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A Spectrum Analysis Method to Space Vector Pulse Width Modulation

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Abstract. Aiming at that the extremely complicated spectrum expression of the space vector pulse width modulation strategy, a universal procedure and algorithm is proposed to analyze the harmonic spectrum. The key steps and technique of the procedure and algorithm are given firstly. The realization method and the key codes are presented secondly. Finally, three numerical experiments are presented to verify the developed algorithm, and the results verify its correctness, reliability and convenience.

Keywords: Space vector pulse width modulation, spectrum analysis, fast Fourier transformation, adaptive precision

1 Introduction

Because the space vector pulse width modulation (SVPWM) technology is based on the volt-second balance principle, the undesirable harmonic is inevitable [1,2]. The harmonic has heavy effects on the application, such as loss, dynamic characteristic of the motor system, electromagnetic compatibility and audible noise[3-11]. The theoretical spectrum expression of the inverter output is often extremely complicated, and the magnitudes of the harmonics always include the summation of the infinite series [2, 10]. Huge differences in the spectrum expression exist in different SVPWM strategies. To a new strategy, the deducing process is very difficult, most tedious and quite error-prone, and the explicit expression cannot be usually gotten. In this paper, a new spectrum analysis algorithm with adaptive precision is proposed, and the key steps and analysis procedure are presented.

2 SVPWM Technology

The classic two-level inverter has 8 permissible states that are corresponding to 8 basic space vectors as shown in Fig.1 (a). The three-level neutral-point clamped (NPC) inverter has 27 permissible states, and the 27 corresponding space vectors are shown in Fig.1 (b).

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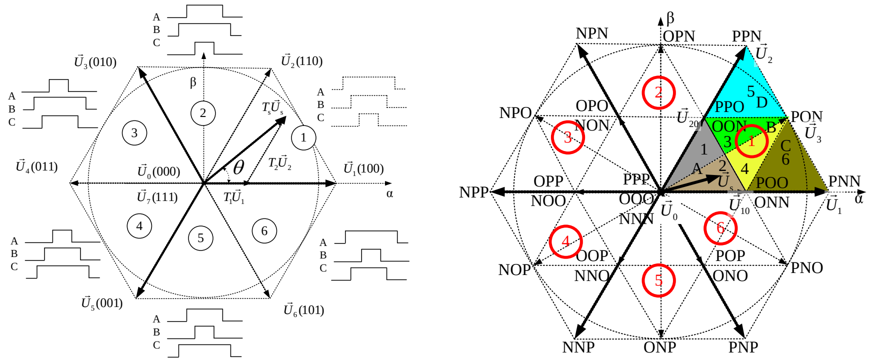


(a) Two-level three-phase inverter (b) Three-level three-phase inverter

Fig. 1. The vector diagram of the inverter. The notations P, O and N refer to that the three phase output terminals are positive, zero and negative, respectively

3 Spectrum Analysis Algorithm

The algorithm for the spectrum analysis with adaptive precision is as follows.

Step 1: Store the switching states and vector sequences in a vector sequence matrix S.

Step 2: Compute the duration times of the basic space vectors that are used to generate the command/reference voltage vector.

Step 3: Store the duration times of the basic space vectors in Step 2 in a time matrix ST.

Step 4: Sample the output waveform of the inverter and compute the spectrum using the Fast Fourier Transform (FFT) algorithm.

The Step 4 can be divided into several sub-steps as follows.

Step 41: The output voltage pulse series is sampled according to the vector sequence matrix S in Step 1 and the time matrix ST in Step 4, and then a discrete time sequence DS can be got.

Step 411: Compute the cumulative sum of the elements of the time matrix ST and store the cumulative sum in a cumulative time matrix STC. The q-th element of the cumulative time matrix STC is got through Equation (1).

$$\mathrm{STC}[q] = \sum_{i=1}^{q} \mathrm{STC}[i] \qquad \textbf{(1)}$$

Step 412: The sampling time of the r-th element of the discrete time sequence DS is corresponding to the k-th element of the cumulative time matrix STC. The index k is determined using Equation (2).

$$\left\lfloor \frac{\mathrm{STC}[k]-\mathrm{ST}[k]}{\Delta_t} \right\rfloor < r \le \left\lfloor \frac{\mathrm{STC}[k]}{\Delta_t} \right\rfloor \quad (2)$$

Step 413: Sample the voltage value according the k-th element of the vector sequence matrix S.

Step 42: The representation in the frequency domain of DS is got using FFT algorithm. Let the Q discrete amplitude values are $A_1, A_2, A_3, \cdots, A_Q$ and Q discrete phase values are $\varphi_1, \varphi_2, \varphi_3, \cdots, \varphi_Q$.

Step 43: Precision control and processing.

Step 431: If it is the first time for sampling and computing the frequency spectrum, go to Step 435.

