Modeling and Simulation of Photovoltaic Grid-connected Inverter

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Abstract. Based on the topology of diode clamped three-level inverter, this paper introduces the working principle and control method of the inverter. This paper focuses on the midpoint potential balance problem and PWM control method of Diode-clamped three-level inverter and the SVPWM control method developed thereby. In this paper, the analysis of inverter topology and control method is focused on the maximum power point tracking problem and phase-locked loop problem in photovoltaic grid-connected process. This paper proposes a complete system for photovoltaic grid connection using inverters. At the end of this paper, the results of simulation and analysis of the system using computer software are given.

1. Introduction

In recent years, due to the widespread concern of the development of solar energy resources, designing high-performance inverters has been the focus of many current research scholars. The three-level three-phase inverter has been continuously improved due to its high withstand voltage. The SVPWM controlled Diode-clamped three-phase three-level inverter has the following three advantages.

In a three-level topology, the switching device is subjected to a shutdown voltage that is half the DC link voltage, while in a two-level topology, the switching device is subjected to a shutdown voltage that is the voltage of the entire DC link. Therefore, when the withstand voltage level of the switching components is the same, the three-level topology can be applied to medium and high voltage large-capacity frequency conversion. Compared with the two-level inverter, the three-level inverter output is a three-level step wave, the shape is closer to the sine, thereby making the system loss small. The use of maximum power point tracking technology and phase-locked loop technology on the basis of the inverter can achieve photovoltaic grid-connected, so that solar energy can be fully utilized.

2. System Block Diagram of Photovoltaic Grid-Connected Inverter

Fig.1 shows the overall framework of a photovoltaic grid-connected system. The system consists mainly of two parts: the main circuit and the control circuit. The main circuit includes a DC/DC circuit and a DC/AC circuit. The control circuit includes a drive circuit, a phase-locked loop circuit, and a maximum power point tracking circuit.
3. Diode-Clamped Three-Phase Three-Level Inverter Main Circuit

Fig. 2 shows the main circuit of a diode-clamped three-level three-phase inverter consisting of three bridge arms, each of which consists of four IGBT tubes and six diodes. Two capacitors are connected in series to the DC side of the circuit, and each capacitor is subjected to half of the DC side voltage.\cite{1}

Working principle of Diode-clamped three-level three-phase inverters, Vx is the main power tube, D1—D12 are freewheeling diodes, D13—D18 are clamp diodes, and C\textsubscript{i} is a voltage equalizing capacitor. The DC voltage is divided into three levels. Taking the phase A of the diode-clamped three-level inverter as an example, the operation mode is introduced. The specified output voltage value +U\textsubscript{dc}/2 is 2 levels, voltage 0 is 1 level, and voltage -U\textsubscript{dc}/2 is 0 level. 2 Level state—The main power transistors V1 and V2 are turned on, and V3 and V4 are turned off. 1 Level state—The main power transistors V2 and V3 are turned on, and V1 and V4 are turned off. In this state, D1 and D2 clamp together with V2 and V3 to clamp the load terminal. 1 level status is omitted.

![Diode-clamped three-phase three-level inverter main circuit](image)

Table 1 shows the state of the switch tube when the output of one phase circuit is at different levels.

| Level state | V1 | V2 | V3 | V4 | Output level |
|-------------|----|----|----|----|--------------|
| 2           | ON | ON | OFF| OFF| +U\textsubscript{dc}/2 |
| 1           | OFF| ON | ON | OFF| 0            |
| 0           | OFF| OFF| ON | ON | -U\textsubscript{dc}/2 |
The midpoint potential balance problem is a major difficulty in diode-clamped three-level three-phase inverters. Midpoint potential imbalance will affect the performance of the inverter, usually using software algorithms to solve the midpoint potential imbalance problem. Ideally, the capacitor voltage is equal to Udc/2, and the output voltage has +Udc/2, 0, -Udc/2. The three states correspond to P, O, N. Inverter output voltage synthesis v inverter is symmetrical, the instantaneous values of the three-phase voltage output by the inverter are Ua, Ub, Uc, vector is Vref. Assuming that the load of the three-phase

\[ U_a = U_m \sin(wt) \quad U_b = U_m \sin\left(wt - \frac{2}{3}\pi\right) \quad U_c = U_m \sin(wt + \frac{2}{3}\pi) \]

\[ V_{ref} = \frac{2}{3} \left( U_{an} e^{j2/3\pi} + U_{bn} e^{-j2/3\pi} \right) \]

According to the vector diagram, it is obvious that every vector in the sector can be combined by other vectors. SVPWM is based on this principle to control the inverter to solve the midpoint potential balance problem and make the inverter output waveform quality better.[2]

![Space vector map](image)

**Figure 3.** Space vector map

Fig.3 shows in full that any output state can be equivalently equivalent to other output states, thereby avoiding the occurrence of a switching state in which the midpoint potential is unbalanced.

