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Research and Simulation of Photovoltaic Power Generation System

Su Wang, Yiming Zou, and Liang Zeng*

Electrical and Electronic Engineering, Hubei University of Technology University, Wuhan, China
**Corresponding Author: 229381675@qq.com*

Abstract: *With the rapid development of China's socialist market economy, more and more people begin to pay attention to the development and utilization of new energy, and new energy has begun to attract people's attention. The main circuit structure and working principle of the most important inverter circuit in the whole photovoltaic power generation system are analyzed in detail, and the calculation method of the main components of the photovoltaic inverter circuit selected in this study is given and confirmed through simulation and experiment. When the main circuit of the whole photovoltaic inverter is analyzed and studied, in order to improve the output power of the whole circuit, the basic circuit structure is modified appropriately. The whole circuit uses high switching frequency, high voltage resistance IGBT, achieved the purpose of simplifying the whole circuit, and the overall efficiency of the circuit can be reduced, while ensuring the good output waveform of the whole circuit.*

Keywords: *Photovoltaic Inverter, IGBT, PI Controller.*

1. Introduction

The photovoltaic grid-connected power generation system refers to the direct conversion of solar energy into direct current by using solar photovoltaic modules. After the grid-connected inverter is converted into alternating current that meets the requirements of the municipal power grid, it can be directly connected to the public power grid for use. Figure 1 shows the composition view of the grid-connected photovoltaic power generation system. The grid-connected solar photovoltaic power generation system is composed of grid-connected inverter, photovoltaic array, intelligent controller and system protection device. The main function of photovoltaic arrays is to convert solar energy into electricity.

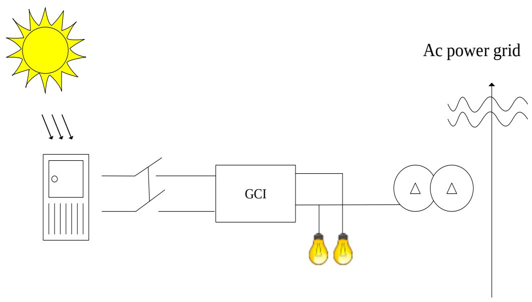

Fig. 1. Structure of grid-connected solar photovoltaic power generation system

The photovoltaic array can reach the DC voltage and output power required by the project. The main function of the grid-connected inverter is to convert the power output of the photovoltaic array into alternating current with the same voltage and frequency as the grid. The voltage inverter in general use is mainly composed of power electronic switching devices, through the way of pulse width modulation to supply electricity to the mains grid. Intelligent controller is generally composed of single chip microcomputer or DSP chip, as the core device. It is the core component of the whole photovoltaic power generation system. The controller can control the maximum power tracking of the photovoltaic cells in the whole system, and control the waveform and power of the grid-connected current of the photovoltaic inverter, so that the power provided by the grid can be balanced with the maximum power provided by the photovoltaic array. The protection device of the system is used to protect the safety of the entire photovoltaic inverter system in the working environment, and can protect the safety of the power network. The main work of this paper firstly studies the topological structure of the main loop of

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the photovoltaic inverter, designs the grid-connected inverter, and also designs the main loop system structure of the photovoltaic inverter. Secondly, the basic working principle and control strategy of the inverter are studied. Finally, the control system based on current feedback control is simulated and debugged.

2. Design of Main Circuit of Inverter System

Due to the influence of photovoltaic inverter hardware circuit on power output, the selection of inverter hardware has high requirements. In terms of hardware selection, the stability, safety and high efficiency of the inverter need to be met. Minimize the loss due to reactive power.

2.1. System Main Circuit Parameter Selection

2.1.1. Selection of switch tube

When the inverter circuit connected to the grid is in normal operation, the peak current flowing in the IGBT power switch is consistent with the peak of the filter inductor current, and the rated current of the switch is the maximum that allows for a slight allowance greater than the induction peak. The output power of the grid-connected inverter designed in this project is 10KW, and the peak output current is about 64.3A. At the same time, considering the system allowance, the current resistance value of the power switch should be more than 100A.

