

A Study on Diode Clamped Multilevel Inverter Modulation Simulation based on Third Harmonic Injection

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Abstract: Since the multi-level diode inverter was put forward, it has solved the voltage resistance problem of power element in the middle and high voltage situation, improved the output waveform of the inverter, and reduced the dV/dt in the switching process. It has become a hot research topic in power transmission and power electronics technology. In this paper, the multi-carrier PWM control method is studied, and the simulation is carried out with the diode-clamp-bit five-level inverter. At the same time, the third harmonic injection method is used to improve the harmonic of the output waveform. Finally, a five-level diode-clamp-bit inverter model is set up with Simulink, and the inverter model is simulated. The results show that the output of the five-level diode clamp-bit inverter is stable and the ideal waveform is obtained.

1. Introduction

Since the Japanese scholar A. Naba proposed three-level neutral-point clamping inverter, people pay more attention to it. Because of its great advantages in energy saving, reliability and performance index, it is used more and more. The main structure of the current multilevel inverter is: Cascaded H-bridge; Capacitor-Clamped; Diode-Clamped [1]. In order to make better use of this technology, many researchers have proposed some improvements: in topology research, the main direction of improvement is to reduce the number of power electronic devices used, and to solve the problem. In the aspect of control, the main direction of improvement is to optimize the output waveform and algorithm.

Diode clamped multilevel inverter is one of the earliest and most widely used multi-level inverters. Diode clamped multilevel inverter divides the higher voltage into a series of lower voltages by a series of capacitors. By the action of clamping diode, the voltage on each switch device is limited to $1/4$ of the voltage of a capacitor, so the output voltage synthesized by the inverter can be increased relatively. Diode clamped multilevel inverter only needs a common DC power supply, which makes its rectifier side design simpler.

PWM is a technology that turns DC voltage into a series of voltage pulse sequences with the switch on and off of semiconductor switch devices to realize the multilevel inverter to change voltage, frequency conversion, and control and eliminate harmonics [2].

2. Basic Principle of Multi-level Inverter

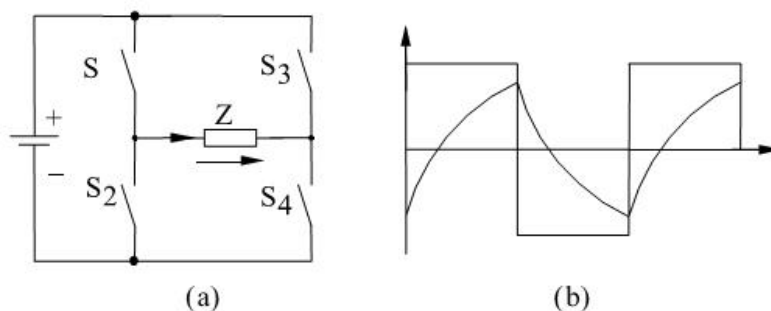


Fig. 1 Inverter principle and its waveform

Fig. 1 (a) shows the principle of a single-phase bridge inverter circuit. When the switch S1,S4 is closed and S2,S3 is open, the load voltage u_o is positive; when S1,S4 is open, S2,S3 is closed, u_o is negative, so alternately the alternating current is obtained on the load, and the waveform of u_o is as shown in Fig. 1(b). The frequency of the output AC is proportional to the switching frequency of the two sets of switches. In this way, the inverter of DC to AC is realized[3].

By extending the topology of the diode clamped three-level inverter to five levels, the one-phase topology diagram of the five-level inverter can be obtained. As shown in the figure, the number of main switching devices per phase and the number of diodes for continuation are eight, the number of clamped diodes is six, and the average positive voltage per supervisor is $U/4$. Taking the five-level diode clamping phase as an example, the main circuit of the five-level inverter is shown in the analysis diagram. When the VT1,VT2,VT3,VT4 onduction trigger pulse is given, if the load current is in the direction of inflow, then the P1 point current flows through VT1,VT2,VT3,VT4 , The output potential of the phase is equal to that of the P1 point potential. If the load current is in the direction of outflow, the output potential of the phase is still equal to that of the P1 point potential when the current flows through the D1,D2,D3,D4 injection point of the diode.

