A New Space Vector Modulation Strategy Based on MC

Chuyun Li¹ and Yougui Guo¹,*

ABSTRACT

This paper presents a control method based on space vector modulation matrix converter (SVMMC). The method calculates the corresponding rotating voltage space vector according to the expectations of output voltage, and uses the strategy presented in the paper to adapt the expectation of the output voltage space vector. Through theoretical derivation, the method of the algorithm is given. Using the control method proposed in this paper will greatly simplify the modulation strategy, the output voltage of matrix converter will well follow the expectations of a given voltage, and can effectively inhibit the matrix converter output voltage and input current waveform distortion. The simulation results verify the correctness of the theoretical analysis.

Keywords: matrix converter, space vector modulation, harmonic suppression.

INTRODUCTION

In the current, with the development of the modern power electronic technology, microelectronics technology and so on, a variety of high-performance power electronic transform devices have been appeared. The matrix converter has been present for decades[1-2], and research has made great progress. Matrix converter circuit topology is different to the traditional pay - direct – converter. It is composed of bidirectional switch. Meanwhile, matrix converter, as a kind of directly-transform topology, can realize arbitrary frequency and amplitude phase output. Compared with the traditional two level converter, matrix converter has many advantages, such as: no energy storage link, four quadrant operation, small volume, light weight, unit input power factor, etc[3-4]. Like other converter, the basic working principle of matrix converter is a high frequency waveform synthesis principle. The mature system algorithm is: double space vector algorithm (DSVM), switch function algorithm modulation function, double line voltage and current hysteresis control algorithms. At present, the more research and the most promising control mode are: synthesis of dual voltage modulation and space vector modulation, this paper just for space vector modulation matrix converter carry out in-depth study.

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Matrix converter is a type of direct ac power conversion which can eliminate the dc large or large inductance with the same time no intermediate storage link. Although matrix converter provides benefits, matrix converter also has many problems, such as power grid voltage abnormal condition, difficult control strategy of matrix converter switch and so on. In the traditional pay-direct-alternating voltage converter, it can take advantage of the dc capacitor energy storage function, when the grid voltage have such problem like waveform distortion, unbalance, voltage drop, and so on to maintain relative stability of dc voltage, so as to ensure the normal output of the inverter. When the grid voltage appears afore-mentioned problems, because of lacking the intermediate energy storage link, the only thing can rely on is voltage detecting. But just using the voltage detecting to regulate the matrix converter is not far enough, as its timeliness and reliability are not ideal. For the above problems, the new modulation strategy becomes the hot research. Different modulation strategies for harmonic suppression have different effect, the dual voltage synthesis regulation law, for example, the harmonics of the input voltage has certain inhibition, because the modulated matrix of duty ratio is based on two aspects of the actual input voltage and expected output voltage information, but for other reasons harmonic there is no inhibition. In the space vector modulation method, the calculation of the space ratio is based on the expected value, which is independent of the actual input and output voltage, and has no inhibitory effect on the harmonics. In order to improve the ability of harmonic suppression and simplify the control strategy, this paper proposes a new control strategy. According to the matrix converter the expectations of the output voltage, it can calculate the corresponding rotating the voltage space vector, which is based on the current to the output of a maximum of line voltage to fit the expect voltage space vector. The theory and simulation analysis show that this control can effectively reduce the distortion of output voltage and input current waveform[5].

THE BASIC PRINCIPLE OF SVMMMC

The MC is composed of a two-way switching matrix connected to two independent three-phase systems. Each phase output of the three-phase and it’s input is connected by a two-way switch, which is a direct AC-AC converter. The schematic diagram of matrix converter is shown in Figure. 1. It main circuit consists of nine two-way switches. Each two-way switch has the capability of bi-directional opening and closing, which can be made up of two IGBT devices and two fast recovery diode[6-7].

![Figure 1. The simplified structure of a MC.](image)

The most common space vector modulation methods of matrix converters are the direct space vector modulation method and the indirect space vector modulation method.

Indirect space vector modulation method is a kind of double modulation method of the space, the method will artificially regard matrix converter as pay-direct–converter, which is
divided into two parts of the virtual rectifier and inverter. In rectifier, it uses space vector modulation for sinusoidal input current and adjustable input power factor. In the inverter part, it uses space vector modulation amplitude and frequency adjustable sinusoidal output voltage, and then they will be the one.

The direct space vector modulation method requires the input current and output voltage, and the switching state is determined by the output phase voltage and the input phase current. This method solves a series problem of matrix converters, such as input voltage imbalance, stability analysis of system performance, common mode and low frequency current component prediction.

