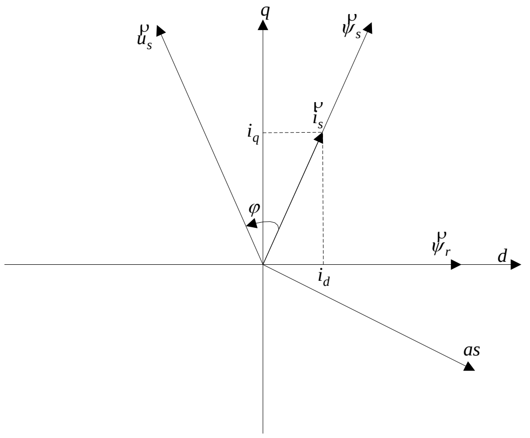


Figure 2. Permanent magnet synchronous motor rotor flux oriented vector space

Permanent magnet flux is the rotor flux, rotor flux axis is the rotor d axis, q axis exceeds the d axis of 90 degrees. $i_d = 0$ control is a vector control using rotor flux orientation, and a simple current control method, which has the following characteristics:

(1)The d axis current is 0, and the mathematical model of the motor is further simplified;

(2)There is no demagnetization of the d axis, which will not produce demagnetization effect, and the electromagnetic torque is positively proportional to the stator current;

(3)For the salient pole motor, due to the reluctance reaction torque in torque is 0, failing to make full use of torque output capacity of motor; for the cathode, $i_d = 0$ vector control is the maximum torque / current control, and the minimum current produces the maximum torque, conductive to reduce motor copper consumption and switching loss;

(4) With the increase of the load, the stator current is increased, and the stator voltage increases. We can see from Figure 2, the power factor angle φ will increase, and the power factor is reduced; therefore, the $i_d = 0$ vector control is simple, better in torque characteristics and wide in debugging range, especially suitable for polar type, small capacity permanent magnet synchronous electric machinecontrol system.

3 RESULTS

The parameters of permanent magnet synchronous motor used in the simulation are as follows: pole P=2, stator resistance $R = 0.027QN$, d axis inductance $L_d = 89\mu H$, q axis inductance $L_q = 89\mu H$, back EMF constant $0.5V/krpm$, and moment of inertia $4.99e-6kg.m^{\wedge}2$. When the single-phase power supply input voltage is 110V, the frequency is 50Hz.

(1) The switching frequency of PMSM vector control model based on SPWM and SVPWM is 50KHz, the sampling frequency is 50KHz, and the system reference speed is 60000rpm. Table 1 shows the SPWM switch signal, table 2 presents the SVPWM switch table, and table 3 displays the relationship between the supply voltage of the two models and the power supply current fundamental component phase. A in Table 1 represents the supply voltage signal, and B represents the SPWM signal.

Table 1. SPWM switch signal(x=a,b,c)

	A=1 B=1	**A=1 B=0**	**A=0 B=1**	**A=0 B=0**
S_{x1}	1	0	1	1
S_{x2}	1	1	0	1
S_{x3}	0	1	1	1
S_{x4}	1	1	1	0

Table 2. SVPWM switch table

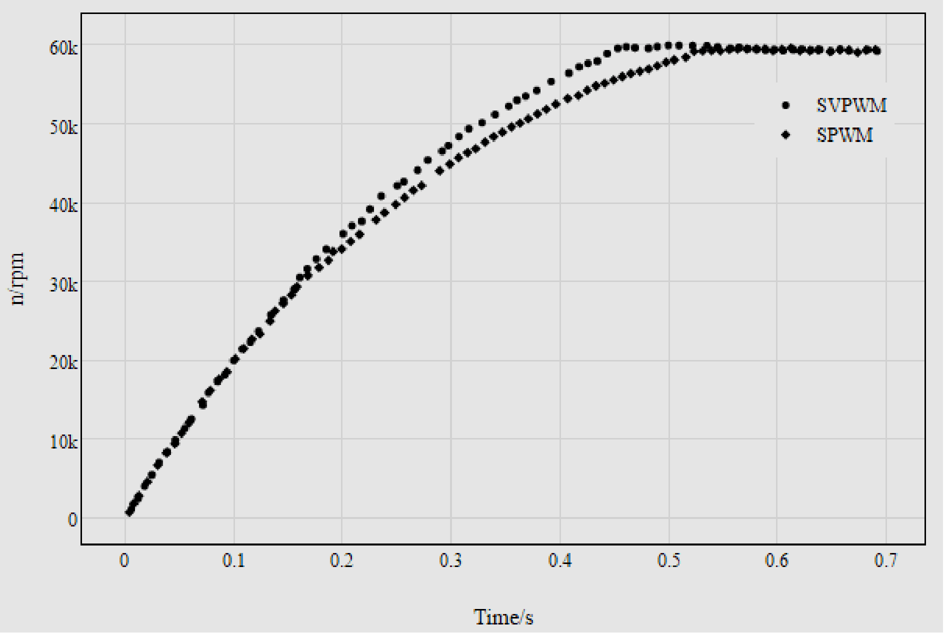
Source voltage is positive								
	(1 0 0)	**(1 1 0)**	**(0 1 0)**	**(0 1 1)**	**(0 0 1)**	**(1 0 1)**	**(0 0 0)**	**(1 1 1)**
S_{a1}	1	1	0	0	0	1	0	1
S_{a2}	1	1	1	1	1	1	1	1
S_{a3}	0	0	1	1	1	0	1	0
S_{a4}	1	1	1	1	1	1	1	1
S_{b1}	0	1	1	1	0	0	0	1
S_{b2}	1	1	1	1	1	1	1	1
S_{b3}	1	0	0	0	1	1	1	0
S_{b4}	1	1	1	1	1	1	1	1
S_{c1}	0	0	0	1	1	1	0	1
S_{c2}	1	1	1	1	1	1	1	1
S_{c3}	1	1	1	0	0	0	1	0
S_{c4}	1	1	1	1	1	1	1	1
Source voltage is negative								
	(1 0 0)	**(1 1 0)**	**(0 1 0)**	**(0 1 1)**	**(0 0 1)**	**(1 0 1)**	**(0 0 0)**	**(1 1 1)**
S_{a1}	1	1	1	1	1	1	1	1
S_{a2}	0	0	1	1	1	0	1	0
S_{a3}	1	1	1	1	1	1	1	1
S_{a4}	1	1	0	1	0	1	0	1
S_{b1}	1	1	1	1	1	1	1	1
S_{b2}	1	0	0	0	1	1	1	0
S_{b3}	1	1	1	1	1	1	1	1
S_{b4}	0	1	1	1	0	0	0	1
S_{c1}	1	1	1	1	1	1	1	1
S_{c2}	1	1	1	0	0	0	1	0
S_{c3}	1	1	1	1	1	1	1	1
S_{c4}	0	0	0	1	1	1	0	1

