Study and Realization of SVPWM Algorithm’s Key Technology

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Abstract: Control algorithm is the core of AC servo system. In order to improve the performance of system, on the basis of vector control system and space vector pulse width modulation (SVPWM), inverse matrix and projection of $U_{out}$ on plane rectangular coordinate system were used to determine the nonzero vector movement time $t_1$, $t_2$. Then, a calculation method of vector switch point $T_{cm1}$, $T_{cm2}$, $T_{cm3}$ was given. Finally, a judgment method of sector which vector locate was given based on the one-to-one relationship between index number and sector. Simulation was carried on and some simulation results show that the system has good dynamic response and steady-state accuracy.

Keywords: Key Technology, Nonzero Vector, Sector, SVPWM, Vector Movement Time.

1. INTRODUCTION

Good dynamic response and steady-state accuracy are very important in industrial field. such as, high positioning accuracy, rapid response speed, wide speed range (above 1:10000), high torque output [1, 2]. Realization of SVPWM algorithm’s key technology play an important role in the improving of the performance and the SVPWM algorithm’s key technology is becoming a hot work to scholars at home and abroad.

Nowadays most scholars focus on intelligent control, adaptive control, sliding mode variable structure control, direct torque control and vector control. Although intelligent control, adaptive control, sliding mode variable structure control and direct torque control has been a certain development, but vector control has many advantages, such as linear characteristics of torque output, high utilization rate of current and easy realization of regulator [3]. So vector control algorithm is still used in most field.

In this article, calculation method of vector’s sector will given detailed and judging method of vector switch point $T_{cm1}$, $T_{cm2}$, $T_{cm3}$, determine method of nonzero vector movement time $t_1$, $t_2$, calculation method of sector of voltage vector $V_{out}$ will all given. The realization of SVPWM algorithm’s key technology will provide good dynamic response and steady-state accuracy AC servo system [4].

2. PRINCIPLE AND REALIZATION OF SVPWM ALGORITHM

The ideal output of SVPWM is a three-phase symmetrical voltage source. The frequency and voltage of the voltage source can be adjusted. One of the purpose of SVPWM algorithm is to reduce the harmonic component the voltage source. A three phase plane static coordinate system which was defined by motor’s three phase stator winding has three shafts. The shafts is interval by 1200 and each shaft on behalf of a phase. The three phase stator phase voltage $U_a$, $U_b$, $U_c$ are add on the motor’s three phase stator winding and turned into three phase voltage vector $U_a$, $U_b$, $U_c$. The direction of the three phase voltage vector always on its own axis and size of the three phase voltage vector is changed by time according to sine law, so the three phase vector voltage add up and turned into a voltage space vector named $U$. The rotation speed of the voltage space vector is angular frequency of voltage source that was named $\omega$ [5,6]. The computation formula is shown as follows.

$$U = U_a + U_b + U_c \quad (1)$$

In the ABC plane coordinate system, each voltage vector corresponding to a phase voltage, so in $O\alpha\beta$ plane coordinate system, there is a unique coordinate corresponding to a non-zero voltage vectors. Vector’s sector and waveform of SVPWM is given as Fig. (1). Start from $0^\circ$, hat is the first sector, the number of sector is added to one by each 600 interval according to the counterclockwise direction. The regulation of the sector is not the only one, in some documents the sector was defined into $0_{\beta5}$ according to the counterclockwise direction, in some other documents the sector was defined as $315_{46}2$. The former is adopted in this passage. In each sector, order of tube angle of conduction and the best vector approximation group of SVPWM are given [7]. The order of tube angle of conduction and the best vector approximation group is the only one. The sector and the best vector approximation group are confirmed, so how to confirm the time of each nonzero vector need to considering. In this passage, the method of seven phase Voltage space vector...
3. DETERMINE METHOD OF NONZERO VECTOR MOVEMENT TIME $t_1$, $t_2$

Determine of the nonzero vector movement time $t_1$, $t_2$ is the key to vector control algorithm. The following expression is exist when $U_{out}$, $U_x$, and $U_{x\alpha} = U_{x60\alpha}$ was projected onto a plane rectangular coordinate system [8].

$$\begin{bmatrix} t_1 \\ t_2 \end{bmatrix} = T_{PWM} \begin{bmatrix} U_{x\alpha} & U_{x60\alpha} \\ U_{x\beta} & U_{x60\beta} \end{bmatrix}^{-1} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}$$

(2)

If the inverse matrix $\begin{bmatrix} U_{x\alpha} & U_{x60\alpha} \\ U_{x\beta} & U_{x60\beta} \end{bmatrix}^{-1}$ and the projection $\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}$ of $U_{out}$ on plane rectangular coordinate system $O\alpha\beta$ is known, the nonzero vector movement time $t_1$, $t_2$ can be calculated. Calculating method of the inverse matrix $\begin{bmatrix} U_{x\alpha} & U_{x60\alpha} \\ U_{x\beta} & U_{x60\beta} \end{bmatrix}^{-1}$ and the projection $\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}$ of $U_{out}$ on plane rectangular coordinate system $O\alpha\beta$ was given as following.

