An Implementation Method of SVPWM Modulation Algorithm

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Abstract: SVPWM algorithm is widely used in the field of power electronic frequency conversion power supply, motor frequency conversion control, power quality optimization and other technical fields. In this paper, the principle of SVPWM modulation is analyzed, in order to make the over-modulation algorithm more simplistic, the adverse effects on the system are smaller, and a phase and amplitude are used to change the modulation method to optimize the algorithm of the cross modulation II zone [1,2]. And using Matlab software to build SVPWM model for simulation verification. Explains the correctness of this method.

1. Introduction

With the development of power electronics technology, frequency conversion power supply, motor control, AC frequency conversion speed regulation and other technologies have been greatly improved. Space vector pulse width (SVPWM) technology is widely used in permanent magnet synchronous motor (PMSM). At present, there are two main ways to deal with SVPWM modulation [3,4]: One is the over-modulation algorithm that only changes the amplitude, [5] and the other is the over-modulation algorithm which changes the phase angle and amplitude at the same time. The former implementation method is simple, but the output base wave voltage amplitude can only be reached, the latter existing modulation algorithm is complex, and cause frequency distortion, so that the output voltage harmonic components increase, but the output base wave voltage amplitude can be achieved[6]. Therefore, in order to realize the over-modulation algorithm, the adverse effects on the system are smaller, the minimum phase error over modulation is used in the over modulation I area, and the phase and amplitude are used to change the modulation mode simultaneously in the II region. Using Matlab for simulation verification. Simulation results show the feasibility of the algorithm[7].

2. SVPWM Fundamentals

The basic principle of SVPWM is to regroup the basic vector of voltage in a switching period, so that the actual voltage vector and reference voltage vector approximation, by fixing the opening source shutdown of a three-phase inverter in a time period to achieve this control effect, that is, through the superposition of the voltage vector of a certain period. Then control the action time of the three-phase inverter and make the magnetic chain circle of the voltage synthesis closer to a complete circle, the difference between the two after the coordinate transformation into the PWM modulation module, and finally form the PWM wave output to the inverter.
### 3. SVPWM over-modulation principle

In order to measure the over-modulation depth of the inverter, the modulation coefficient is defined: \[ m = \frac{V_{\text{ref}}}{V_{\text{MI}}} \]. The \( V_{\text{MI}} \) is the phase voltage base amplitude value that the inverter outputs under the working state of six-level ladder wave, and when the modulation coefficient MI reaches 0.9069, the inverter begins to enter the modulation region, and the greater the modulation coefficient, indicates that the deeper the modulation depth, the less the reverse. Linear modulation zone when \( MI \leq 0.9069 \), when \( MI > 0.9069 \) is a modulation zone. According to the different modulation coefficients of modulation coefficient, the over-modulation I area and the over-modulation II zone are divided.

#### 3.1 Liner Modulation Zone

As shown in Figure 1, in a linear modulation region, any reference vector can be combined with two adjacent basic voltage vectors and zero vectors. At this point, the trajectory of the voltage vector is circular. By calculating the action time of two adjacent non-zero basic voltage vectors and zero vectors in the sector, then the voltage vector is synthesized.

Take the first sector, for example, \[ \tau_1 = \left( \frac{3}{2} U_{\alpha} + \frac{\sqrt{3}}{2} U_{\beta} \right) T_0 / U_a ; \quad \tau_2 = \sqrt{3} U_{\beta} T_0 / U_a ; \] \[ \tau_0 = \eta - \tau_1 - \tau_2 ; \] When the reference voltage angle is \( \pi/6 \), the maximum amplitude of the output voltage vector is \( V_{\text{ref}} / \sqrt{3} \). That is, the inner tangent circle radius of the hexagon. At this point \( MI = 0.9069 \). The output base wave reaches the maximum value of the linear zone. This modulation zone is called a linear modulation zone.

#### 3.2 Overmodulation Area I

At that time, \( 0.9069 < MI \leq 0.9517 \), in the modulation I area. The trajectory part of the reference voltage vector \( V_{\text{ref}} \) in the Overmodulated I region is inside the regular hexagon, and partly outside the positive hexagon. The Overvoltage I area limits the voltage vector in part beyond the hexagonal boundary to the hexagonal boundary without changing the phase of the voltage vector, and the voltage vector amplitude of this loss is compensated by the compensating voltage vector with an amplitude greater than the reference voltage vector amplitude value. The action phase of the compensating voltage vector is determined by reference angle \( \alpha \), and the trajectory of the whole region voltage vector is shown by the black trajectory in the Figure 2.
3.3 Over modulation II area

At that time, $0.9517 \leq M_I \leq 1$, it was in the modulation II area. The reference voltage vector trajectory in the over-modulation II area is located outside the positive hexagon. Because the reference voltage vectors in the over-modulation II area are outside the positive hexagonal region, linear modulation cannot be implemented. It is necessary to pass the modulation algorithm to correct the base amplitude value of the reference voltage. Although the reference voltage of the over-modulated II area exceeds the positive hexagonal excision circle, the base wave of its actual output is still in the positive hexagonal excision circle.

