Two-phase SVPWM Modulation Method and Its Application in Stepper Motor

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Abstract:**Two-phase space vector pulse-width modulation (SVPWM) algorithm is proposed in this paper based on the SVPWM analysis. Formulas of space voltage vector pulse width modulation (SVPWM) is calculated. Two-phase SVPWM is applied on the current most widely used two-phase hybrid stepping motor in this paper and simulated by Matlab/Simulink. Simulation results show that the method is feasible.**

Keywords:SVPWM; two-phase hybrid stepping motor; Matlab/Simulink.

1 INTRODUCTION

Space vector pulse width modulation (SVPWM) is a strategy that controls converter by the switching of AC space-voltage vector. It was proposed by foreign scholars in the 1980s for the variable frequency drive of AC motor[1], meets the requirements of the circular air-gap magnetic field and aims at adjusting the trajectory of AC motor flux space vector to approach circle.

This paper proposes a two-phase SVPWM control method based on H-bridge driver for the most widely used two-phase hybrid stepping motor in the current.

2 TWO-PHASE SVPWM MODULATION ALGORITHM

In this paper, we select two-phase hybrid stepping motor for the motor model. The most critical part in the whole control system is the inverter output. Fig.1 is the two-phase hybrid stepping motor's drive circuit.

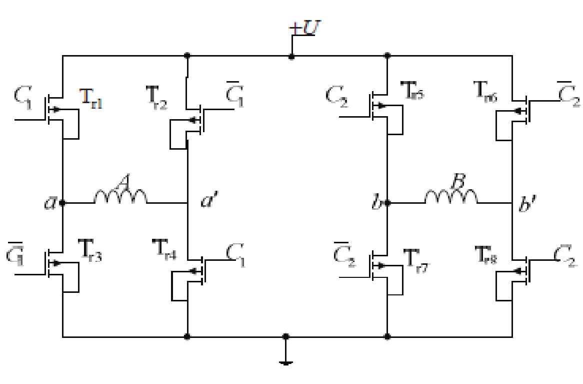

Fig. 1.Power driving circuit of two-phased hybrid stepping motor

Space position of given voltage space vector is decided through the drive signal C_1 of A-phase power tube T_{r1} and the drive signal C_2 of B-phase power tube T_{r5} [2,3]. As is shown in Fig.2, four non-zero basic space-voltage vectors are built by the state of C_1、C_2.The modules of four non-zero basic space-voltage vectors are $\sqrt{2}U$,and their phase differ 90° electric angle each other.

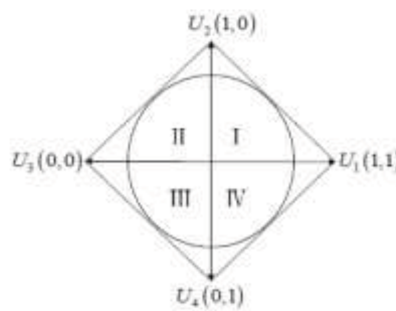

Fig. 2.Four space vectors in the two-phase inverter

Sector I is taken as an example to explain how to determine the parameters of SVPWM. Fig.3 shows the given space-voltage vector U^* is located in sector I. U_1 and U_2 are the two basic space-voltage vectors in sector I,t_1 and t_2 are the time duration of U^* spent on U_1 and U_2. ΔU means the difference vector between U^* and the maximum voltage locus, which is divided into two equal parts, and each part effect on the two coordinate axes are t_{11} and t_{21}. So a new space-voltage vector $U^* + \Delta U/2$ is formed in sector I. In order to meet the time constraint condition, the opposite reference voltage vector $-(\Delta U/2)$ must be generated in sector III to offset the flux linkages produced by the extra reference voltage $\Delta U/2$ at the sector I.