So the inverse matrix $\begin{bmatrix} U_{x\alpha} & U_{x60\alpha} \\ U_{x\beta} & U_{x60\beta} \end{bmatrix}^{-1}$ can be calculated. By observing the product of the inverse matrix $\begin{bmatrix} U_{x\alpha} & U_{x60\alpha} \\ U_{x\beta} & U_{x60\beta} \end{bmatrix}^{-1}$ and the projection $\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}$, twelve vectors were obtained. In these vectors only six vectors are independent, and the independent vectors are three vectors and it’s contra-variants [9]. There are six equations were given as following.

- $\frac{t_0 - t_1}{2} \sim \frac{t_0 - t_2}{2} \sim \frac{t_0}{4}$ is adopted in this passage, so the key technology is the calculation method of $t_0$, $t_1$, $t_2$.

**Fig. (1)**. Vector’s sector and waveform of SVPWM.
Table 1. Relational table between index number, sector and nonzero vector movement time.

<table>
<thead>
<tr>
<th>Index Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector N</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>t1</td>
<td>Z</td>
<td>Y</td>
<td>−Z</td>
<td>−X</td>
<td>X</td>
<td>−Y</td>
</tr>
<tr>
<td>t2</td>
<td>Y</td>
<td>−X</td>
<td>X</td>
<td>Z</td>
<td>−Y</td>
<td>−Z</td>
</tr>
</tbody>
</table>

\[
\begin{bmatrix}
U_{0a} & U_{0b} \\
U_{60a} & U_{60b}
\end{bmatrix}
= \begin{bmatrix}
\sqrt{2}/\sqrt{3} & \sqrt{2}/\sqrt{6} \\
0 & \sqrt{2}/\sqrt{2}
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_\beta
\end{bmatrix}
= \begin{bmatrix}
\sqrt{2}/\sqrt{3} & \sqrt{2}/\sqrt{6} \\
0 & \sqrt{2}/\sqrt{2}
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_\beta
\end{bmatrix}
\]

(3)

\[
\sqrt{2} \begin{bmatrix}
\frac{\sqrt{3}}{2} & -\frac{1}{2} \\
0 & 1
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_\beta
\end{bmatrix}
= -V_x
\]

(8)

\[
\sqrt{2} \begin{bmatrix}
0 & \frac{1}{2} \\
-\frac{\sqrt{3}}{2} & 1
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_\beta
\end{bmatrix}
= -V_y
\]

(9)

\[
\begin{bmatrix}
0 & \frac{1}{2} \\
-\frac{\sqrt{3}}{2} & 1
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_\beta
\end{bmatrix}
= -V_z
\]

(10)

\[
\begin{bmatrix}
0 & \frac{1}{2} \\
-\frac{\sqrt{3}}{2} & 1
\end{bmatrix}
\begin{bmatrix}
V_a \\
V_\beta
\end{bmatrix}
= -V_x
\]

There are three variables named X, Y, and Z were defined in this paper, and can be calculated by the following equations [10].

\[
X = \sqrt{2} \cdot T_{PWM} \cdot \frac{V_\beta}{U_d}
\]

(9)

\[
Y = \sqrt{2} \cdot T_{PWM} \cdot \frac{1}{U_d} \left( \frac{\sqrt{3}}{2} V_a + \frac{1}{2} V_\beta \right)
\]

(10)

\[
Z = \sqrt{2} \cdot T_{PWM} \cdot \frac{1}{U_d} \left( -\frac{\sqrt{3}}{2} V_a + \frac{1}{2} V_\beta \right)
\]

(11)

Variables X, Y, Z, and −X, −Y, −Z are shown in above equations, so the number of nonzero vector movement time t1, t2 can be selected by multi-channel selector on the case of knowing of sectors. In order to clear expression the number of variables X, Y, Z, the relational table between index number, sector and nonzero vector movement time is shown as Table 1.

4. CALCULATION OF VECTOR SWITCH POINT

\[T_{cm1}, T_{cm2}, T_{cm3}\]

Assume the following definitions:

\[T_a = (T_{PWM} - T_1 - T_2) / 2 \quad T_b = T_a + t1 \quad T_c = T_b + t2 \]

The number of Ta, Tb, Tc were transferred to Tcm, the assignment table of vector switch point Tcm1, Tcm2, Tcm3 is shown as Table 2.