In a full-bridge grid-connected inverter circuit, the maximum voltage applied to the main power switch must exceed the maximum voltage on the DC input side (450V). At the same time, considering the influence of the allowance and the parasitic parameters of the line, the selected IGBT voltage value should be greater than 500V. 20 KHZ frequency.

2.1.2. Diode selection

The diodes in the booster circuit shall have a low on-state voltage drop and a fast reverse recovery to withstand currents up to 370V and 40A. Therefore, APT100DL60B is selected. Its important parameters are voltage: 600V and current: 100A.

For a universal converter, when the supply voltage drops, in order to stabilize the output voltage, the control circuit always increases the duty cycle as much as possible to make the voltage gain larger to maintain the stability of the output voltage. However, due to the parasitic resistance of the inductor and capacitor, when the input voltage is constant and the duty cycle exceeds a certain value, the output voltage does not increase, but decreases. Therefore, the original component of the parasitic resistor should be selected as small as possible when designing and selecting the filter element. In practice, the duty cycle is adjusted within 0.88. The circuit shall operate in continuous conduction mode.

2.2. Hardware Design of Grid-connected Inverter Control System

2.2.1. Auxiliary power design

The auxiliary power supply designed in this system is powered by DC input, and the control chip UC3844 is adopted. Transformer main chip, IPM module, relay and a variety of active chip production of four-way isolated power supply. This is shown in Figure 2.

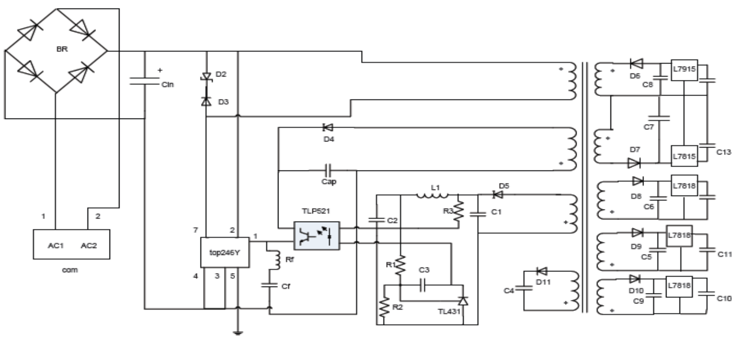

Fig. 2. Auxiliary power circuit

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2.2.2. Design of voltage detection circuit

Hall voltage sensor design must detect two voltage signals, namely DC voltage signal and AC voltage signal. In this design, the Hall voltage sensor with model HNV025A is selected. The insulation voltage of the sensor is 3kV, the power supply voltage is ±15V, the input rated current is ±10mA, the output rated current is ±25mA, the accuracy is 0.6%, the turn on time is less than 40μs. In the design, the Hall voltage sensor output voltage amplitude between [-5V, 5V]. The output voltage obviously does not correspond to the port with DSP, so the voltage detection circuit and signal conditioning circuit must be designed. The voltage detection and conditioning circuit is designed as shown in Figure 3.

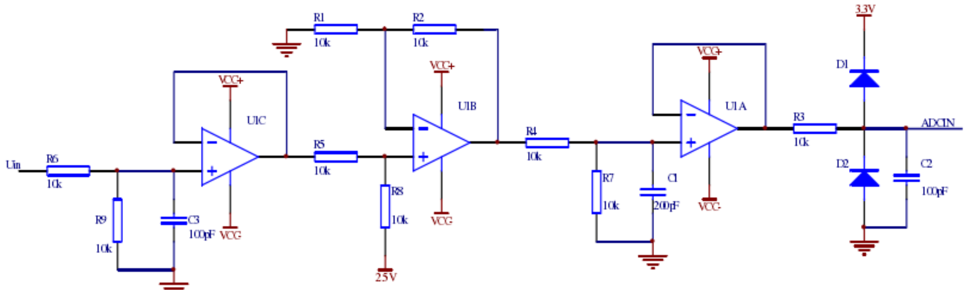

Fig. 3. Voltage detection and conditioning circuit principle

2.2.3. Zero-crossing detection circuit design

When the system is running, the phase and frequency of the grid voltage must be detected and input to the main control chip to realize synchronization. At this time, the collected voltage signal of the power grid must be processed into a pulse signal consistent with the zero crossing of the power grid voltage sine wave signal through the conversion circuit. The pulse signal is required to be 3.3V, because the TMS320F2808 chip must input a 3.3V signal. Figure 4 shows the zero crossing detection circuit.

