DESIGN OF AN INTELLIGENT LOAD FEEDBACK SYSTEM FOR CHARGING PILE IN ELECTRIC VEHICLES

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A project report submitted in partial fulfilment of the
requirements for the award of Master of Engineering (Electrical)

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

As the industry becomes more and more developed, the power source as a power source has been paid more and more attention, and the requirements have become higher and higher. At the same time, there are more and more types. The quality assurance of the power supply needs to pass corresponding inspections. As an emerging product, electric vehicle charging piles especially need good quality assurance. General power detection uses fixed resistance or variable resistance to release energy. This traditional method has many shortcomings, such as poor controllability, serious pollution, high power grid power, and easy aging requirements. This method currently cannot meet the current advocates. New requirements for environmental protection, energy saving, and low carbon emissions. With the development of society, energy saving, emission reduction and new energy vehicles are a general trend. The detection of charging piles is gradually being valued, so the intelligent feedback load of charging piles came into being. The intelligent feedback load can detect the characteristics of charging piles, and at the same time, feed the detected energy back to the grid to realize energy saving and emission reduction during the detection process, save costs for charging pile enterprises and increase product qualification rate. This article divides the intelligent feedback load into a front-stage DC boost DC-DC module and a rear-stage inverter DC-AC module. The front-end module adopts the capacitive energy storage type Cuk circuit, and realizes the detection of the characteristics of the charging pile through the switching of three control modes of constant current, constant voltage and constant power. The back-stage inverter module realizes stable control of the DC bus voltage and at the same time controls the grid-connected quality so that the grid-connected current meets the relevant standards.

This paper first conducts a theoretical analysis of the front-level module, selects a suitable main circuit topology, and then simulates and verifies it through Simulink in MATLAB, and analyzes the simulation waveform; conducts a theoretical analysis of the back-level inverter module and selects a suitable full-bridge inverse As the main circuit, the variable circuit can stabilize the DC bus voltage and control the grid-connected current at the same time. The overall connection test of the two stages is carried out, and the final result meets the system requirements.

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CHAPTER 1

INTRODUCTION

1.1 The background of the subject and the purpose and significance of the research

The power supply has become an indispensable equipment for daily life and industrial production. Various requirements have led to a variety of types and functions of the power supply, and the factory quality assurance of the power supply needs to pass corresponding inspections. As an emerging product, electric vehicle charging piles especially need good quality assurance. When testing these batteries with different functions, the power supply is required to carry out a load output test. Generally, the energy is released through a fixed resistance or a variable resistance. This traditional method has poor controllability, serious pollution, and power grid power. With many shortcomings, such as large and easy aging requirements, this method currently cannot meet the new requirements of environmental protection, energy saving, and low carbon emissions advocated by the state.

1.2 Problem Statement

At present, there are some energy feedback load products on the market, which have gradually replaced the traditional power supply factory tests that detect various functions of the load, such as aging test, sudden load, sudden load test, output accuracy characteristic test, etc. Some products have also reached Better performance. However, due to the wide variety of power products and their different functions, there are many problems that need to be improved and developed urgently. For example, many regenerative loads are still energy-consuming loads, which have not achieved the purpose of environmental protection and conservation, and some regenerative loads have simple functional modes. Can not meet the special test needs of the actual power supply.

Therefore, this paper will develop an intelligent feedback load. Under the premise of meeting the test of universal power supply, according to the particularity of charging piles, an intelligent feedback load suitable for charging pile detection is designed to meet the input/output voltage range, accuracy, Grid-connected quality, control mode and other requirements, so as to further the research and learning of intelligent feedback load.

1.3 Aims and Objectives

The research task of this paper is to develop a kind of intelligent feedback load, realize the connection between the energy output of the charging pile and the grid, and feed the detected energy back to the grid. The overall structure is shown in Figure 1.1.

The research of this paper is mainly divided into the DC conversion and the performance test of the charging pile. The DC power output by the charging pile is boosted to the DC bus to prepare for the inverter and grid connection. There are 3 load working modes: constant current mode, Constant voltage resistance mode and constant power mode are used to meet the test requirements of charging piles; complete the design of grid-connected converter, lock the phase of the grid, make the converter and the grid voltage at the same frequency to ensure the operation of the energy feeder network At the same time, the output current and voltage harmonics are small, reducing the impact on the power grid, and improving the quality of energy incorporated into the power grid.

