Research on Photovoltaic Power Generation and Diode Clamped Three-Phase Three-Level Inverter

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Abstract. Since the industrial revolution, natural resources such as coal and oil on the earth have been continuously consumed. And the earth's ecological environment is constantly deteriorating, and human beings urgently need to find new energy sources that are less polluting and renewable. After the 1950s, with the development of materials science, photovoltaic power generation gradually entered the field of vision. After decades of development, chip technology and controllable switching devices have gradually matured, and researchers have made controllable inverter devices based on this. Based on the research of photovoltaic cells, this paper introduces a diode-clamped three-phase three-level inverter, and proposes to use the latest control method to solve the midpoint balance problem of the inverter and the problem that the switchgear is difficult to withstand high voltage. At the end of this article, the simulation results obtained by using the simulation software are given.

1. Introduction

The photovoltaic power generation system is mainly composed of three parts, a solar power generation board, a main circuit, and a control circuit. Most of the current solar panels are made of monocrystalline or polycrystalline silicon, and the photoelectric effect of the semiconductor converts solar energy into electrical energy. The main circuit consists of a DC/DC boost circuit and a DC/AC inverter circuit. The control circuit mainly comprises a phase locked loop control part, a maximum power point control part, a SVPWM main control unit and a driving circuit [1].

This paper mainly introduces the physical model and simulation model of photovoltaic cell, the main circuit working principle of diode clamped three-phase three-level inverter, and SVPWM control method. Solving the midpoint potential balance problem of diode clamped three-phase three-level inverter and the withstand voltage of switching device by circuit topology and control method.

2. Working principle and physical model of photovoltaic panels

At present, most photovoltaic panels are made of monocrystalline silicon or polycrystalline silicon. N-type semiconductors and P-type semiconductors are combined to form a P-N junction, and the photoelectric effect of the semiconductor P-N junction is used for power generation. When the sunlight illuminates the P-N junction, electrons and holes are generated, which forms a voltage drop.
According to the working principle of the photovoltaic cell, the physical model of the photovoltaic cell is shown in Figure 1. And according to the physical model, the relationship between the output current and voltage of the photovoltaic cell can be obtained.

\[
I_0 = I_t - I_d - I_F
\]  
\[
I_0 = I_t - I_{sat} \left\{ \exp \left[ \frac{q(U + I_o R_S)}{AKT} \right] - 1 \right\} - \frac{U + I_o R_S}{R_p}
\]

Rs is the internal resistance of the photovoltaic cell, Rp is the parallel resistance of the photovoltaic cell, K represents the Boltzmann constant, A is the ideal constant of the diode. Resistance Rp can be ignored in engineering applications. Using the technical parameters of the photovoltaic panel, the output current can be obtained. The parameters include the maximum power voltage Vm, the maximum power current Im, the open circuit voltage Voc, and the short circuit current Isc.

\[
I = I_{sc} \left\{ 1 - C_1 \left\{ \exp \left[ \frac{V}{C_2 V_{oc}} \right] - 1 \right\} \right\}
\]
\[
C_1 = \left( 1 - \frac{I_m}{I_{sc}} \right) \exp \left( - \frac{V_m}{C_2 V_{oc}} \right)
\]
\[
C_2 = \left( \frac{V_m}{V_{oc}} - 1 \right) \left[ \ln \left( 1 - \frac{I_m}{I_{sc}} \right) \right]^{-1}
\]

**Figure 1.** Photovoltaic cell model

Under the actual conditions, the technical parameters of the photovoltaic power generation board will change, and the technical parameters of the power generation board under arbitrary light intensity G and temperature T can be obtained by mathematical methods.

\[
\Delta T = T - T_{ref}
\]
\[
\Delta G = \frac{G}{G_{ref}} - 1
\]
\[
I_{sc} = I_{sc} \frac{G}{G_{ref}} (1 + a \cdot \Delta T)
\]
\[
V_{oc} = V_{oc} \ln(1 + b \cdot \Delta G)(1 - c \cdot \Delta T)
\]
\[
I_m = I_m \frac{G}{G_{ref}} (1 + a \cdot \Delta T)
\]
\[
V_m = V_m \ln(1 + b \cdot \Delta G)(1 - c \cdot \Delta T)
\]
Gref reference solar radiation intensity, Tref reference battery temperature, a, b, c are the compensation coefficients, which are analyzed by a large amount of experimental data. \( G_{\text{ref}} = 1000 \text{W/m}^2, T_{\text{ref}} = 25^\circ \text{C} \), \( a = 0.0025/\text{C} \), \( b = 0.0005 \left( \text{W/m}^2 \right)^{-1} \), \( c = 0.00288/\text{C} \).