4. **Analysis of Maximum Power Point Tracking Problem of Inverter**

The maximum output power of a photovoltaic cell varies with light intensity and temperature. In order to make the utilization efficiency of the photovoltaic cell reach a large value, it is necessary to ensure that it can work in the vicinity of the maximum power point under any circumstances.[3] In order to make solar energy fully utilized during PV grid-connecting, maximum power point tracking is usually required. The commonly used methods for maximum power point tracking are constant voltage tracking method, conductance increment method, and disturbance observation method. This paper focuses on the analysis of disturbance observation method.

As shown in the fig.4, the maximum power point is tracked by slightly changing the change in voltage detection output power. In this method, the effect can be improved by reducing the amount of voltage change.
Figure 4. Schematic diagram of disturbance observation

The simplified circuit model of the photovoltaic cell is shown in Fig. 5. The circuit model can be easily used for engineering applications. The use of this model requires four parameters provided by the solar cell manufacturer, short-circuit current Isc, open circuit voltage Voc, maximum power current Im and maximum power voltage Vm.[4]

\[ I_0 = I_1 - I_{sat} \left\{ \exp \left[ \frac{q(U + I_0 R_S)}{AkT} \right] - 1 \right\} \]

Figure 5. Ideal simplified model for photovoltaic cells

The photovoltaic cell simulation system is shown in Fig. 6. The system consists of a DT submodule, an Isc' submodule, an Im' submodule, a Voc' submodule, a Vm' submodule, a C1 submodule, and a C2 submodule. After the math module operation operations such as the division operation module, the addition operation module, and the mathematical operation module, the output current I. Isc represents the short-circuit current, which is 2.02A, Voc represents the open circuit voltage, which is 86.8V, Im represents the maximum power point operating current, which is 1.93A, Vm is the peak operating voltage, which is 70.4V, and Tref represents the reference battery temperature, which is 55°C.[5]
Figure 6. Photovoltaic cell simulation system

The maximum power point tracking is simulated by Matlab. The simulation diagram and results are as follows. The maximum power point tracking inductor value is set to 100uH, the capacitance value is set to 220uF, and the resistance value is set to 40 ohms. Diode forward voltage drop is set to 0.08V, The internal diode forward voltage of the switch is set to 100V.

Figure 7. Maximum power point tracking system

The module simulates the curve of output voltage, current and power of the grid-connected inverter under the condition of changes in light intensity and other factors. The simulation results are shown in Fig.8. When the voltage changes, the output power follows the change. The simulation results prove that the model is established correctly and the expected results are obtained.
5. Result Analysis

After analyzing the main circuit, control method and maximum power point of photovoltaic grid-connected inverter, the photovoltaic grid-connected inverter system is simulated by Matlab software. The snubber resistance of the switch is set to 0.00005 Ohms. The grid voltage peak-to-peak value is set to 5000V and the frequency is set to 50Hz.

![Figure 8. Maximum power tracking simulation results](image)

The photovoltaic grid-connected system simulation circuit obtains the inverter output voltage waveform as shown in Figure 10. Fig.10 shows that the designed PV grid-connected system can output three-phase sinusoidal voltage with good voltage quality. The diode-clamped three-phase three-level inverter and SVPWM control, maximum power point tracking system not only enable the inverter to output high-quality sinusoidal voltage but also maximize the use of solar energy.

![Figure 9. photovoltaic grid-connected system simulation circuit](image)
6. Conclusions
This paper introduces a diode clamped three-phase three-level inverter, and analyzes the SVPWM control method and the maximum power point tracking method. Modeling and simulating each unit of photovoltaic grid-connected, using software to obtain simulation results. According to the simulation results, the sinusoidal voltage of the inverter output can meet the requirements of grid-connected voltage.

7. Reference
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