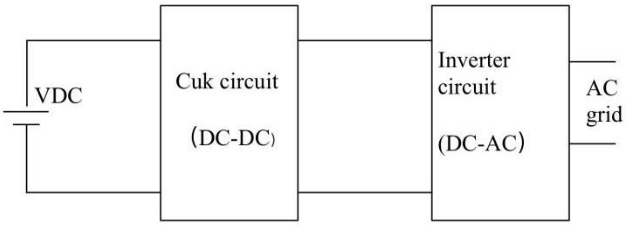

Figure 1.1: Overall structure of smart feedback load

Main technical requirements of the system:

(1) DC power supply

Input voltage: 50～800VDC; output voltage rating: 850VDC; output voltage accuracy: ±1%;

(2) Simulated load accuracy

The load current/impedance/power can be guaranteed to be less than 2% within the maximum fluctuation range of the DC power supply voltage and the maximum fluctuation frequency range.

(3) Grid-connected converter output

AC voltage output: 400VAC±5%; frequency: 50Hz.

1.4 Structure of the Research Report

This research report consists of six main chapters:

1) Chapter 1 (Introduction). In this chapter, the brief background of the research, the problem statement as of why we need to carry out this research and the aims and objectives of this research are stated.
2) Chapter 2 (Literature review). In this chapter, different types of overvoltage surges are identified and discussed. Information about lightning impulse waveform and lightning protection standards are also investigated and discussed.
3) Chapter 3 (Research and analysis on front-end modules) Firstly, by comparing the circuit topology of multiple mature front-end DC/DC converters, choose an optimal deformed structure using this system; secondly, determine The control strategy under constant voltage, constant current, and constant power modes; finally, through theoretical analysis and simulation, the selected control strategy and topology are verified.
4) Chapter 4 (Research and analysis on the subsequent modules) First select a control method suitable for the bridge inverter circuit of the system, and at the same time select the parameters of the filter, and then conduct an in-depth analysis and understanding of the overall system plan; finally pass the theory Analysis and simulation verify the main circuit and control algorithm of the inverter.
5) Chapter 5 (Simulation and Results) Firstly, connect the DC converter and the inverter, analyze its working principle and conduct simulation verification of the whole system, realize the following control modes, and improve the concurrent feedback quality; The parameter setting and control parameter debugging of the whole system are analyzed.
6) Chapter 6 (Conclusions and Discussion) In this chapter, the results obtained from the research will be used to draw conclusions. Summarized some shortcomings in the design and gave some suggestions.

Table 1.1: The main indicators of the design

Network side parameters	**Input mode**	**Specific value**
DC side parameters	Voltage	380V±10%
	Frequency	50Hz±5%
	Power Factor	0.98
	Total current harmonics	<3%
	Voltage range	50V-800VDC
	Current range	Approximate 0-400ADC
	Power	200KW
	Output voltage accuracy	⩽±0.3%FS±0.2%RD
	Output current accuracy	⩽±0.3%FS±0.2%RD
	Ripple	⩽±0.5%FS±0.1%RD
	Source effect	⩽±0.3%FS±0.1%RD
	Load effect	⩽±0.1%FS±0.5%RD
	Response time	⩽5ms
	Switching time	⩽20ms
Display and interface	Communication interface	Standard configuration RS485, RS232, TCP / IP, can be selected
	Display	7 inch full color touch screen as standard
	Control mode	Touch screen control, upper computer control, open communication protocol
	Other interfaces	Optional external emergency stop and fault node output
Security	Grounding resistance	⩽400m
	Protect	Over voltage, under voltage, over current, over temperature, short circuit, emergency stop and other faults cut off the output
	Withstand voltage	1500VDC, 1min, no breakdown, no flashover
Usage environment	Temperature	-10℃-40℃
	Place of use	IP20 (indoor use only)
	Ambient humidity	⩽90% (No condensation, no salt fog)
	Altitude	⩽2000m (for use beyond the required derating)

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With the deepening of energy conservation and emission reduction and the development of power electronics technology, energy feedback load is an emerging product that contributes to energy conservation and emission reduction. As a new type of test equipment came into being, the load simulation is carried out through the two-way flow technology of power electronic energy, the equipment that needs to be tested is connected to the feedback load, the grid-connected current is synchronized with the grid voltage through the DC to AC mode, and then the energy Sending it back to the grid can not only test the characteristics of the power supply, but also save power, reduce business costs, and provide flexible operability.