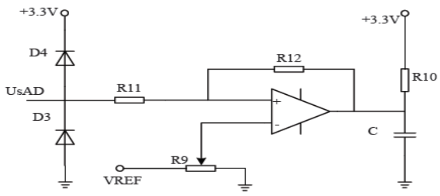

Fig. 4. Zero-crossing detection circuit

2.2.4. IGBT drive circuit design

Because the PWM wave output by the master control chip cannot drive the IGBT directly, the IGBT in the main circuit must have a control circuit. The main function of the drive circuit is signal transmission and protection. The drive circuit protects the control circuit by photoelectric or magnetic isolation to isolate the control circuit of the main circuit.

In this paper, the photoelectric coupling driver HCPLJ312 is used to isolate the drive circuit as shown in Figure 5. PWM signal from DSP is converted to 74LVX4245 level and sent to the 2-pin forward input signal terminal A of HCPLJ312. Then, it is isolated and amplified inside HCPLJ312 to provide the forward drive voltage of +18V to IGBT and the reverse quick recovery voltage of -9V.

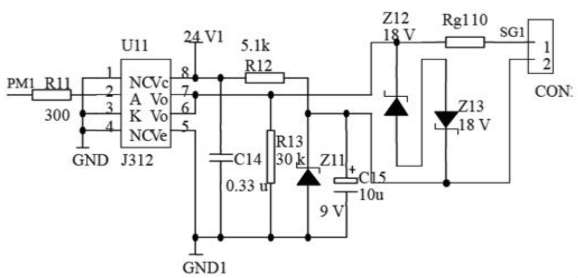

Fig. 5. IGBT isolation drive circuit

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2.3. Signal Acquisition Circuit

Because the inverter works in high voltage and high current environment, it is easy to cause interference to DSP and cause system failure. Combined with the advantages and disadvantages of the sampling methods in the above table and the main voltage and current signals that need to be collected by the system, it is easy to calculate and debug. Hall sensor transformer is used for the selected voltage and current. At the same time, the designed signal detection and conditioning circuit is required to be uniformly adjusted to 0.1V/LSB and 0.01A/LSB.

2.4. Mathematical Model of Grid-connected Current Closed-loop Control System

Current closed loop design is the core of control system design. The current closed-loop design can make the system obtain good dynamic and static current characteristics, so that the current has a good anti-interference ability to the external interference signals. In this paper, triangular wave comparison control based on instantaneous value feedback is used. The block diagram of grid-connected current closed-loop control system is shown in Figure 4.5. It can be seen from the figure that the reference current IL* is compared with the instantaneous feedback value iL of grid-connected current obtained through sampling. The error of the two is sent to the controller and adjusted. After adjusting the output signal, it is compared with the triangular wave as the modulated wave, and the SPWM signal is obtained. After driving the circuit to drive the IPM module, the filter current is obtained after inductance filtering. Wherein, Uab is the output voltage of the inverter bridge, Ugrid is the grid voltage, G1(s)is the controller transfer function, G2(s)is the inverter bridge transfer function, and G3(s)is the filter transfer function.

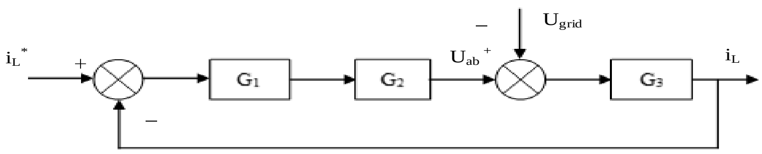

Fig. 6. Block diagram of grid-connected current closed-loop control system

The output end of the inverter is:

$$L\frac{di_L}{dt} = U_{ab} - U_{grid} - i_L \cdot R_L \tag{1}$$

U_{ab} is the output voltage of the inverter bridge, U_{grid} is the grid voltage, i_L is the grid-connected current, L is the filter inductance value, R_L is the series equivalent resistance of the inductor.

$$i_L(s) = \frac{1}{Ls+R_L}(U_{ab}(s) - U_{grid}(s)) = G_3(s)(U_{ab}(s) - U_{grid}(s)) \tag{2}$$

$$G_3(s) = \frac{1}{Ls+R_L} \tag{3}$$

This is the filter transfer function.

