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Narrow Pulse Distribution of Three-level Inverter Virtual Space Vector PWM

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Abstract: Virtual space vector pulse width modulation of three-level inverter is widely used, while narrow pulses will be generated in certain region, which will result in unnecessary switching loss and heat accumulation. In this paper, the state duty expressions of each phase of the virtual space vector PWM are derived, and the distribution area of the narrow pulse is analyzed accordingly.

1. Introduction

Compared with two-level inverter, three-level inverter has many advantages, such as lower output harmonic, lower switching tube voltage and lower EMI, which have been widely used in photovoltaic inverter, motor drive and other fields [1]. Virtual space vector pulse width modulation (VSVPWM) eliminates the neutral-point potential ripple and simplifies the switching strategy, but the switching times increase and the DC offset of the neutral-point potential cannot be eliminated. The switch is a non-ideal state in the actual working process, there are opening delay, rise time, turn-off delay and drop time. If the driving pulse width is less than Tmin, the sum of the time mentioned above, it will cause the switch failure, the output waveform distortion and even the damage of the switch caused by thermal accumulation [2, 3]. The driving pulse is called narrow pulse.

2. VSVPWM Duty Ratio Expression

The switching strategy is one of the key technologies of the three-level inverter, which is related to the harmonics of the inverter output waveform, the magnitude of the common mode voltage, the fluctuation of the midpoint potential, the inverter efficiency and the heat. The switching strategy of the three-level inverter is developed on the basis of a two-level inverter, which is mainly divided into Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM).

The SPWM generates a PWM wave by directly comparing the modulated wave with the carrier wave. The calculation amount is small and easy to implement, which is beneficial to high-speed real-time operation. In order to realize the modulation of the three-level inverter, two triangular carriers are needed, which are a positive triangular carrier and a negative triangular carrier, and the corresponding PWM waveform can be obtained by comparing the amplitude of the sinusoidal modulated wave with the two carriers. The output voltage of each phase of the SPWM is only half of the bus voltage, and the voltage utilization ratio is relatively low.

The SVPWM bus voltage has high utilization rate, and low harmonic content is smaller than SPWM, so it is widely used in motor drive systems. Two prototypes studied in the three-level inverter SVPWM are the nearest three-vector PWM (NTVPWM) and the virtual space vector PWM (VSVPWM).

Reference [4] proposed a three-level inverter SVPWM strategy based on the two-level inverter SVPWM strategy. The method divides the space vector of the three-level inverter into six 2-level hexagons. In the hexagon, the reference voltage can be corresponding to the corresponding vector of the small vector and the two-level inverter SVPWM strategy. Besides, the size and angle of the two-level corresponding vector need to be calculated.

VSVPWM was proposed by Sergio Busquets-Monge in 2004, and the open-loop method is used to effectively eliminate the AC ripple at the neutral-point voltage balancing [5]. VSVPWM constructs virtual space vectors using the principle that the sum of the three phase currents is equal to zero, including virtual small vectors and virtual medium vectors. The virtual small vector is composed of 1/2 of the positive small vector and 1/2 of the negative small vector, and the virtual medium is composed of 1/3 of the two small vectors and 1/3 of the medium vector. The advantages of the virtual space vector include that no complex partitioning is required, and the duty ratio of the three phases can be calculated from the angles of the modulation factor and the reference voltage vector, and the switching strategy is greatly simplified.

The 0-60 degree voltage vector diagram is shown in Figure 1.