Table 2.1: Comparison of traditional resistive load and smart feedback load

Traditional resistive load	Intelligent feedback load
The higher the power, the higher the temperature of the load resistance, the non-linear relationship between voltage and current, low accuracy, and poor test performance	Perfectly simulate various load performance (constant current, constant voltage, constant power) to meet power supply test requirements
Huge power loss will occur during the test	Except for a small amount of switching loss and line loss of power electronic devices, the rest of the energy can be fed back to the grid through the inverter circuit.
Excessive volume will cause difficulty in heat dissipation	Small size, there is almost no heat dissipation problem due to low power consumption
Single function, uncontrollable	Controllable status, stepless adjustment can be realized
The components are prone to ageing and inconvenient to use	Long life, convenient and practical

Based on the above advanced performance of intelligent feedback load, energy feedback is the current development trend, especially in the context of energy saving, emission reduction and environmental pollution, it will be more suitable for factory inspection of charging piles. Therefore, the research and development of intelligent feedback load has become an urgent and meaningful work.

2.2 Research status and analysis of feedback load

For power supply detection, the traditional method is to use a resistive load. The detection function is simple and cannot simulate the actual application scenario. At the same time, the energy of the tested power supply is converted into heat energy and is consumed, so that electrical energy is wasted. The traditional method is gradually eliminated, replaced by a load with energy feedback, which can not only simulate the on-site usage, but also return the energy under test to the grid, achieving the goal of saving energy. The intelligent feedback load studied in this paper is a load specially designed for charging pile testing.

The intelligent feedback load is mainly divided into two parts: the bidirectional DC-DC converter and the bidirectional converter (DC-AC) part, as shown in Figure 1.1. Among them, the bidirectional DC-DC converter mainly realizes the bidirectional flow of energy, the matching of the input voltage, and the matching with the DC bus of the bidirectional converter; the bidirectional converter mainly feeds back the energy of the DC bus to the AC power grid and guarantees grid connection The power quality meets the requirements. Many achievements have been made in the fields of academic research and engineering in these two parts.

2.2.1 Research status of DC boost circuit topology

The traditional DC conversion is a Boost step-up chopper circuit. Under the ideal condition of infinite inductance and capacitance, the boost of this circuit is infinite. However, due to the internal resistance and other characteristics of the inductance and capacitance in the application, the ideal characteristics are not achieved. The maximum duty cycle of the Boost boost chopper circuit is 0.88, that is, it can be implemented better when the boost ratio is not greater than 7.3. This topology is simple and reliable, and the control method is simple. The disadvantage is that the boost ratio is limited, and as the switching frequency increases, the switching loss becomes larger and the efficiency becomes lower.

In some occasions with higher requirements for step-up, the use of isolated DC conversion circuit topology is the first choice, such as a flyback circuit or a push-pull circuit. In this topology, a step-up transformer increases the step-up ratio, but the transformer use of the device increases the loss and volume of the equipment, and the system becomes more complex and difficult to maintain. Therefore, the topology is only suitable for current intermittent feedback loads.

Through the continuous efforts of domestic and foreign scholars, in the past two decades, many improved topologies have been proposed. For example, Gupta proposed connecting multiple modules in series to increase the input voltage; Edson Adriano proposed the use of a new type of DC converter to increase the input voltage. In particular, the Cuk converter is used to control the input current. This structure follows his own design in 1996. He once proposed a new type of Cuk converter topology, which uses capacitive energy storage. Its structure is as follows As shown in Figure 2.2. This circuit topology controls the input and output current separately, and without other auxiliary circuits, the soft turn-off of the switching tube can be realized through proper control, and the switching loss is reduced. Its disadvantage is that the boost ratio is relatively small. Suitable for occasions with high requirements for boosting.