5. CALCULATION METHOD OF SECTOR OF VOLTAGE VECTOR V_{out}

The sector of voltage vector V_{out} can be calculated by the following methods [11]. Definitions are done as follows.
The calculation method of sector can be obtained by the Fig. (1). The three lines are defined as follows:

\[ B_0 = V_\beta \]  \hspace{1cm} (12)

\[ B_1 = \frac{\sqrt{3}}{2} V_\alpha - \frac{1}{2} V_\beta \]  \hspace{1cm} (13)

\[ B_2 = -\frac{\sqrt{3}}{2} V_\alpha - \frac{1}{2} V_\beta \]  \hspace{1cm} (14)

Index number \( P \) is calculated by the following formula:

\[ P = 4 \text{Sign} (B_2) + 2 \text{Sign} (B_1) + \text{Sign} (B_0) \]  \hspace{1cm} (15)

The reason is that in the Plane rectangular coordinate system where \( V_\alpha, V_\beta \) location the sectors are composed of three lines [12]. The three lines are defined as follows:

\[ V_\beta = 0 \]  \hspace{1cm} (16)

\[ V_\beta = \sqrt{3} V_\alpha \]  \hspace{1cm} (17)

\[ V_\beta = -\sqrt{3} V_\alpha \]  \hspace{1cm} (18)

The calculation method of sector can be obtained by the Fig. (2).

From Fig. (2) it can be that the \( O\alpha\beta \) plane is divided into six regions by the three lines. The six regions are the six sectors. There is a provisions that \( \text{Sign} (B_0) = 1 \) in the plane above the line \( V_\beta \geq 0 \), on the contrary \( \text{Sign} (B_0) = 0 \). There is another provisions that \( 2 \text{Sign} (B_1) = 2 \) in the plane under the line \( V_\beta = -\sqrt{3} V_\alpha \), on the contrary \( 2 \text{Sign} (B_1) = 0 \). There is also another provisions that \( 4 \text{Sign} (B_2) = 4 \) in the plane under the line \( V_\beta = -\sqrt{3} V_\alpha \), on the contrary \( 4 \text{Sign} (B_2) = 0 \). Based on the above provisions, there is only one index number can be confirmed by the number of \( \alpha, \beta \). From Fig. (2) it can be that there is a one-to-one relationship between the index number and the sector, so the sector of voltage vector \( V_{out} \) can be calculated easily.

### Table 2. Relational table between index number, sector and timer time.

<table>
<thead>
<tr>
<th>Index Number ( P )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector N</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>( T_{\text{em}1} )</td>
<td>( Ta )</td>
<td>( Tb )</td>
<td>( Ta )</td>
<td>( Tb )</td>
<td>( Ta )</td>
<td>( Tb )</td>
</tr>
<tr>
<td>( T_{\text{em}2} )</td>
<td>( Ta )</td>
<td>( Tb )</td>
<td>( Ta )</td>
<td>( Tb )</td>
<td>( Ta )</td>
<td>( Tb )</td>
</tr>
<tr>
<td>( T_{\text{em}3} )</td>
<td>( Ta )</td>
<td>( Tb )</td>
<td>( Ta )</td>
<td>( Tb )</td>
<td>( Ta )</td>
<td>( Tb )</td>
</tr>
</tbody>
</table>

6. SIMULATION

Simulation was carried on the system and motor parameters were selected as following,

\[ R_s = 4 \Omega, L_s = 34 mH, \psi = 0.51 Wb, J = 0.05 N \cdot m^2, \]
\[ R_Q = 4 N \cdot s, J = 20 N \cdot m, k_f = 86, k_g = 57. \]

System’s input is selected as step signal and oblique wave signal. The output of the system is shown as Fig. (3) and Fig. (4). In the two figures, curve A is the reference line.
and curve C is the response curve of conventional system. When the system’s algorithm was adopted as SVPWM whose key technology is realized, the reference line is shown as curve B. From the simulation results it can be seen that the response time of curve B is about 0.054 seconds and the response time of curve C is about 0.063 seconds. It also can be seen that on the case of interference is carried on system the recovery time of curve B is about 0.053 seconds and the recovery time of curve C is about 0.067 seconds, so the anti-interference ability of curve B is better than curve C.

CONCLUSION

In this article, calculation method of vector’s sector is given detailed. Using projection source and matrix as tools, judging method of vector switch point $T_{cm1}$, $T_{cm2}$, $T_{cm3}$ and determine method of nonzero vector movement time $t_1$, $t_2$ and calculation method of sector of voltage vector $V_{out}$ are given. In the last, simulation was carried on and from the simulation results it can be seen that the dynamic response time of system is improved by 16.7% and the precision of steady state response of system is improved by 20.7%. The realization of SVPWM algorithm’s key technology will provide a reference for future research. For this article, the future research work is further optimize algorithm and improve the control performance of the system.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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