The space vector modulation algorithm is widely used in matrix converter modulation and is the basic algorithm in matrix converter modulation. The position, amplitude of instantaneous target voltage in the state space can be deduced by using Clarke conversion, The output of the three-phase line voltage is $U_{ab}$, $U_{bc}$, $U_{ca}$, formula (1) gives the calculation method of space vector.

$$U_{out} = \frac{2}{3} \left( U_{ab} + U_{bc} e^{\frac{2\pi}{3}} + U_{ca} e^{\frac{4\pi}{3}} \right)$$

In actual operation, the switch which can meet the demand of no suddenly voltage short circuit or suddenly current open circuit is a total of 27, but there are 6 kinds of switch state, the output of the phase voltage and input current space vector without fixed direction, which cannot effectively adjust output voltage, so the 6 kinds of switch state is defined as "invalid vector". There are 18 switching states, so the corresponding output line voltage and the space vector of the input phase current are defined as the "effective vector". There are three switch states, and the corresponding vector is zero vector. The modulation algorithm in this paper only uses the effective vector and the zero vector in total 21 switching states[8-9].

The output line voltage corresponding to each switch state is shown in table I. Since the sampling frequency is much higher than the input and output frequency, so the phase and reference value of the output voltage space vector can be considered unchanged during a sampling period.

<table>
<thead>
<tr>
<th>TABLE I. MATERIAL PROPERTIES OF STEELS.</th>
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<tbody>
<tr>
<td>21 vector</td>
</tr>
<tr>
<td>switch</td>
</tr>
<tr>
<td>+1</td>
</tr>
<tr>
<td>-1</td>
</tr>
<tr>
<td>+2</td>
</tr>
<tr>
<td>-2</td>
</tr>
<tr>
<td>+3</td>
</tr>
<tr>
<td>-3</td>
</tr>
<tr>
<td>+4</td>
</tr>
<tr>
<td>-4</td>
</tr>
<tr>
<td>+5</td>
</tr>
<tr>
<td>-5</td>
</tr>
<tr>
<td>+6</td>
</tr>
</tbody>
</table>
The table I combined equation (1) can obtain six voltage space vector. Through the calculation and analysis, it can be concluded that in the 18 valid vectors the $\pm 1,2,3$ in total 6 vectors are commuted to the line of $V_2$ and $V_5$. Based on the above analysis, the state space vector diagram of output voltage can be obtained, as shown in Figure 2.

![Figure 2. The simplified structure of MC.](image)

Unlike traditional dual-space vector modulation, the modulation strategy in this paper only involves the voltage space vector. As there are 21 valid switching states, there is no current space vector as an auxiliary selection switch state. Using voltage space vector for synthesis of the desired output voltage condition will be facing in such a problem that the same sector of the corresponding two directions both has useful switches. How to choose become the key to the problem. Next, this paper will detail how to select a switch state. At a certain moment in the first sector, for example, it assumes that the anticipant output of the voltage space vector is in the first sector (in Roman numerals), state of the switch should be decided by the adjacent two vector, the Figure. 2 shows the first sector has $V_2$ and $V_5$ two direction vector. It assumes that the output voltage correspond to the switch state in these six switch vector selection, and through the voltage space vector formula we can get such a conclusion: the 18 effective space vectors see zero vector as the center of a fixed line, back and forth its size with the corresponding sine voltage do change. Because the size of voltage is not a constant value, if the voltage size is too small, the present switch is not suitable for the current space vector, so it can be directly select the space vector corresponding to maximum voltage size switch state[10].

Setting the current output voltage vector is $U_{max}$, though table I, on the same straight
line can be drawn from six size of the voltage vector corresponding to the instantaneous input voltage $U_{ab}, -U_{ab}, U_{bc}, -U_{bc}, U_{ca}, -U_{ca}$ is ix values, and the largest voltage space vector in those six voltage is selected. Every corresponding vector has a corresponding switch state, there is only one vector that can meet the both two demand about the max vector and the corresponding direction, so the corresponding switch state can correspond to the table II.

Three-phase instantaneous voltage space vector can be synthesis by pulse width modulation. When the desired output voltage of the rotating space vector $U$ is in some sectors, the $U_a$ and the $U_a$ is available to compound the desire output voltage.