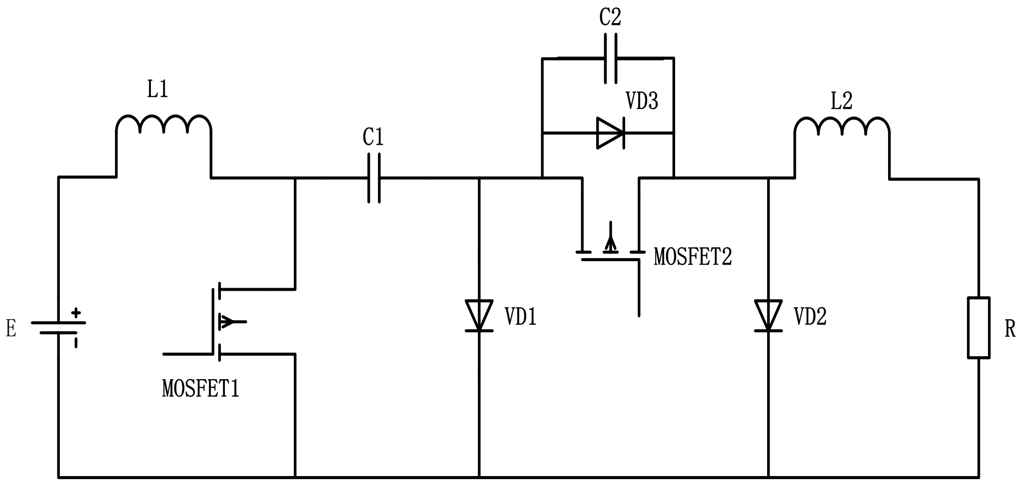

Figure 2.1: A new type of Cuk converter

2.2.2 Research status of various load characteristics

In existing control strategies, it is a common method to use current as a reference. By sampling the instantaneous amount of current and comparing it with the reference current through a certain algorithm, PI control is used for modulation to change the duty cycle of the switching device, so as to match Different load characteristics, this is a more traditional and common control method. In addition, new load control algorithms are also applied. For example, the scholars of Central South University used fuzzy control to realize load mode control, and achieved better control results.

In terms of engineering application, a control chip is adopted as the core of sampling, calculation and control of the entire system. With the complexity of the control algorithm and the requirement for response time, the traditional single-chip microcomputer cannot meet the current demand, so the DSP chip is used to realize the control of the system.

2.2.3 Research status of inverter grid connection

After the DC booster obtains a higher DC bus voltage, it is connected to the grid through a two-way converter. The control methods mainly include SPWM control and hysteresis comparison control. Both have different advantages and disadvantages and applicable occasions; in addition, There are some other inverter topologies, such as multiple inverters or multi-level inverters, because the structure is more complex and the control system is difficult to implement, so they are rarely used in practical applications.

The output PWM wave of the bridge-type full-control inverter circuit topology needs to be connected to the grid through an inductance filtering link and an isolation transformer. Inductance filters, LC filters, LCL filters, etc. are often used in the filtering link to achieve a better filtering effect, and the transformer acts as an electrical isolation.

2.2.4 Project realization and product status

In practical engineering applications, the research and application of intelligent feedback load has achieved many results, and many products have emerged at the same time, and have been applied in power supply factory tests, such as Inovance, INVT and other companies.

2.3 The main design ideas of the system

The intelligent feedback load is mainly divided into two parts: the bidirectional DC-DC converter and the bidirectional converter (DC-AC) part. Among them, this article mainly studies the part of the bidirectional DC-DC converter and the functional design for the load characteristics of the charging pile. Design the main control circuit, current and voltage sampling and conditioning circuit, PWM drive, etc., and various control modes.

2.3.1 Topological structure selection of bidirectional DC-DC converter circuit

List several typical DC boost circuit topologies: Boost DC boost circuit, push-pull circuit, center-tapped inductor DC boost circuit, capacitor energy storage Cuk circuit, etc. The best topology is selected by comprehensively considering many factors such as boost ratio, circuit stability and loss, hardware implementation difficulty, control method difficulty and so on.

In addition, the design of capacitance, inductance, and other circuit components and other details of the design are further explored and researched in the circuit design and simulation process.

2.3.2 Implementation of load working mode

The system needs to implement three load modes: constant current mode, constant voltage mode, and constant power mode.

The basis for realizing multiple modes is to sample and control the input voltage and current.

Figure 2.3 is a control model of a DC boost circuit as an example. The input current I_{in} is taken as the control object, and the difference between the input current I_{in} and the expected (set) current I_{ref} is modulated by the PID to control the duty cycle of the power switch, thus The current is controlled within the desired range through a closed-loop negative feedback system.