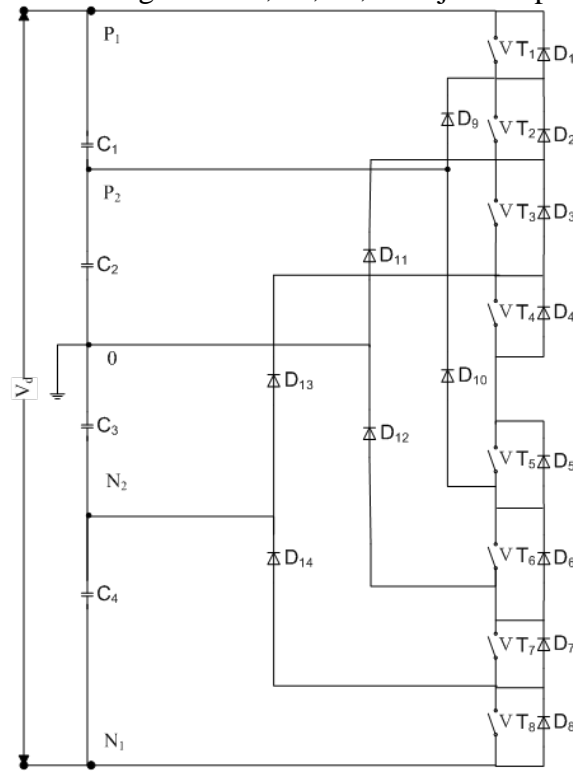


Fig. 2 One-phase topology of five-level diode clamps

The third harmonic injection method[3][4] is the method of adding the same phase third harmonic to the modulated wave. When the line voltage is synthesized, the third harmonic of each phase voltage cancels each other, and the line voltage is sine wave. The advantage of the third harmonic injection modulation is that the amplitude of the output voltage is increased and the THD of the output voltage is not affected. When the modulation wave of the three-phase inverter circuit is sinusoidal, the three-phase output phase voltage is expressed as follows:

$$\begin{cases} u_A = m \sin \omega t \\ u_B = m \sin(\omega t - 120^\circ) \\ u_C = m \sin(\omega t - 240^\circ) \end{cases} \quad (1)$$

The expression of the three-phase sinusoidal modulation signal with the third harmonic is as follows:

$$\begin{cases} u_{mA} = m \sin \omega_o t + k \sin 3\omega_o t \\ u_{mB} = m \sin(\omega_o t - 120^\circ) + k \sin 3\omega_o t \\ u_{mC} = m \sin(\omega_o t - 240^\circ) + k \sin 3\omega_o t \end{cases} \quad (2)$$

3. Simulink Model of Diode clamped Five-level Inverter

Fig.3 shows the main circuit diagram of a diode-clamped five-level inverter. The main circuit can be divided into: pulse module, inverter module, current and voltage measurement module and POWERGUI module. The pulse module and the inverter module are encapsulated. P is the pulse module with three output ports, which respectively controls the switching on and off of the three-phase switch tube of the inverter module. Inverter is the inverter circuit module. There are three-phase pulse input terminals which control the three-phase sub-modules respectively. a,b,c is a three-phase output, N is a neutral point. The phase voltage, line voltage and phase current are connected between a,b,c three-phase and the load Powergui can set and analyze the simulation parameters of the whole circuit.

