The Study on Suppression Common-mode Voltage Strategy Based on Predictive Control

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Abstract. The traditional two-level pulse width modulation strategy will generate a higher common-mode voltage and cause common-mode interference to the inverter load-side equipment. This paper uses predictive control to implement current tracking control. The algorithm is simple to implement and can be adjusted by adjusting the value factor to suppress the common-mode voltage output of the inverter, and the simulation verifies the correctness of the algorithm, which has certain reference value for further research on the suppression of the common-mode voltage on the load side of the inverter.

1. Introduction

With the rapid development of power electronics technology, three-phase inverters are widely used in the fields of AC drive, reactive power compensation and new energy power generation[1-2]. Pulse width modulation[3] is a common modulation strategy for voltage source inverters, but the digital implementation is complicated, the controller has a heavy calculation load, and the influence of common-mode voltage on the load is less considered. If common-mode voltage suppression is considered, some vectors need to be discarded[4-5], resulting in poor output harmonic characteristics. This paper uses predictive control[6] to achieve effective control of the inverter, and its output current harmonic characteristics are better. In addition, this paper considers the impact of the common-mode voltage on the load.

2. Two-level inverter topology

The topology of the two-level voltage source inverter is shown in figure 1. The switching state of each bridge arm is defined as Sx, where x=a, b, c. If Sx=1, which means that the upper arm bridge is on and the lower arm bridge is off. If Sx=0, which means that the lower arm bridge is on and the upper arm bridge is off. In general, each phase arm has two switching states, and the three-phase arm has eight switch states. The distribution of the corresponding space voltage vector in the $\alpha\beta$ plane is shown in figure 2.
The traditional two-level voltage source inverter often uses pulse width modulation. Among them, the space voltage vector modulation is widely used due to the high DC voltage utilization rate and the small output harmonic distortion rate. However, when the modulation algorithm is digitalized, it needs to judge the sector, calculate the action time of each switching vector, select the switching sequence of the switch, and the implementation is complicated. This paper uses predictive control modulation strategy, the algorithm is simple and easy to implement.

3. Predictive control modulation strategy

Predictive control is based on the detected load current at the nth sampling period $T$, combined with the corresponding circuit parameters to establish a mathematical model to predict the expected current $i(k+1)$ of the n+1th switching period, and then the optimal vector is selected from the switching vectors of inverter, so that after the vector acts on the inverter bridge switch, the actual current of the n+1th sampling period tracks the corresponding reference current $i_{ref}(k+1)$ with the optimal characteristics.

According to the topology diagram shown in figure 1.

$$V(k) = Ri(k) + L \frac{di}{dt}$$

Where k= a, b, c. L is the circuit inductance value, R is the circuit resistance value, $V(k)$ is the phase voltage output of the inverter, because the sampling period $T$ is small, it can be considered that the current value in each sampling period is constant.

$$\frac{di}{dt} \approx \frac{i(k+1) - i(k)}{T}$$

The predictive current of the k+1 sampling period is:

$$i(k + 1) = (1 - \frac{RT}{L})i(k) + \frac{T}{L}V(k)$$

Substituting each switching vector into $V(k)$ in the formula (3), the predicted current value of the k+1th sampling period can be obtained, and the optimal switching vector can be obtained according to the principle of minimum current error to achieve current tracking control. The corresponding value function is as follows formula.

$$g = |i_{ref}(k + 1) - i(k + 1)|$$

The high-speed turn-on and turn-off of the power switching device will produce a high-frequency common-mode voltage $V_{cm}$ at the output, which affects the normal operation of the load. Therefore, the value factor $B = g_{cm}|V_{cm}|$ can be added to the formula (4) to consider the common-mode voltage and control the output current, where $g_{cm}$ is the adjustment factor.

$$g = |i_{ref}(k + 1) - i(k + 1)| + g_{cm}|V_{cm}|$$
It can be known from the literature [5] that the common-mode voltage is the output connected to the motor load, and when the three-phase windings are connected in a star connection, the potential difference of the star-connected load neutral point to the reference ground.

\[ V_{cm} = \frac{V_a + V_b + V_c}{3} \]  

(6)

The output voltage of the inverter is:

\[ V_s = S_x \frac{V_{dc}}{2} \]

(7)

Where \( x = a, b, c \).