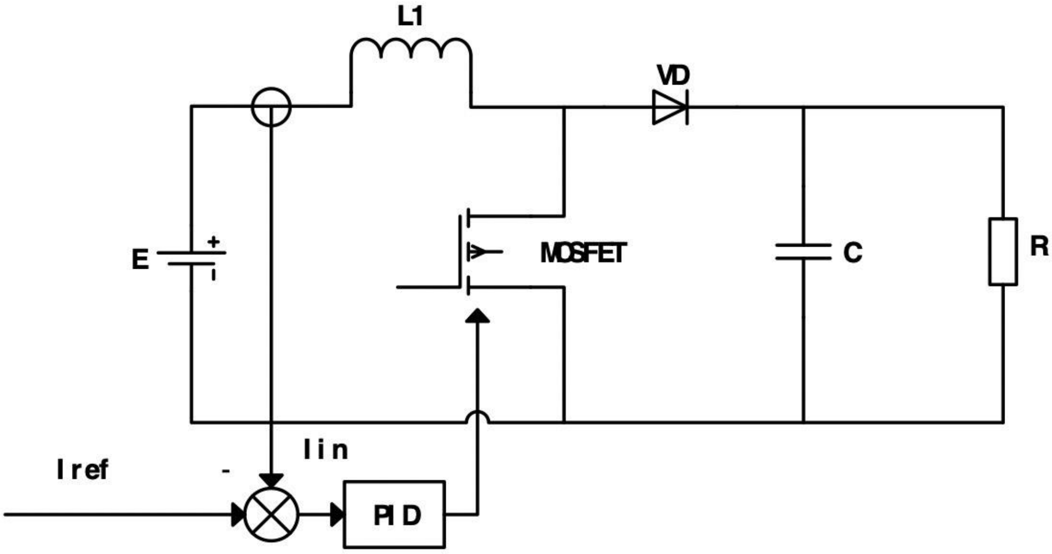

Figure 2.2: A load simulation control strategy

2.3.3 Design of inverter and grid connection

The design of this paper mainly considers providing the front-stage stable DC bus voltage for the inverter. The inverter grid-connected adopts the full-bridge inverter circuit topology. The control methods mainly include SPWM and current hysteresis comparison control. Through the analysis of these two control methods , Get the control suitable for this system.

In addition, the study and design of filter-related theories and applications, the calculation of filter inductance and capacitance parameters, and the selection of grid-connected electrical isolation transformers are also considered. At the same time, the grid-connected power quality is improved, and the phase of the grid is the same as that of the grid. Impact on the grid.

The choice of grid-connected control method is the key to the grid current and voltage waveform, phase and power transmission direction. Therefore, grid-connected under the premise of stable DC bus, select a comprehensive control strategy to realize the system mode.

The planning of electric vehicle charging piles is mainly divided into two aspects: location and quantity. According to the location, charging piles can be divided into: charging piles in residential areas and public charging piles. The charging piles in residential areas are mainly for fixed users, with fixed locations and relatively fixed charging times. Therefore, the number of charging piles in residential areas should be equal to the number of electric vehicles. Public charging piles are mainly used to meet the demand caused by the imbalance of supply and demand in residential areas. At last, the location of public charging stations can be determined by solving optimization problem with the objective function that the distance between users and public charging stations is shortest.(Zhang et al., 2016)

2.4 Analysis and comparison of three DC boost circuit topological structures: Boost DC boost chopper circuit, Buck-Boost DC boost chopper circuit and Cuk circuit.

For DC boost, there are two main types of circuit topology, one is DC-DC mode and the other is DC-AC-DC mode. DC-DC boost circuit topology mainly includes Boost topology, Buck-Boost circuit, Cuk circuit, etc .; DC-AC-DC mode mainly includes push-pull circuit, flyback circuit, forward circuit and so on.

High-step-up, high-efficiency, and cost-effective dc–dc converters, serving as an interfacing cell to boost the low- voltage output of renewable sources to the utility voltage level, are an important part in renewable energy systems. Over the past few years, there has been a substantial amount of studies devoted to high-step-up dc–dc converters. Among them, the category of coupled-inductor boost converters is widely researched and considered to be a promising solution for high-step-up applications. In renewable energy systems, high step and high efficiency dc / dc converters are often required. The high-step-coupled inductive boost converter has the advantages of simple structure, high voltage gain, low switching voltage stress, and small reverse recovery problem of the output diode. It is a promising application. This paper reviews five types of high-step coupled inductor boost converters, all of which are derived from traditional boost converters. The general derivation process is: 1) use the coupled inductor to adjust the voltage gain to avoid extreme duty cycles; 2) use different clamping circuits to recover leakage energy and suppress voltage spikes; 3) use voltage multipliers to expand the voltage conversion ratio Reduce the diode voltage stress, use the integration and interleaving technology to reduce the input current ripple and increase the power level.[8] Boost circuit is relatively simple, but the loss is relatively large. A switch is used to control the input, but there is no switch to control the output, so the quality of the output current is average. This is not suitable for use in a charging pile, so give it up.(Liu et al., 2016)