When the time constraint condition is meet, there is

$$T_s = (t_1 + t_{11}) + (t_2 + t_{21}) + t_{11} + t_{21} = t_{10} + t_{20} + t_{11} + t_{21} \quad (1)$$

Where $\quad t_{10} = t_1 + t_{11}$； $t_{20} = t_2 + t_{21}$

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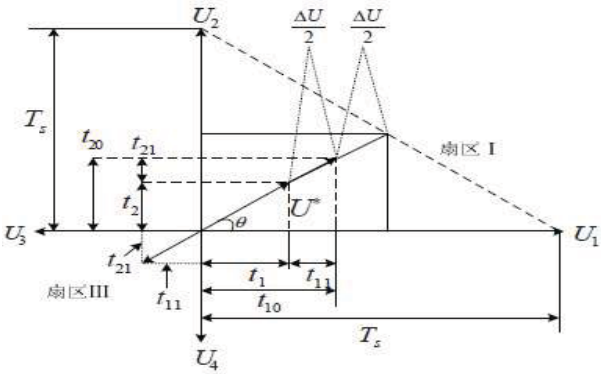


Fig. 3.Operating principle of 2-phased SVPWM

As is shown in Fig.3,when the angle between the given space-voltage vector U^* and the basic space-voltage vector U_1 is θ ,we can get:

$$(U^* + \Delta U)\cdot(\sin\theta + \cos\theta) = \sqrt{2}U \approx U' \tag{2}$$

$$U^* + \Delta U = \frac{U'}{\sin\theta + \cos\theta} \tag{3}$$

So (4) can be got

$$\Delta U = \frac{U'}{\sin\theta + \cos\theta} - U^* \tag{4}$$

Then the new space-voltage vectors in sector I and sector III are

$$U^* + \frac{\Delta U}{2} = \frac{U'}{2(\sin\theta + \cos\theta)} + \frac{U^*}{2} \tag{5}$$

$$-\frac{\Delta U}{2} = -\frac{U'}{2(\sin\theta + \cos\theta)} + \frac{U^*}{2} \tag{6}$$

So there is (7) and (8) in sector I and III

$$\int_0^{t_{10}+t_{20}} \left[U^* + \frac{\Delta U}{2}\right] dt = \int_0^{t_{10}} U_1 dt + \int_{t_{10}}^{t_{10}+t_{20}} U_2 dt \tag{7}$$

$$\int_{t_{10}+t_{20}}^{T_s} \left[-\frac{\Delta U}{2}\right] dt = \int_{t_{10}+t_{20}}^{t_{10}+t_{20}+t_{11}} U_3 dt + \int_{t_{10}+t_{20}+t_{11}}^{T_s} U_4 dt \tag{8}$$

when the frequency of carrier wave is high, the equations (7) and (8) can be approximately expressed as

$$(t_{10} + t_{20})\left[U^* + \frac{\Delta U}{2}\right] = t_{10}U_1 + t_{20}U_2 \tag{9}$$

$$(t_{11} + t_{21})\left[-\frac{\Delta U}{2}\right] = t_{11}U_3 + t_{21}U_4 \tag{10}$$

From the above equations, we can get

$$T_s\left[U^* + \frac{\Delta U}{2}\right]\begin{bmatrix}\cos\theta \\ \sin\theta\end{bmatrix} = t_{10}U'\begin{bmatrix}1 \\ 0\end{bmatrix} + t_{20}U'\begin{bmatrix}0 \\ 1\end{bmatrix} \tag{11}$$

$$T_s\left[\frac{\Delta U}{2}\right]\begin{bmatrix}\cos\theta \\ \sin\theta\end{bmatrix} = t_{11}U'\begin{bmatrix}1 \\ 0\end{bmatrix} + t_{21}U'\begin{bmatrix}0 \\ 1\end{bmatrix} \tag{12}$$

So the operating time of every basic voltage vector can be obtained

$$t_{10} = \frac{T_s}{2U'}\left[\frac{U'}{\sin\theta + \cos\theta} + U^*\right]\cos\theta \tag{13}$$

$$t_{20} = \frac{T_s}{2U'}\left[\frac{U'}{\sin\theta + \cos\theta} + U^*\right]\sin\theta \tag{14}$$

$$t_{11} = \frac{T_s}{2U''}\left[\frac{U'}{\sin\theta + \cos\theta} - U^*\right]\cos\theta \tag{15}$$

$$t_{21} = \frac{T_s}{2U'}\left[\frac{U'}{\sin\theta + \cos\theta} - U^*\right]\sin\theta \tag{16}$$

When the reference space-voltage vector is given, the times of four basic voltage vectors can be obtained according to (13)-(16).

