Research on PWM Inverter Based on New Space Vector Selection Mode

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Abstract
Space Vector Pulse Width Modulation (SVPWM) can use the power supply with high efficiency. However, the traditional SVPWM algorithm has the disadvantage of complex calculation. At the same time, the low frequency causes the motor to generate pulsating torque, which has high switching frequency, large power loss and other shortcomings. Aiming at the deficiencies of traditional SVPWM modulation, a new SVPWM algorithm for insertion of zero vector is designed in this review. Under the condition that the waveform quality is guaranteed, the power loss of the switch is reduced and the low frequency is enhanced. And MATLAB simulation is used to simulate and verify the correctness of this method.
Keywords: *SVPWM; active inverter; simulation.*

1. Introduction

The SVPWM modulation technology is highly valued by people. Its unique vector modulation takes the motor and the PWM inverter as a whole, focusing on how to make the motor to obtain constant amplitude of the circular magnetic field. It is based on the ideal flux circle in AC moter when three-phase symmetrical sinusoidal voltage is supplied, and approximating the circle by using effective vectors of flux linkage generated by different switching modes of the inverter. That is, approximating the circle by polygons. Both theoretical analysis and experiments show that SVPWM modulation has the advantages of low torque ripple, low noise and high dc voltage utilization [1]. It has been widely used in production.

In the high frequency modulation of SVPWM, the introduction of zero vector can make the waiting time become more uniform. Thus it can reduce the high harmonic of the current and make the motor's pulsation torque smaller. And it can reduce the power loss of the switch and finally improve the utilization rate of the power supply.

However, the traditional SPWM algorithm is complicated. The pulsating torque is large at low frequencies. And the control effect is not satisfactory [2]. In this review, the pulsation torque and switching power loss are reduced and the effective vector insertion is selected to enhance the quality of the output signal and improve the utilization rate of the power supply.

2. Space vector PWM inverter

2.1 Analysis of torque ripple in space vector modulation

The magnetic chain generated by a pure fundamental wave cosine three-phase voltage is:

$$\psi_s = R_0 e^{j\omega t} \quad (1)$$

The flux vector generated by the space vector is

$$\psi = \mathrm{Re}^{-j\Phi} \quad (2)$$

As shown in Figure 2-1, in the same time, the angle of walking is different.

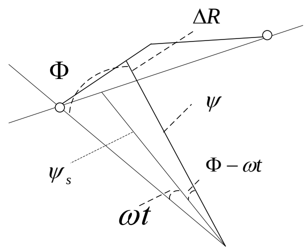


Fig 1. Magnetic chain trajectory.

$$\begin{aligned} \Delta R &= R - R_0 \\ \Delta\Phi &= \Phi - \omega t \end{aligned} \quad (3)$$

The torque ripple is a function of ΔR and $\Delta\Phi$:

$$\overline{\Delta T_e} = k_R - \overline{\Delta R} + k_\Phi \Delta\Phi \quad (4)$$

Among them

$$\overline{\Delta T_e} = \frac{T_e - T_{e0}}{T_{e0}}$$

$$\overline{\Delta R} = \frac{R - R_0}{R_0}$$

$$\Delta\Phi = \Phi - \omega t$$

Both k_Φ and $k_{\overline{R}}$ are constant, and at any time there is $k_\Phi >> k_{\overline{R}}$. It can be seen that there are only two ways to reduce ΔT , reducing ΔR or $\Delta\Phi$ [3-4].

2.2 New vector space allocation table

As mentioned above, the traditional SVPWM modulation is linearly approximated by the two effective vectors of 60 degrees adjacent to each other. When the two effective vectors go too fast, zero vector is inserted as waiting. The new modulation method is a combination of two effective vectors adjacent to 120 degrees [5-7]. The new vector allocation table can be obtained by rotating the[1] start point in the illustrated direction of rotation as shown in table 1:

Rearrange the space vector allocation tables corresponding to the six kinds of effective vectors, in which two vectors are separated by 120°. Rotate the start point as shown in the figure to get the new space vector allocation table as shown below.

Table 1 : The space allocation table of new effective vector

-30°~30°	30°~90°	90°~150°
V(101)	V(100)	V(110)
V(110)	V(010)	V(011)
150°~210°	210°~270°	270°~330°
V(010)	V(011)	V(001)
V(001)	V(101)	V(100)

2.3 Formulas Derivation

As shown in the figure 2, 1 vector V (101) and m vector V (110) are taken within the range of 0 ° to 30 °,

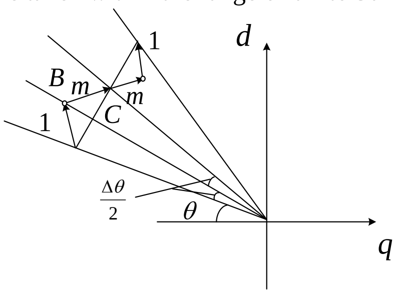


Fig 2. A new vector composition diagram.