In this paper, instantaneous current feedback and triangular wave comparison control are used. In triangular wave comparison control, PI controller is the most widely used, and its transfer function is:

$$G_{PI}(s) = K_p + \frac{K_i}{s} \tag{4}$$

The switching frequency of the inverter designed in this paper is 10KHz, which is much higher than the frequency of the power grid. If the influence of delay and dead time of switch tube is ignored, the inverter bridge is equivalent to a small inertia link, and the transfer function is:

$$G_2(s) = \frac{K_{PWM}}{T_{PWM}s+1} \tag{5}$$

T_{PWM} is a switching period, K_{PWM} is the gain of inverter.

In order to obtain the ideal dynamic stability and realize the rapid response of the system, the control system is designed as a second-order system, and the PI parameters are designed using the second-order optimal method commonly used in engineering. The open loop transfer function of the control system is:

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$$G_0(s) = (K_p + \frac{K_i}{s}) \times \frac{K_{PWM}}{T_{PWM}s+1} \times \frac{1}{Ls+R_L} = \frac{\frac{K_p}{K_i}s+1}{\frac{s}{K_i}} \times \frac{K_{PWM}}{T_{PWM}s+1} \times \frac{\frac{1}{R_L}}{\frac{L}{R_L}s+1} \quad (6)$$

$$\frac{K_p}{K_i} = \frac{L}{R_L} \quad (7)$$

Then the open loop transfer function of the system is

$$G_0(s) = \frac{\frac{K_{PWM}K_i}{R_L}}{s(T_{PWM}s+1)} \quad (8)$$

The general form of the open loop transfer function for a typical type I system is

$$G_0(s) = \frac{K}{s(Ts+1)} \quad (9)$$

$$K_p = \frac{0.5L}{K_{PWM}T_{PWM}} \quad (10)$$

The above describes an engineering design approach to PI controller parameter design based on a known inverter transfer function. The inverter transfer function given in this paper is only an empirical model, and there is still a certain error with the actual, so the P and I parameters obtained are only theoretical guidance values, which must be properly adjusted in the actual test process.

3. The Software Design

The overall program of grid-connected inverter control system mainly consists of four parts :(1) the main program; (2) Overflow interrupt program under timer; (3) capture interrupt program; (4) fault protection interrupt program. The main program mainly completes all kinds of initialization Settings of DSP system, including configuration of different types of registers, interrupt enabling, etc. This design uses three interrupts. Among them, the overflow interrupt under the timer mainly completes A/D sampling, the realization of control algorithm and the generation of SPWM wave; The capture interrupt mainly completes the synchronous phase-locking of grid voltage. Fault-protected interrupts are primarily used to block pulses and protect circuits in the event of a system failure.

3.1. The Main Program

Main program flow chart:

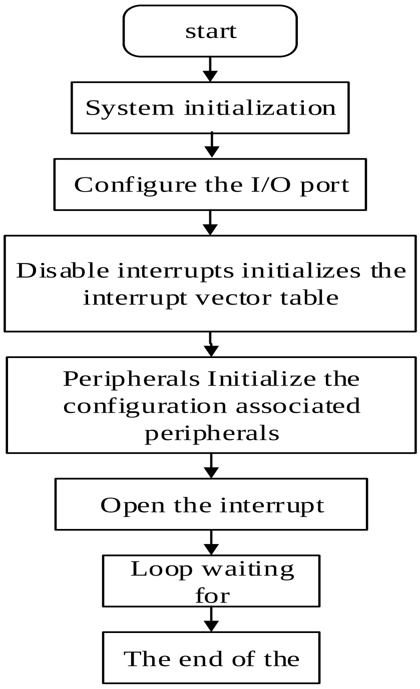

Fig. 7. Master program flow chart

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3.2. Interrupt Service Routine

In the interrupt program, the sampling work of grid voltage, grid-connected current and DC bus voltage is first performed to determine whether the grid-connected conditions are satisfied. If it meets the requirement, the closed relay is connected to the grid, and then the grid voltage is phase-locked to generate sinusoidal reference signal, so as to complete the current control algorithm and generate the SPWM drive signal. The interrupt program also needs to realize overvoltage and overcurrent protection, etc.