4. Over-modulation algorithm

4.1 Over modulation I area

In the over-modulation I area, the phase error minimization method is used, which is not to correct the phase of the reference voltage, only the amplitude is modified accordingly. Take sector 3 as an example, when the reference voltage vector $\mathbf{u}_r$ moves from point A to synchronous rotational angular frequency $\omega_e$ along the arc ABCD, $\mathbf{u}_1^0$ (fixed voltage phase) moves along the arc segment AB, linear segment BC, arc segment CD trajectory with the same rotation angle frequency, the dotted circle trajectory and the thick solid line trajectory are the motion tracks of $\mathbf{u}_r^0$ and $\mathbf{u}_1^0$ in a sinusoidal period, respectively. The specific solution of this interval to the modified voltage vector $\mathbf{u}_1^0$ is as follows: Calculate $t_1, t_2$ and then modify the action time of two adjacent basic voltage vectors to $t_1', t_2'$ by formula (1), and the action time of 0 vectors is 0. According to this correction method, when the reference voltage vector amplitude gradient in the $\left(\omega_{u_k} / \sqrt{3} \sim 2\omega_{u_k} / \sqrt{3}\right)$ range, the actual output voltage base amplitude value changes within $\left(\omega_{u_k} / \sqrt{3} \sim 0.9517 \times 2\omega_{u_k} / \sqrt{3}\right)$ range.
The correction voltage vector $\mathbf{u}$ moves along the arc and the phase changes from zero to the retention angle $\theta_0$ (reference formula (2)), the $\mathbf{u}$ vector remains motionless at point A; in the process of $\mathbf{u}$ moving along the arc to synchronize frequency $\omega_f$ from B to C, $\mathbf{u}$ moves from A to D along the hexagonal boundary at A rotational frequency faster than $\omega_f$, and when $\mathbf{u}$ moves along the arc from C point to phase $\pi / 6$, the correction voltage vector $\mathbf{u}$ remains unchanged at D Point, and other sectors are modified in a similar way. When the reference voltage vector amplitude in the (2$U_{dc} / 3 ~ 2U_{dc} / \pi$) gradient, the retention angle $\theta_0$ in $0 ~ \pi / 6$ according to the modulation ratio of linear operation, the correction angle $\theta_c$ in the retention angle is also calculated in a linear manner, when the actual output pressure vector $\mathbf{u}$'s base amplitude value in the range, $\theta_c$ is 0 that corresponds to the upper modulation 2 zone output voltage value limit, When $\theta_c$ is $\pi / 6$, it meant the beginning of a six-shot ladder wave.

The implementation algorithm of the over-modulation II zone is as follows: first select the Standard one Datum $u_{min}$ (in this article, $u_{min} = U_{dc} / \sqrt{3}$) $U_{min} / \sqrt{3}$, $2U_{dc}/3$, $2U_{dc}/\pi$, the corresponding standard value is $u_{3a}, u_{3b}, u_{3b}, u_{3a}$, the voltage vector $u_{1a}, u_{2a}, u_{3a}$ standard homogeneous amplitude are recorded as $u_{1a}, u_{2a}, u_{3a}, u_{4a}$, the relationship available formula (2) is indicated, In the whole $\omega_f - \beta$ two-dimensional static coordinate system plane, The relationship expression between the amplitude $u_{1a}$ and phase $\theta_c$ of the actual output voltage vector $\mathbf{u}$ and the phase angle $\theta_c$ of the reference voltage vector $\mathbf{u}$ is as as (3), (4), when located in the 3, 1, 5, 4, 6, 2 sector in the figure above, the value $\theta_c$ is $0, \pi / 3, 2\pi / 3, \pi, 4\pi / 3, 5\pi / 3$, respectively.

$$\theta_c = \frac{(u_{PU} - u_{3a})}{u_{3b} - u_{2b}} \times \pi / 6$$

(2)

$$\theta_c = \left\{ \begin{array}{ll}
\frac{\theta_0}{\pi/6 - \theta_0} + \theta_0 & (0 \leq \theta - \theta_0 \leq \theta_0) \\
\frac{\pi}{\theta_0} - \theta_0 & (\theta_0 < \theta - \theta_0 < \pi/3)
\end{array} \right.$$

(3)

$$u_{1a}^{*} = \left\{ \begin{array}{ll}
u_{2b} & (0 \leq \theta - \theta_0 \leq \theta_0) \\
\frac{u_{1b}}{\cos(\theta_0 - \theta_0)} & (\theta_0 < \theta - \theta_0 < \pi/3)
\end{array} \right.$$

(4)

5. SVPWM over-modulation simulation and experimental results
The SVPWM-modulated simulation model is built under the Matlab/Simulink software platform as shown in the Figure 4:
Figure 4. SVPWM simulation model of cross modulation

Figure 5. Phase voltage waveform

Figure 6. Modulation wave
The waveform Figure 5 of phase voltage can be obtained by voltage reconstruction technology, and the phase voltage amplitude transitions smoothly from linear modulation region to six beat ladder wave. SVPWM modulation wave in linear modulation region is saddle Wave Figure 6, and then gradually transition to square wave modulation mode.

![Figure 7 Reference voltage Vector](image)

![Figure 8 Fixed voltage vector](image)

By comparing Figure 7 and Figure 8, it is found that when the reference voltage is less than \( V_{dc}/\sqrt{3} \), the waveforms are exactly the same, and when greater than \( V_{dc}/\sqrt{3} \), the exterior of the inner tangent circle is limited to the hexagonal.

6. Conclusion
In this paper, the SVPWM algorithm is simplified, so that its algorithm is more simplistic, the adverse effects on the system are smaller, and it is easier to engineer and realize. And the Matlab/simulink software is used to verify the SVPWM modulation algorithm. The results show that the modulation algorithm can realize the transition from linear modulation state to six beat step wave running state.

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