Step 432: If this is not the first time for sampling and computing the frequency spectrum, the difference values between the current spectrum $A_1, A_2, A_3, \cdots, A_Q$, $\varphi_1, \varphi_2, \varphi_3, \cdots, \varphi_Q$ and the last spectrum $A_{01}, A_{02}, A_{03}, \cdots, A_{0Q}$, $\varphi_{01}, \varphi_{02}, \varphi_{03}, \cdots, \varphi_{0Q}$. Go to Step 433.

$$\begin{cases} \Delta A_i = A_i - A_{0i} \\ \Delta \varphi_i = \varphi_i - \varphi_{0i} \end{cases} \qquad (i = 1, 2, 3 \cdots, Q) \quad (15)$$

Step 433: If $\max\left(\left|\Delta A_i\right|\right)$ is more than the set amplitude error limit or $\max\left(\left|\Delta \varphi_i\right|\right)$ is more than the set phase error limit, go to Step 435.

Step 434: If $\max\left(\left|\Delta A_i\right|\right)$ is not more than the set amplitude error and $\max\left(\left|\Delta \varphi_i\right|\right)$ is not more than the set phase error, go to Step 436.

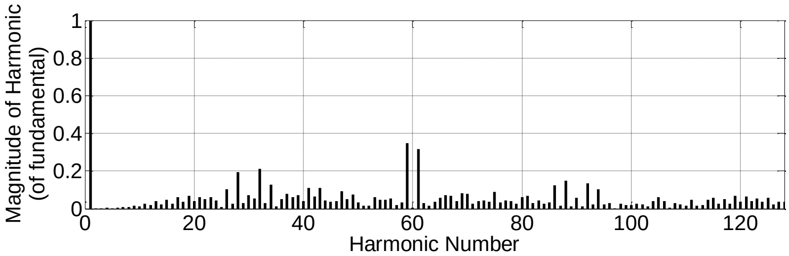
Step 435: Double the sampling number. Go to Step 41.

Step 436: Go to 44.

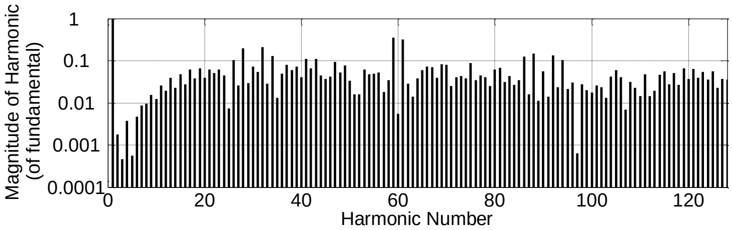
Step 44: Store the last discrete amplitude values and phase values.

4 Examples and results

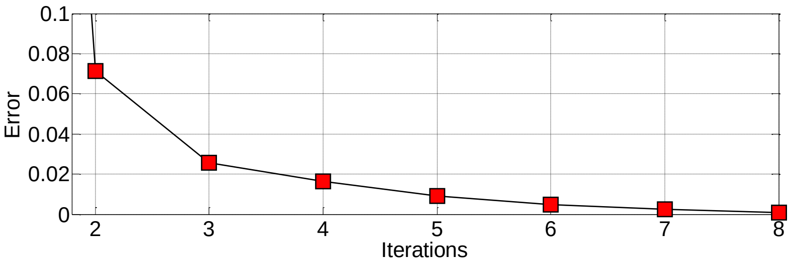
The DC bus voltage U_{DC} is 100V, the fundamental wave frequency is 60Hz, the switching frequency is 1800Hz and the error limit is 0.001. For the random zero-vector partitioning SVPWM strategy, the duration time ratio of the two zero basic vectors is a random variable. This random variable is represented using the pseudorandom numbers. For example, the function random that generates random arrays from a specified distribution can be used to generate the required random number. The command random('norm', A, B) returns a pseudorandom value drawn from the uniform distribution on the open interval(A,B), and random('norm', A, B) can be replaced with the command (B-A)*rand. Given that the duration time ratio of the two zero basic vectors obeys a standard uniform distribution, the computation results are shown in Fig.2.



(a) Harmonic spectra of the line voltage between phase A and B plotted using the linear scale for both axes



(b) Harmonic spectra of the line voltage between phase A and B plotted using a base 10 logarithmic scale for the Magnitude-axis and a linear scale for the Harmonic Number-axis



(c) Error as a function of iteration number

Fig. 2. The computation results for the random zero-vector partitioning SVPWM strategy

5 Conclusion

A new RZDSVPWM scheme with a fixed randomization range is proposed. The implicit modulating voltages, the derivation procedure of the HDF are given in detail. The analysis and computation results show that the new scheme has several advantages. Firstly, the fixed range of the randomization duration time of the zero vectors makes the scheme easily implemented in the digital control system. In addition, the random part of the implicit modulating voltage wave can be regarded as stationary random process, so it can be conveniently analyzed using the corresponding tool and theory. Finally, the proposed scheme has excellent performance on suppressing the cluster harmonic magnitudes around the integer multiple switching frequency.

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