3.3. Fail-protected Interrupt Programming

It is usually necessary to do a good job of protecting the system before turning on the main power. IPM module itself has fault protection function. In order to achieve better protection and improve the reliability of the system, the hardware uses three-state gate LVXC3245, which can control the output of PWM by controlling the OE terminal. When the OE end is pulled up, the PWM output can be blocked. The software is designed to contain fail-safe interrupts and to run in conjunction with hardware circuits. In case of overvoltage, overcurrent, short circuit and other fault signals, IPM will send fault signals to trigger fault interrupts, stop pulses and disconnect relays. Protection interrupts require quick response.

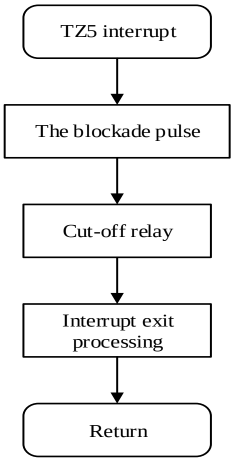

Fig. 8. Fault-protected interrupt flow chart

3.4. Debugging Results and Analysis

3.4.1. Parameter setting of each part of the model

The DC input is simulated using a 400V DC voltage source and the grid voltage is simulated using an AC voltage source. The peak voltage is 311V and the frequency is 50Hz. Assuming the power of the inverter is 10KW, the peak grid-connected current is 64.3A. The simulation model realized is shown in Figure 5.6. The design of the controller is key. The controller mainly realizes the current tracking, reduces the amplitude difference and phase difference, and improves the ability to deal with the disturbance of the power grid. Used in the simulation parameters are as follows: the triangle carrier frequency set to 10 KHZ, design of filter inductance is 3 mH, 0.02 Ω series equivalent resistance, PI parameter Kp = 0.5, Ki = 200.

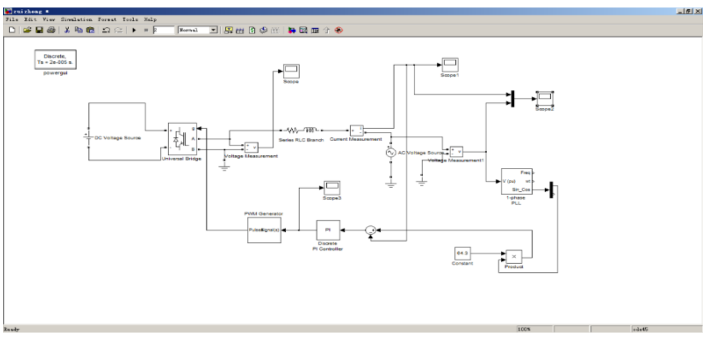

Fig. 9. The simulation model of grid-connected inverter based on PI controller is presented

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The inductance L is set to 3 mH, equivalent resistance R is set to 0.02 Ω. The power grid voltage simulated by the AC voltage source has a peak value of 311V and a frequency of 50Hz. The carrier frequency of PWM waveform generator is set to 10kHz. In PI controller, Ki is 200 and Kp is 0.5.

3.4.2. Simulation results and analysis

Set the simulation time to 0.2s. SPWM waveform output by inverter can be obtained, as shown in Fig. 10. The grid-connected current filtered by the filter is shown in Fig. 11. The waveform of grid voltage is shown in Fig. 12.