3 MATHEMATICAL MODEL OF TWO PHASE HYBRID STEPPING MOTOR

The mathematical model of two-phase hybrid stepping motor is described in [4-8] .Motor differential equations are:

$$\frac{di_a}{dt} = \frac{1}{L_a}[U_a - R_a i_a + k_m\omega\sin(N_R\theta)]$$

$$\frac{di_b}{dt} = \frac{1}{L_b}[U_b - R_b i_b + k_m\omega\cos(N_R\theta)]$$

$$\frac{d\omega}{dt} = \frac{1}{J}[-k_m i_a\sin(N_R\theta) + k_m i_b\cos(N_R\theta) - B\omega - k_D - M_r]$$

$$\frac{d\theta}{dt} = \omega$$

Where i_a and i_b are the two-phase winding currents, U_a and U_b are the terminal voltages of two-phase winding, Ra and R_b are the two-phase winding resistances, L_a and L_b are the two-phase winding inductance, N_r is the number of rotor teeth, J is the rotor inertia, B is total friction coefficient, k_m is the rotor torque constant, w is the rotor speed, θ is the position angle of rotor and M_r is the load torque.

4 THE COMPUTATIONAL SIMULATION OF TWO-PHASE SVPWM IN MATLAB/SIMULINK

In order to achieve the two-phase SVPWM in Matlab/Simulink, the sector where the given voltage vector located in must be determined[9]. Assume that V_{sa}、V_{sb} are the given two phase space-voltage vectors of motor, the sector that the given space-voltage vector located in can be determined by the sign of V_{sa}、V_{sb}. If $V_{sa} > 0$、$V_{sb} > 0$,the given space-voltage vector locates in sector I; If $V_{sa} < 0$、$V_{sb} > 0$,the given space-voltage vector locates in sector II. If $V_{sa} < 0$、$V_{sb} < 0$,the given space-voltage vector locates in sector III. If $V_{sa} > 0$、$V_{sb} < 0$,the given space-voltage vector locates in sector IV. The simulation modules of two-phase SVPWM are shown in Fig.4 and Fig.5.

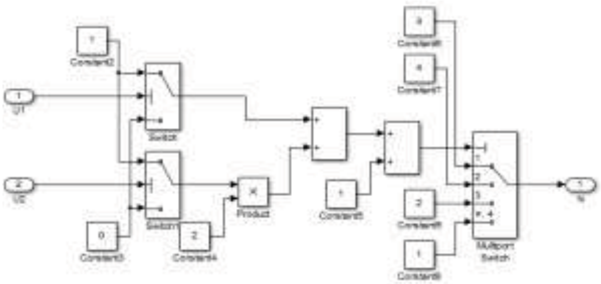


Fig. 4.Simulation model of N

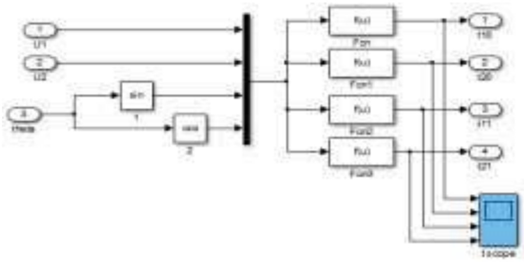
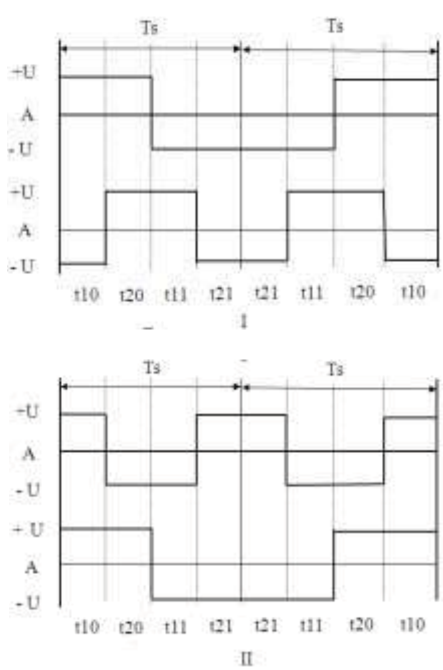


Fig. 5.Simulation model of t

When the given reference voltage vector is located in sector I,II,III and IV, winding voltages, working order and time duration of the four basic space-voltage vectors are shown in Fig.6. Using the two phase PWM pulse signals in Fig.6 as the control signals of A-phase and B-phase winding, the driving signal C_1 and C_2 can be obtained through a power amplification. Thus the control of two-phase SVPWM can be achieved.