Table 3. The relationship between the power supply voltage and the fundamental component of the power supply current

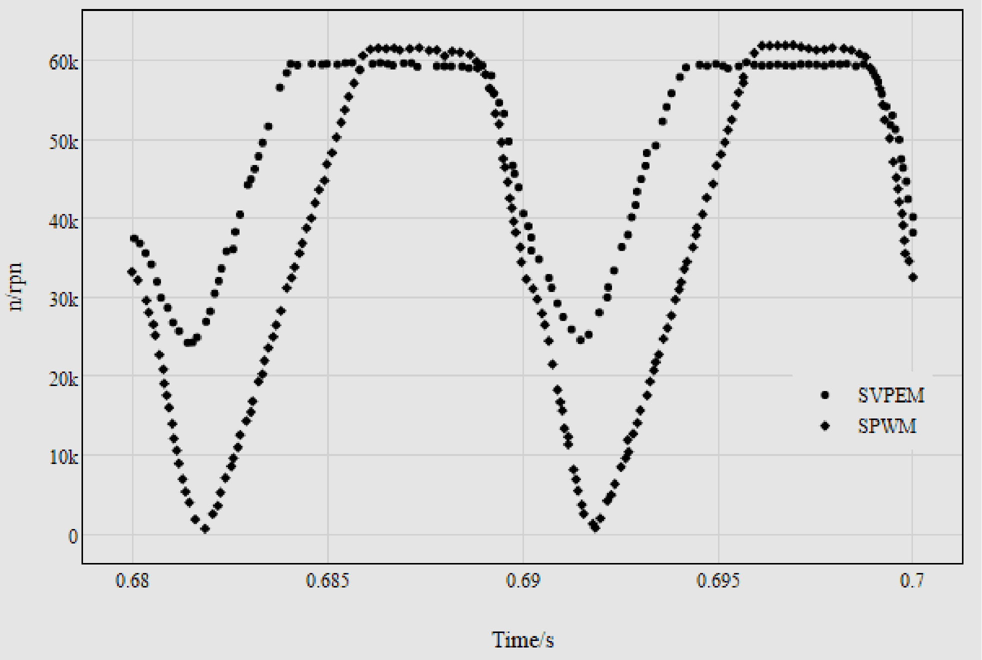
	$\Delta\varphi$
SPWM	1.20
SVPWM	19.60

(2) Simulation results:

Figure 3 (a) and (b) show the motor speed waveform of PMSM vector control system using SPWM and PMSM vector control system using SVPWM. It can be seen that PMSM vector control system using SPWM motor speed rising time is 0.56s, and when stable, the speed fluctuation is 500rpm; PMSM vector control system using SVPWM motor speed rising time is 0.45s, and when stable, the speed fluctuation is 300rpm. The rise time of motor speed is reduced in turn, and the fluctuation of speed is decreased in turn. Therefore, compared with SPWM, SVPWM can improve the utilization of the voltage, and reduce the speed rising time and the fluctuation in stability.



(a) 0~0.7s speed comparison



(b) 0.68~0.7s speed comparison

Figure 3. Motor speed comparison of PMSM vector control system based on SPWM and SVPWM

Due to the load for the high-speed motor, in the following, we will consider the loss of the system, including the switching loss and copper consumption. Copper loss, switching loss and system efficiency are calculated when the system is in steady state. Table 4 is the loss analysis and the transmission efficiency of the matrix converter of the above two control systems.

Table 4. Loss analysis of different control systems and transmission efficiency of matrix converter

	Consumption of copper/w	**Switching loss/w**	**System efficiency**
SPWM	18.91	89.2	0.7256
SVPWM	11.04	59.17	0.7997

As can be seen from table 4, the copper loss and switching loss of the PMSM vector control system using SPWM and PMSM vector control system based on SVPWM decrease in turn. Since the singlephase - threephase matrix converter consists of 12 switches, the switching loss is relatively large.

4 CONCLUSION

In this paper, first of all, the voltage transfer coefficient of the converter with SPWM and SVPWM modulation is deduced and verified. The mathematical model of permanent magnet synchronous motor (PMSM) is introduced and the $i_d = 0$ vector control is analyzed. Then, the PMSM control system is simulated and analyzed by the vector control of SPWM and SVPWM two models. The simulation results show that SVPWM, relative to SPWM, can improve the voltage utilization rate and reduce speed rising time and fluctuations in stability; at the same time, the copper consumption, switching consumption of PMSM vector control system using SVPWM is lower than the PMSM vector control system adopting SPWM, and transmission efficiency of the converter is higher.

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