3. Diode clamped Three-phase Three-level inverter main circuit

The main circuit of the diode clamped three-phase three-level inverter consists of two parts: the booster circuit and the inverter circuit. This paper introduces the booster circuit and the inverter circuit respectively. After measurement, the output voltage of a minimum photovoltaic panel is about 3V. After assembling the photovoltaic panels into PV modules, it needs to be boosted. The step-up DC/DC conversion is completed by the boost chopper circuit, and the boost chopper circuit schematic is shown in Figure 2 [2].

\[
U_0 = E \frac{T}{T_{\text{off}}} \tag{12}
\]

\( T \) represents a time period, and \( T_{\text{off}} \) represents the turn-off time of the switch in one cycle. The most important part of the main circuit is the inverter circuit. The circuit diagram of the diode clamped three-phase three-level inverter is shown in Figure 3.

Using A phase as an example to introduce the working principle of diode clamped three-phase three-level inverter. Define the positive potential of the DC power supply to be \( +\text{UDC}/2(P) \), and the negative potential of the DC power supply to -\( \text{UDC}/2(N) \), and get the N point potential to be \( 0(O) \). The switching tubes V1 and V2 are turned on, the potential at point A is \( +\text{UDC}/2 \), the switching tubes V2 and V3 are turned on, the potential at point A is \( 0 \), the switching tubes V3 and V4 are turned on, and the potential at point A is \( -\text{UDC}/2 \).

There are 27 output states for diode clamped three-phase three-level inverters. Table 1 shows a summary of 27 output states. 27 states are represented by vector mode, and the three phases are respectively set to x, y, z axes. In some state, capacitor C1 appears to be charged or discharged. The N
point potential will change instead of 0. Therefore, the problem of midpoint potential imbalance will appear. The SVPWM control algorithm can solve the problem of midpoint potential imbalance.

A vector diagram of 6 sectors can be obtained from 27 vectors, and one of the sectors is taken as an example to introduce the SVPWM control method. Figure 4 shows all the vectors in a sector. Displayed by vector graphics, any vector can be synthesized by other vectors. Therefore, the vector state of the midpoint potential shift can be generated by the vector state synthesis without generating the midpoint potential shift, thereby solving the midpoint potential balance problem [3].

Table 1. Output vector table

| State grouping          | Switch status                  |
|------------------------|--------------------------------|
| Long vector            | PNN, PPN, NPN, NPP, NNP, PNP   |
| Middle vector          | PON, OPN, NPO, NOP, ONP, PNO   |
| Positive short vector  | ONN, PPO, NON, OPP, NNO, POP   |
| Negative short vector  | POO, OON, OPO, NOO, OOP, NON   |
| Zero vector            | PPP, OOO, NNN                   |

Figure 4. First sector vector

4. Simulation of photovoltaic cells and Grid-connected systems

The photovoltaic cell was simulated by Matlab software [4]. The simulation model is shown in Figure 5. In this model, the maximum power point current \( I_m \) is set to 1.93A, the maximum power point voltage \( V_m \) is set to 70.4V, the photovoltaic cell output open circuit voltage \( V_{oc} \) is set to 86.8V, and the photovoltaic cell short-circuit current \( I_{sc} \) is set to 2.02A, environmental reference. The temperature \( T_{ref} \) is set to 25°C. The ambient temperature \( T_a \) is set to 30°C, the light intensity is set to 1000W/m², and the battery output I-P and P-V simulation results are shown in Figure 6.
Through the analysis of the battery simulation results, the output power of the photovoltaic cell can be changed with the change of the voltage. In order to make the solar energy fully utilized, the disturbance observation method is used to maximize the output power of the photovoltaic power generation board. The simulation model is shown in Figure 7 [5]. Create a grid model parallel package, the grid voltage is set to 5000V, the frequency is set to 50Hz. The model is shown in Figure 8.

After all modules are modeled and packaged, all modules are connected to build the entire PV grid-connected simulation system. In this simulation system, the IGBT switch tube parameters are set to: \( R_{on}=1 \times 10^{-4}\Omega \), \( R_{on}=1 \times 10^{-3}\Omega \), \( V_f=0V \), \( V_{fd}=0V \). The diode parameter is set to: \( R_{on}=1 \times 10^{-4}\Omega \), \( V_f=8 \times 10^{-2}V \), \( R_s=500\Omega \), \( C_s=2.5 \times 10^{-7}F \). The photovoltaic grid-connected system diagram is shown in Figure 9. The drive signal of the IGBT tube is shown in Figure 10. The line voltage of the inverter output is shown in Figure 11.
Figure 9. Photovoltaic grid-connected whole circuit

Figure 10. IGBT switch tube trigger signal

Figure 11. Line voltage simulation result of inverter output

5. Conclusion
After simulating each module, the photovoltaic grid-connected system was simulated, and the line voltage of the inverter output and the driving signal of the switch tube were obtained. The simulation results show that the line voltage waveform output by the inverter basically meets the requirements of grid connection, and the overall simulation result of the PV grid-connected system meets the actual requirements.

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