By the triangle sine theory there

$$\frac{\overline{AB}}{\sin\angle ACB}=\frac{\overline{BC}}{\sin\angle BAC}=\frac{\overline{AC}}{\sin(\pi/3)} \quad (5)$$

Among them

$$\angle BAC=\frac{\pi}{3}+\Phi$$

$$\angle ACB=\frac{\pi}{3}-\Phi$$

$$\Phi=\theta+\Delta\theta/2=\omega t+\omega\Delta T/2$$

$$\overline{AB}=\sqrt{\frac{2}{3}}U_{dc}T_1$$

$$\overline{BC}=\sqrt{\frac{2}{3}}U_{dc}T_m$$

$$\overline{AC}\approx\Psi_m\Delta\theta=\Psi_m\omega\Delta T$$

(6) and (7) can be deduced

$$T_1=k\Delta T\sin\left(\frac{\pi}{3}-\Phi\right) \quad (6)$$

$$T_m=k\Delta T\sin\left(\frac{\pi}{3}+\Phi\right) \quad (7)$$

Where $k=\sqrt{2}u_1/u_{dc}$, at this time, there is T_1+T_m less than or equal to the establishment of ΔT , That is

$$T_1+T_m=k\sqrt{3}\Delta T\cos\Phi\le\Delta T \quad (8)$$

So

$$T_0=\Delta T-T_1-T_m \quad (9)$$

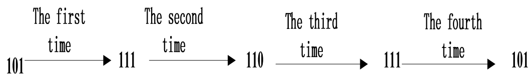
In the next period of time, the order of vectors is the opposite. When Φ equals 0, T_1+T_m is the largest, which is equal to $k\sqrt{3}\Delta T$. Because $k\sqrt{3}\Delta T\le\Delta T$ is established at any time, so the maximum line voltage $u_l=u_{dc}/\sqrt{6}$ can be derived. Considering variable voltage and variable frequency control, the output frequency f is proportional to the line voltage [8-9], that is:

$$f=g*u_l \quad (10)$$

Where g is the proportional coefficient, and the highest frequency of the 120° space vector combination can reach the $1/\sqrt{3}$ of traditional SVPWM modulation, which means that when the output frequency is low, the zero vector waiting time T_0 of the 120 degree space vector combination is much less than that of traditional SVPWM modulation. The time of 1 or m vector action in the range of -30 ° to 0 ° can be obtained by translating the ΔR range of 0 ° to 30 ° [10-11].

2.4 The selection of zero vector

The principle of zero vectors selection should also minimize the change of the switch. The role of the point is different from the traditional SVPWM modulation, which inserts the zero vector as shown in Figure 2. It is easy to conclude that the switch moves 4 times in total when a period of $2\Delta T$ is completed [12-13]. As shown below:



However，the traditional SVPWM modulation takes 6 times to complete a cycle. Therefore, the same switching frequency, 120 degree space vector combination can make circular space magnetic field more fine, and at this time the switching frequency is

$$f_s = \frac{2}{3}\frac{1}{2\Delta T}。$$

2.5 Comparison and analysis with traditional SVPWM

1. Choosing the combination of 120 degree space vector, T_0 of the traditional SVPWM modulation is reduced, which also means $\Delta\Phi$ is reduced. But ΔR is increased. Because the torque ripple formula: $\overline{\Delta T_e} = k_R - \overline{\Delta R} + k_\Phi$. $\Delta\Phi$ is standardized, ΔR needs to divide by R_0, and the corresponding weight $k\Phi$ of $\Delta\Phi$ is much larger than that of ΔR [14]. When the partitioning of the flux space is small, which means the switching frequency of components is very large, the effect of decreasing $\Delta\Phi$ and increasing ΔR will be offset much when both ΔR and $\Delta\Phi$ are very small.

2. As mentioned above, at the same switching frequency, the 120 degree space vector combination can divide the flux chain space than the traditional SVPWM modulation better, and makes the flux linkage track closer to the circle.