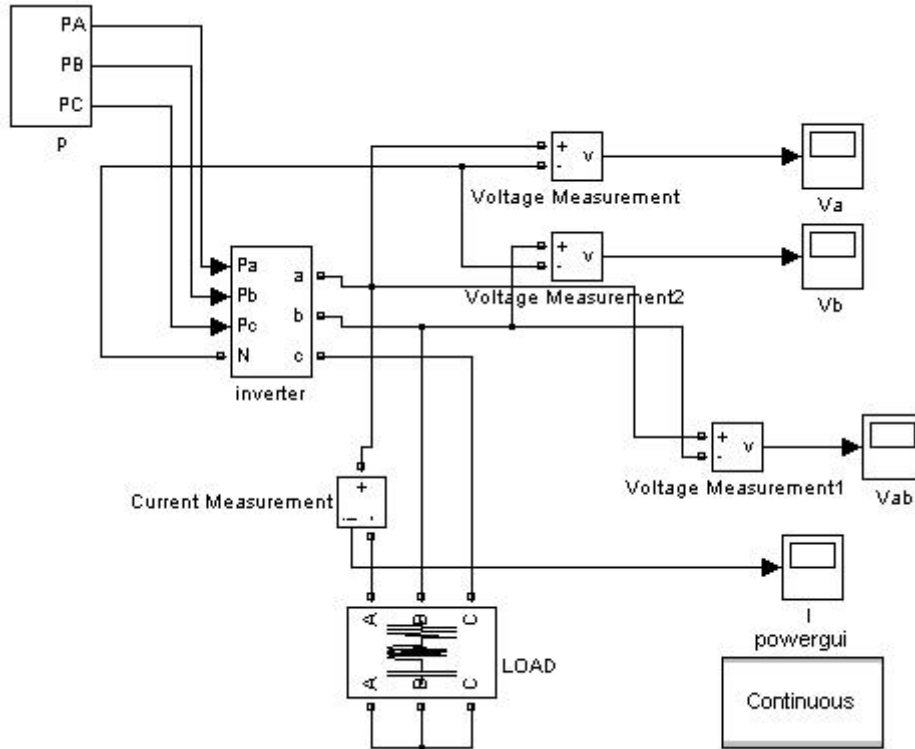
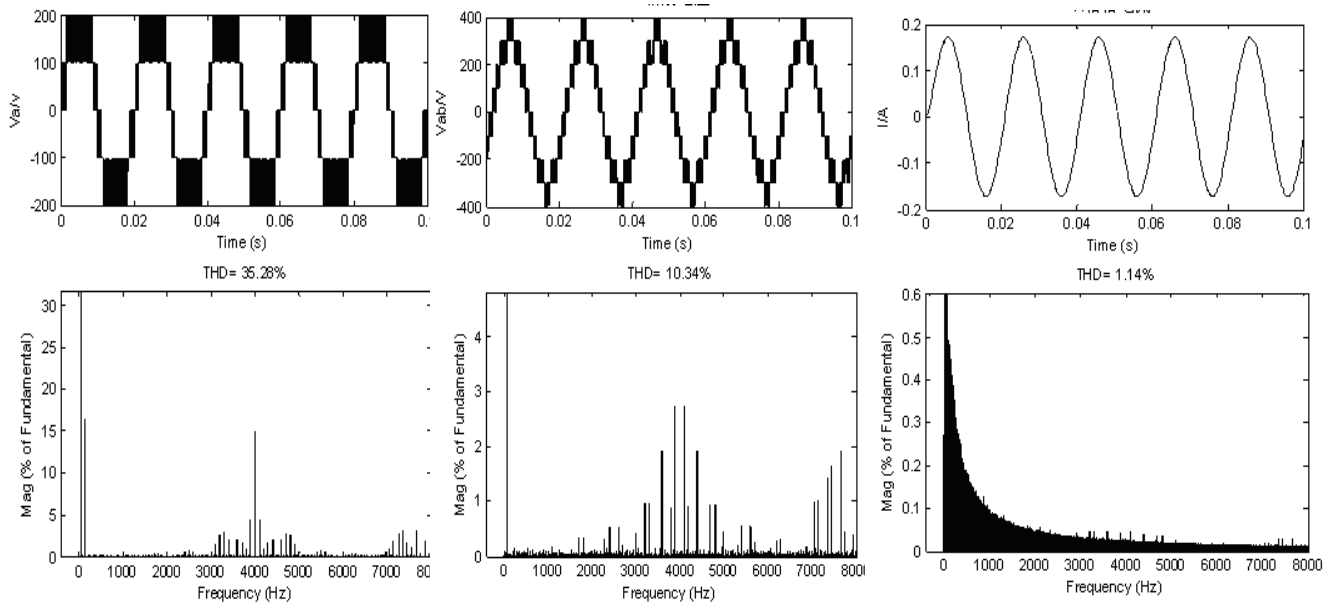


Fig.3 Diode clamped five-level inverter model

4. Simulation Results and Analysis

The simulation parameters are as follows: carrier ratio $mf = 80$; regulation system $ma = 0.9$ (mf equal to the ratio of carrier frequency to modulation frequency; ma equal to the ratio of the peak modulation wave to the carrier peak); the operating frequency of the power supply $fm = 50$ Hz; DC side voltage $E = 400$ V, third harmonic is injected.