Substituting equation (7) into equation (6) gives:

\[ V_{cm} = \frac{V_{dc}}{6} \sum (2S_x - 1) \]

(8)

The common-mode voltage value factor B is:

\[ B = g_{cm} \frac{V_{dc}}{6} \sum (2S_x - 1) \]

(9)

Corresponding to each space voltage vector, the common-mode voltage on the load side of the inverter is shown in Table 1. It can be seen that the common-mode voltage corresponding to switching vectors of 000 and 111 reaches \( V_{dc}/2 \), and when other switching vectors act, the common-mode voltage amplitude is \( V_{dc}/6 \). Substituting equation (9) into the equation (5), the effective control of the inverter output common-mode voltage can be achieved by adjusting the \( g_{cm} \). If \( g_{cm} = 0 \), the influence of the common-mode voltage on the load is not considered. The modulation strategy only achieves effective tracking of the reference current with minimum tracking error, the common-mode voltage of the inverter reaches \( V_{dc}/2 \). If \( g_{cm} \neq 0 \), considering effective tracking of the reference current and suppressing the common-mode voltage, the amplitude of the common-mode voltage of the inverter is limited to \( V_{dc}/6 \).

Table 1. Common-mode voltage corresponding to each space voltage vector.

| Vector | \( V_a \) | \( V_b \) | \( V_c \) | \( V_{cm} \) |
|--------|--------|--------|--------|--------|
| 000    | \(-V_{dc}/2\) | \(-V_{dc}/2\) | \(-V_{dc}/2\) | \(-V_{dc}/2\) |
| 100    | \( V_{dc}/2\) | \(-V_{dc}/2\) | \(-V_{dc}/2\) | \(-V_{dc}/6\) |
| 110    | \( V_{dc}/2\) | \( V_{dc}/2\) | \(-V_{dc}/2\) | \( V_{dc}/6\) |
| 010    | \(-V_{dc}/2\) | \( V_{dc}/2\) | \(-V_{dc}/2\) | \(-V_{dc}/6\) |
| 011    | \(-V_{dc}/2\) | \( V_{dc}/2\) | \( V_{dc}/2\) | \( V_{dc}/6\) |
| 001    | \(-V_{dc}/2\) | \(-V_{dc}/2\) | \( V_{dc}/2\) | \(-V_{dc}/6\) |
| 101    | \( V_{dc}/2\) | \(-V_{dc}/2\) | \( V_{dc}/2\) | \( V_{dc}/6\) |
| 111    | \( V_{dc}/2\) | \( V_{dc}/2\) | \( V_{dc}/2\) | \( V_{dc}/6\) |

4. Simulation analysis

The MATLAB/Simulink simulation software is used to simulate and verify the two-level inverter modulation algorithm based on predictive control. The simulated main circuit is consistent with the topology shown in Figure 1. The main circuit experimental parameters are as follows: DC side voltage \( V_{dc} = 540V \); the sampling period is 20kHz; the three-phase load is symmetrical, the inductance \( L = 5mH \), the resistance \( R = 10\Omega \); the reference current is a three-phase symmetrical current, and the amplitude is 30A.
Figure 3. A-phase voltage waveform.

It can be seen from figure 3 that the phase voltage waveform diagram of the inverter with predictive control modulation is consistent with the waveform diagram of the space voltage vector modulation. It can be seen from figure 4 that the output three-phase sinusoidal current is consistent with the reference current. It shows that the modulation strategy based on predictive control can be well implemented on the two-level inverter, which verifies the correctness of the algorithm adopted in this paper.

Figure 4. Three-phase current waveform.

Figure 5. Waveform of common-mode voltage when \( g_{cm} = 0 \).

Figure 6. Waveform of common-mode voltage when \( g_{cm} = 0.05 \).

It can be seen from figure 5 and figure 6 that when \( g_{cm} = 0 \), the common-mode voltage value factor is not added to the control strategy, and the maximum value of the output common-mode voltage amplitude is \( V_{dc}/2 = 270 \text{V} \); when \( g_{cm} = 0.05 \), the common-mode voltage value factor is based on the current tracking control, the vector with the smaller output common-mode voltage is selected to act on the inverter. The maximum value of the output common-mode voltage is \( V_{dc}/6 = 90 \text{V} \), indicating that adding the common-mode voltage value factor can effectively control the inverter output common-mode voltage.

5. Conclusion

The traditional two-level pulse width modulation strategy is complicated to calculate and difficult to implement. In this paper, predictive control is used for current tracking control. The algorithm is simple to implement, and a value factor is added to the value function to suppress the common-mode voltage on the load side of the inverter. It has a certain reference order for further research on suppressing the common-mode interference of the inverter.

References
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