3. When the output frequency is low and the switching frequency is high, it can be deduced that the minimum duration of the effective vector of traditional SVPWM modulation is $k\Delta T\sin\left(\frac{\Delta\theta}{2}\right)$, and the influence of the combination of 120 degree space vector is smaller than that of traditional SVPWM [15].
The output frequency is proportional to the line voltage, which is $k\Delta T\sin\left(\frac{\Delta\theta}{2}\right)$. If f =10 H_Z, g=7.6, the comparison table with different switching frequency f_s can be selected as follows:

Table 2： Comparison of the minimum effect time of effective vector

Switching frequency f_s （H_Z）	The minimum effect of the effective vector （μ_s）	
	Traditional SVPWM	New space vector
1K	1.6	50
2K	0.4	25
3K	0.2	16

From IGBT's dead zone are a few μ_s in use, it can be seen that in the traditional SVPWM modulation of 2 KH_Z, some valid vectors will be ignored due to the short acting time (shorter than the dead time). The new space vector combination will not be lost, which means that the impact of the dead zone is much smaller.

3. Simulation model diagram of SVPWM control circuit

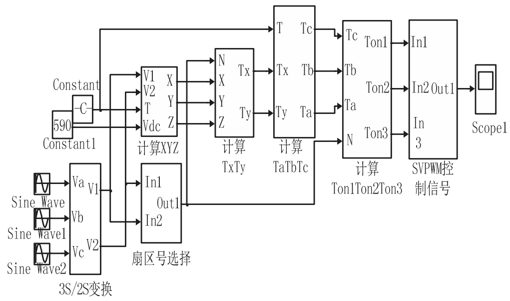


Fig 3. MATLAB / SIMULINK simulation model.

The calculation formula of sector number is: N=A+2B+4C, and the sector selection is shown in figure 4-a:

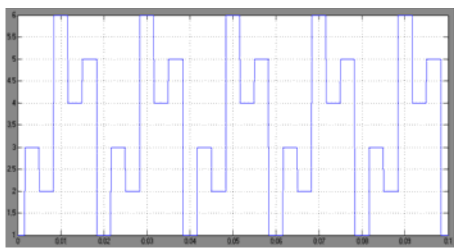


Fig 4-a. Sector number selection circuit waveform.

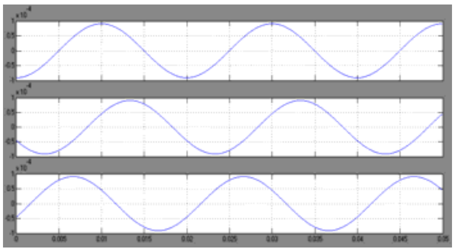


Fig 4-b. XYZ output waveform.

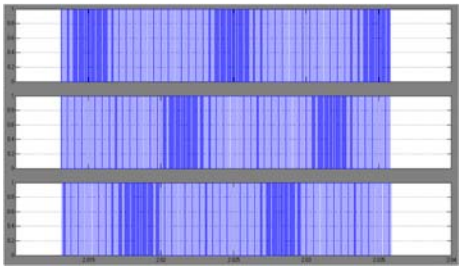


Fig 4-c. T_{on1}、T_{on2}、T_{on3} circuit output waveform.

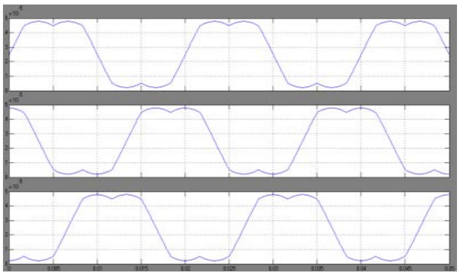


Fig 4-d. Inverter control signal waveform.

The output waveform is "steamed bread" wave, and its voltage utilization ratio is higher than that of sine wave. Therefore, the utilization ratio of DC voltage is improved, and the operation of asynchronous motor is more favorable. The control signal of the inverter is a three-phase complementary signal. The output voltage is similar to the sinusoidal voltage, so the rotating magnetic chain of the asynchronous motor is close to the circle. Control circuit parameters: IGBT switch on T=0.0001s, $V_{dc} = 590V$, input sinusoidal voltage of 311V. The rotation of the magnetic chain of the motor is close to the circle, which is shown in Figure 5.

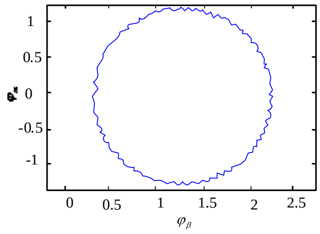


Fig 5. Magnetic chain simulation diagram of motor.

4. Conclusion

SVPWM control technology is an advanced PWM control technology. It has high voltage utilization rate. Besides, the asynchronous motor's flux linkage tracking is a circular track. And it has small torque ripple, stable speed and low noise. However, at low frequency, the torque ripple needs to be further reduced. In the new space vector selection mode, the effective vector selection can improve the torque ripple of the asynchronous motor at low frequency output and improve the low speed performance. The new space vector selection mode control system has high control accuracy, good real-time performance and fast dynamic response. It is the best choice for asynchronous motor's AC speed regulation at present.

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