Fig. 4 shows the spectrum analysis of phase A phase voltage V_a with a maximum frequency of 8000 Hz. It can be seen from the figure that when the fundamental frequency is 50 Hz, the harmonic components are mainly distributed in the vicinity of 4000 Hz and 8000 Hz, and the THD is 35.28%. Since phase B and phase C are only shifted to 120 degrees in turn, the total harmonic distortion and harmonic distribution of the voltage spectrum of phase B and phase C are basically the same as those of phase A.



Phase A phase voltage

(b) Phase AB line current

(c) Phase A phase current

Fig.4 Spectrum analysisl

In the case of sinusoidal modulation and third harmonic injection with the same parameters, the THD is listed as follows:

Table.1 Comparison of THD between sinusoidal modulated wave and injected third-harmonic wave

	THD	Phase voltage	Line voltage	Phase current
Sinusoidal modulation wave		27.69%	10.55%	1.21%
Injected third harmonic wave		35.28%	10.34%	1.14%

From the statistical results in the above table, it can be seen that the THD value of the phase voltage increases when the third harmonic is injected into the sinusoidal wave, which is because the third harmonic injection increases the harmonic content in the sinusoidal modulation wave. So the THD value of the phase voltage increases when the third harmonic is injected. The effect of the third harmonic injection on the line voltage is less than that on the phase voltage, which is due to the fact that the third harmonic in the line voltage cancels out each other by using the three-phase three-wire connection method in the load, so the THD of the line voltage does not change much before and after the third harmonic is injected. This shows that the third harmonic injection method has no effect on the THD of output voltage at the same time as increasing the output voltage amplitude. This is the biggest advantage of the third harmonic injection method.

5. Conclusion

In this paper, the basic principle of multilevel inverter and the working process of topology of multilevel inverter are analyzed. The multi-level inverter PWM control technology is the core of this research. This paper analyzes the different PWM control methods of multi-level inverters, and focuses on multi-carrier PWM control methods. The simulation study is carried out by taking a diode-clamped five-level inverter as an example. At the same time, the third harmonic injection method is adopted to improve the harmonic content of the output waveform. A five-level diode clamp inverter model was built with Simulink, and a multi-carrier PWM control method was used to obtain an ideal waveform.

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References

- [1] Touati Mohamed Tamim, Shaoyuan Li, Jing Wu. Multi-level Model Predictive Controller with Satisfactory Optimization for Multi-level Converters [J]. Simulation Modelling Practice and Theory, 2018.
- [2] Valdez-Resendiz, Guerrero-Ramirez, Gerardo V., Tapia-Hernandez, Alejandro, Juarez, Aldo N. Higuera, Nunez, Adolfo R. Lopez. Voltage balancing in an interleaved high gain boost converter [P]. Energy Conversion Congress and Exposition (ECCE), 2014 IEEE, 2014.
- [3] Dharmaprakash, R. Henry, J. Direct torque control of induction motor using three level diode clamped multilevel inverter [P]. Computation of Power, Energy, Information and Communication (ICCPEIC), 2014 International Conference on, 2014.
- [4] Soeiro, T.B., de Sousa, G.J.M., Ortmann, M.S., Heldwein, M.L.. Three-phase unidirectional buck-type third harmonic injection rectifier concepts [P]. Applied Power Electronics Conference and Exposition (APEC), 2014 Twenty-Ninth Annual IEEE, 2014.
- [5] Baimel, D., Rabinovici, R., Tapuchi, S.. Phase shifted PWM with third harmonic injection for over-modulation range operation [P]. Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), 2014 International Symposium on, 2014.
- [6] Hartmann, M., Fehring, R., Makoschitz, M., Ertl, H.. Design and experimental verification of a third harmonic injection rectifier circuit using a Flying converter cell [P]. Applied Power Electronics Conference and Exposition (APEC), 2014 Twenty-Ninth Annual IEEE, 2014.