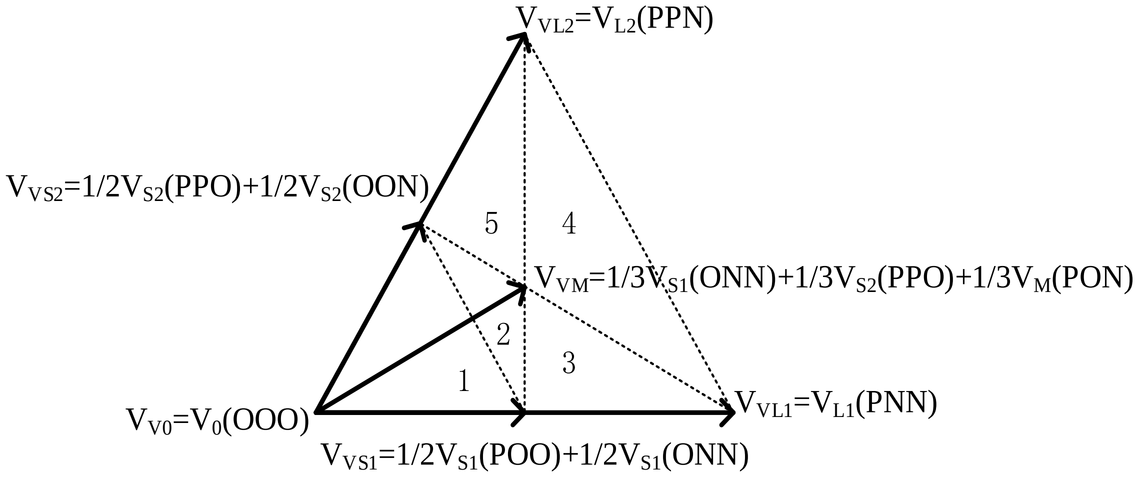

Figure 1. Vsvpwm 0-60 Degree Voltage Vector.

For virtual space vector pulse width modulation, in region I-1, the reference voltage vector is synthesized by virtual small vector and zero vector, and the switching sequence is ONN-OON-OOO-POO-PPO-POO-OOO-OON-ONN [6], virtual the action time of the small vector VVS1 Ta, the action time of the virtual small vector VVS2 Tb and the action time of the zero vector Tc can be calculated as following:

$$\begin{aligned} T_a &= 2\times m\times\cos(\theta+\pi/6)\times T_{PWM} \\ T_b &= 2\times m\times\sin\theta\times T_{PWM} \\ T_c &= \left(1-2\times m\times\cos(\theta-\pi/6)\right)\times T_{PWM} \end{aligned} \tag{1}$$

According to the definition of the virtual vector, the P and N state duty ratio of each phase are

$$\begin{aligned} d_{ap} &= m\cos(\theta-\pi/6) \\ d_{an} &= 0 \\ d_{bp} &= m\cos(\theta-\pi/2) \\ d_{bn} &= m\cos(\theta+\pi/6) \\ d_{cp} &= 0 \\ d_{cn} &= m\cos(\theta-\pi/6) \end{aligned} \tag{2}$$

The duty ratio of each phase in the other subintervals of the I sector is the same expression as in equation (2).

The duty ratio expression for the voltage vector in other sectors is similar to the above. It can be seen that VSVPWM does not require complex partition calculation, and the duty ratio expression of each sector is the same, which greatly saves the calculation amount.

3. VSVPWM Narrow Pulse Distribution

When the voltage vector electrical angle is between 0-60 degrees, it can be concluded that in one PWM cycle, the A phase has two output states of P and O, the B phase has three output states of P, O, and N, and the C phase has two output states of O and N. Therefore, in the A phase, when the driving pulse width of the P state or the N state is less than Tmin, the phase A generates a narrow pulse; in the B phase, when the driving pulse width of the P state or the N state is less than Tmin, the B phase A narrow pulse is generated, and the O state does not produce a narrow pulse as a transition between P and N; in the C phase, when the drive pulse width of the O state or the N state is less than Tmin, the C phase produces a narrow pulse. In combination with the above expression, a distribution in which a narrow pulse is in the range of 0-60 degrees can be obtained: near m=0, near θ=0 degrees, near θ=60 degrees, and near m=1 and θ=30 degrees. According to the symmetry, the VSVPWM narrow pulse distribution can be obtained as shown in the shaded gray part of Fig. 2 without considering the over modulation.

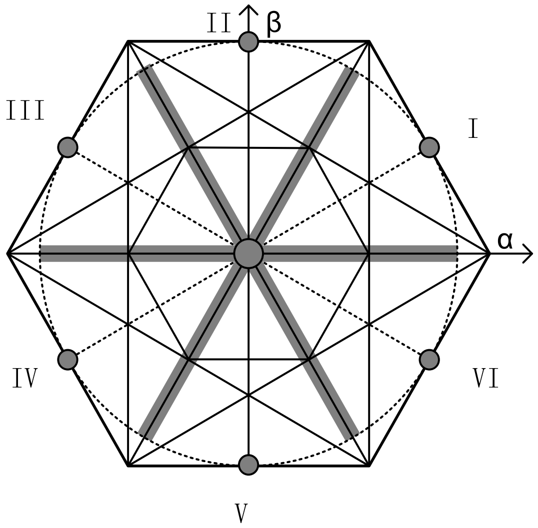

Figure 2. Vsvpwm Narrow Pulse Distribution.

4. Conclusion

The three-level VSVPWM is simple to calculate and maintains the midpoint potential balance for each PWM period. By analyzing the duty cycle expressions of the P and N states of each phase, a narrow pulse distribution map of the three-level VSVPWM can be obtained, which facilitates the implementation of the narrow pulse suppression algorithm.

Acknowledgments

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