<table>
<thead>
<tr>
<th>Maximum voltage</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{ab}$</td>
<td>-4.1</td>
<td>-5.2</td>
<td>-6.3</td>
<td>4.1</td>
<td>5.2</td>
<td>6.3</td>
</tr>
<tr>
<td>$U_{bc}$</td>
<td>-5.2</td>
<td>2.8</td>
<td>3.9</td>
<td>-1.7</td>
<td>-2.8</td>
<td>-3.9</td>
</tr>
<tr>
<td>$U_{ca}$</td>
<td>-6.3</td>
<td>-8.5</td>
<td>-9.6</td>
<td>7.4</td>
<td>8.5</td>
<td>9.6</td>
</tr>
<tr>
<td>$-U_{ab}$</td>
<td>4.1</td>
<td>5.2</td>
<td>6.3</td>
<td>-4.1</td>
<td>-5.2</td>
<td>-6.3</td>
</tr>
<tr>
<td>$-U_{bc}$</td>
<td>5.2</td>
<td>-2.8</td>
<td>-3.9</td>
<td>1.7</td>
<td>2.8</td>
<td>3.9</td>
</tr>
<tr>
<td>$-U_{ca}$</td>
<td>6.3</td>
<td>8.5</td>
<td>9.6</td>
<td>-7.4</td>
<td>-8.5</td>
<td>-9.6</td>
</tr>
</tbody>
</table>

The real-time modulation of SVPWM signals require the components of the $\alpha$ axis and the $\beta$ axis, the $V_a$ and the $V_\beta$, the PWM periodic $T_{Pwm}$ and the magnitude of the output voltage. According to the principle of area equivalence, the relationship between the output voltage and the switching state in a sector is:

$$V_\alpha = \frac{T_1}{T_{PWM}} \frac{1}{\sqrt{3}} |V_1| \cos \frac{\pi}{6} + \frac{T_2}{T_{PWM}} |V_2| \cos \frac{\pi}{6}$$

$$V_\beta = \frac{T_1}{T_{PWM}} |V_1| (-\sin \frac{\pi}{6}) + \frac{T_2}{T_{PWM}} |V_2| \sin \frac{\pi}{6}$$

$$T_1 = \frac{T_{PWM}}{|V_1|} \left( \frac{1}{\sqrt{3}} V_\alpha - V_\beta \right)$$

$$T_2 = \frac{T_{PWM}}{|V_2|} \left( \frac{1}{\sqrt{3}} V_\alpha + V_\beta \right)$$

If $T_1$ and $T_2$ are greater than the periodic values in one period, the time of the two adjacent vectors in one cycle is:

$$T_1 = \frac{T_1}{T_1 + T_2}$$

$$T_2 = \frac{T_2}{T_1 + T_2}$$

$$T_0 = 0$$

If the sum of $T_1$ and $T_2$ in a period is less than the periodic value, its action time is:

$$T_1 = \frac{T_{PWM}}{|V_1|} \left( \frac{1}{\sqrt{3}} V_\alpha - V_\beta \right)$$

$$T_2 = \frac{T_{PWM}}{|V_2|} \left( \frac{1}{\sqrt{3}} V_\alpha + V_\beta \right)$$
\[ T_0 = T_{pwm} - T_1 - T_2 \quad (11) \]

In order to reduce the harmonic component of the input line current and the output line voltage, we adopt the symmetrical space vector modulation strategy. Assuming the current maximum voltage is \( U_{ab} \), in the first sector. As shown in Figure 3, in a single modulation cycle, the above switch combination is halved, according to: \(-4 \to 10 \to -4 \to 1 \to 11 \to 1\), and 1 lead time sequence: \( \frac{T_1}{2} \to \frac{T_0}{2} \to \frac{T_1}{2} \to \frac{T_2}{2} \to \frac{T_0}{2} \to \frac{T_2}{2} \).

The paper’s control concept is different from indirect space vector modulation algorithm mode, but the basic modulation algorithm is on the principle of SVM, its advantage is that without sampling current it can control the output voltage, greatly simplifying the control strategy.

**SIMULATION RESULTS AND ANALYSIS**

In order to verify the space vector modulation based on matrix converter, Matlab/Simulink is used for digital simulation. The system parameters are: input frequency 50Hz, input line voltage effective value 380V, output frequency of 25Hz, modulation coefficient 1, simulation time: 0.7s. Figure 4 is the line voltage waveform before filtering, and Figure 5 is the three-phase voltage output after filtering, and the THD of the output voltage is 1.58%, which has obvious effect on harmonic suppression.
Figure 5. The three-phase voltage output after filtering.

CONCLUSION

This paper introduces the control method of space vector modulation based on matrix converter. According to the characteristics of matrix converter, 21 switching combinations of matrix converters are obtained. The output voltage switch state can be obtained by sampling the input voltage and the expected voltage. The simulation results show that the output voltage and the expected voltage are basically the same phase, the output line voltage THD is smaller, and the 3-line current sinusoidal changes. The simulation verifies the practical feasibility of this control strategy.

REFERENCES