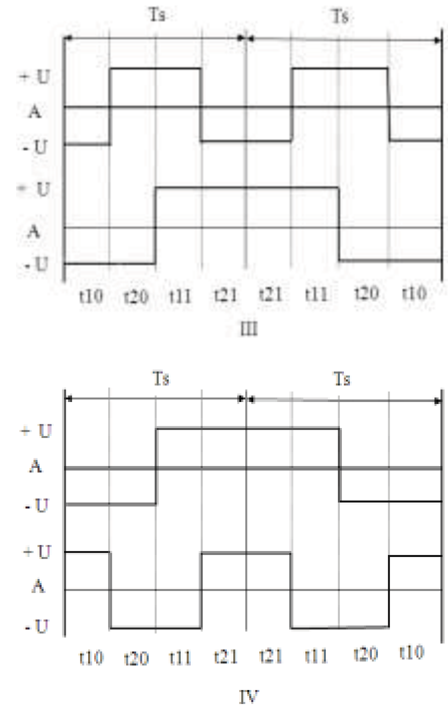


Fig. 6.Working states at sector I、II、III、IV

The system control implemented in the Matlab/Simulink is illustrated in Fig.7.

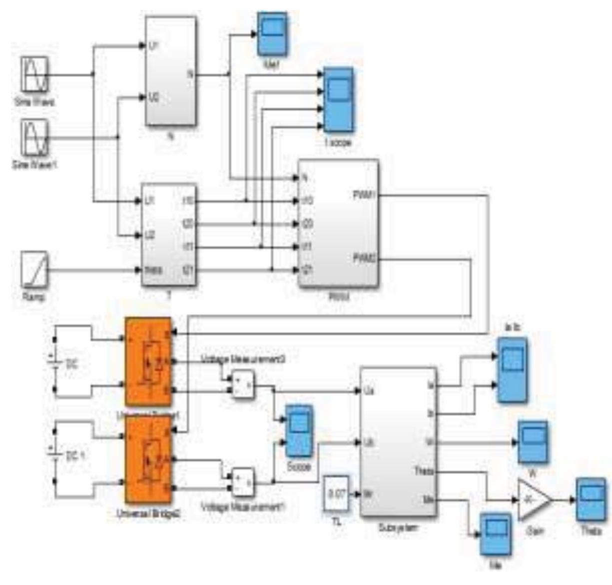


Fig. 7.System control implemented in Matlab/Simulink

Where L_a=L_b=12mH, R_a=R_b=11Ω, N_r=50, K_d=0.022Nm,B=0.025Nm/rad/s,k_m=0.22Nm/A, M_r=0.07N, J=$1.125*10^{-4}\,kgm^2$ .Simulation result based on above parameters is shown in Fig.8-9. Simulation results show that the method is feasible.

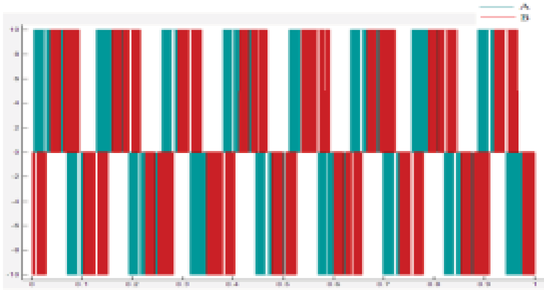


Fig. 8 U_a 、 U_b

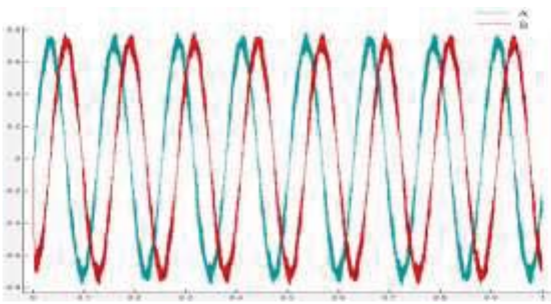


Fig. 9 I_a 、 I_b

5 CONCLUSION

The two-phase SVPWM control strategy is proposed based on the analysis of the principle of two-phase SVPWM. The simulation and experimental results show that the method is correct and feasible.

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