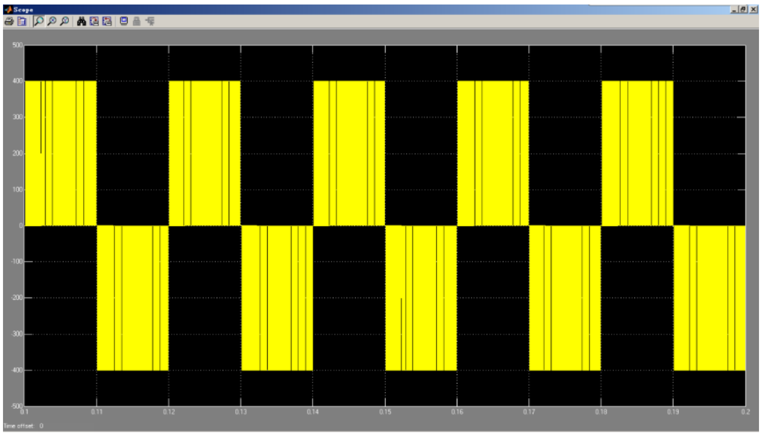

Fig. 10. The inverter output SPWM waveform

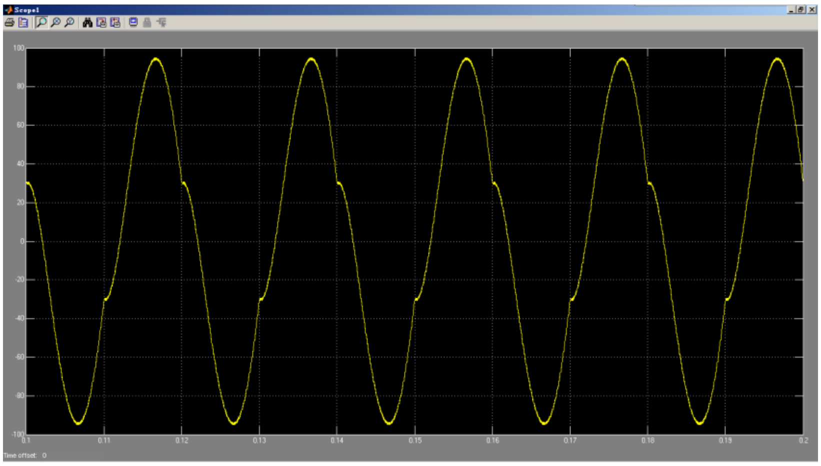

Fig. 11. The grid-connected current after passing through the filter inductance

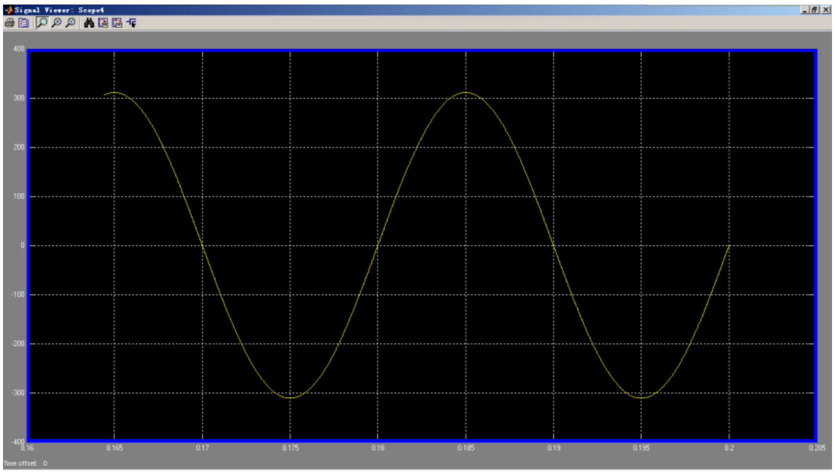

Fig. 12. Grid voltage filter

The waveform in Figure 10 shows that the inverter operates successfully and generates the correct

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SPWM waveform with PI modulation. The waveform in Figure 11 shows that most of the harmonics in the grid-connected current have been successfully filtered out. By comparing Figure 11 with Figure 12, the grid-connected current and grid voltage are basically in the same frequency and in the same phase, thus achieving the purpose of this design.

4. Summary

Solar power generation has important practical significance to alleviate the increasingly tense energy crisis. In this paper, some research is done on the single grid-connected inverter of 10 kW solar power generation system. Firstly, the overall design scheme of the system in this design is given, and the main circuit parameter design method is introduced. Secondly, the hardware design and software design of the inverter control system are introduced in detail, including the circuit realization and software structure of each function module of the system, as well as the specific flow chart. Finally, the PI controller is used to establish the Simulink simulation model and obtain the simulation results. In this paper, it is concluded that by controlling the grid-connected current, the grid-connected current can be in the same frequency and phase with the grid voltage.

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