Then through the experimental analysis and research of these three ways of boosting. The buck inverter has the lowest current semiconductor stress, but has one disadvantage: the output voltage is always lower than the input voltage. The boost inverter voltage stress depends on the maximum gain and the peak output voltage, actually this voltage stress is almost equal than for the buck inverter if the input voltage for the boost inverter is around 50 Volts or lower. The current stress depends on the current demanded, as in the buck inverter case, but multiplied by(l+Gm). This term causes that the current semiconductor stress will increased considerably if Gm is higher, that is the case when the boosting characteristic of the converter is used. The same situation occurs for the buck-boost inverter, this converter has the same voltage and current semiconductor stress than the boost inverter. Actually the advantage of the buck-boost inverter compared to the boost inverter is that the capacitor voltage stress is lower.(Vazquez et al., 1999)

In the experiment, the buck-boost inverter achieves DC - AC conversion as follow: This buck-boost inverter is arranged for two bi-directional buck-boost converters. These converters produce a DC-biased sine wave output, so that each converter only produces a unipolar voltage. The modulation of each converter is 180 degrees out of phase with the other, which in maximizes the voltage excursion across the load. The load is connected differentially across the converters. Thus, whereas a DC bias appears at each end of the load with respect to ground, the differential DC voltage across the load is zero. The generating bipolar voltage is solved by a push-pull arrangement. Thus, converters implementation needs to tie a current bi-directional.(Garcia and Oscar, n.d.)

The regular boost converter in addition to inherently lower efficiency, the standard boost converter has some additional drawbacks such the pulsating output current, which requires additional filtering. To obtain 36V output from the 28V input, a duty ratio of 0.22 is needed When the load current is 14A, the current fed into the output capacitor will be 18A pulses. If a boost converter is used in this design, where extremely low output ripple is required, the output voltage ripple created by this 18A pulsating output will be very hard to handle. On first sight the step-up Cuk converter requires one more inductor than the basic boost converter. However, a more careful observation reveals that the total current in the two inductors in the step-up Cuk converter is the same as in the boost inductor. AS in a basic: Cuk converter, the two inductors in the step-up version can be coupled and the output inductor ripple can be "steered" into the input inductor leaving the output inductor current to be essentially zero ripple. The expected performance advantages of the Step-up Cuk converter over a standard boost converter with output filter have been materialized as demonstrated by the extremely high 97% -98% efficiency obtained for the switching stage. The low current ripple in the output inductor enabled the design to obtain less than 5mV voltage ripple at the output.(Kazmierkowski and Malesani, 1998)

Regarding the current control technology of the three-phase voltage type pulse width modulation converter, various techniques, different in concept, have been described in two main groups: linear and nonlinear. In this paper, the first includes proportional integral stationary and synchronous) and state feedback controllers, and predictive techniques with constant switching frequency. The second comprises bang-bang (hysteresis, delta modulation) controllers and predictive controllers with on-line optimization. CC techniques for VS converters can be divided into two groups: 1) linear, i.e, stationary, synchronous, and predictive deadbeat controllers and 2) nonlinear, i.e., hysteresis, DM, and on-line optimized controllers. The basic principles and the latest developments of these techniques have been systematically described in this paper. The advantages and limitations have been briefly examined, and the application field where each technique is particularly suited has been indicated. Recently, the research trend favors fully digital control. Thus, the methods which allow digital implementation are preferred, even with some sacrifice in accuracy and dynamic performance. In particular, for low-performance applications with large diffusion (e.g., pumps, blowers and fans, and retrofit applications), digitally implemented PI regulators are adequate. Use of linear predictive and on-line optimized CC is growing fast in medium- and high-performance systems, especially for traction and high power units. Hysteresis CC, in their improved versions, are well suited to fast, accurate conversion systems (e.g., power filters and UPS's).(Maksimovic and Cuk, 1989)

Single phase active power filters are effective to compensate harmonics for home appliance and office equipment. Single phase active power filters, however, have some problems. The one of the problems is current control for high frequency components, because coordinate transform cannot be applied to single phase system. Therefore, a current control method based on hysteresis control suitable for a single-phase inverter with an LC output filter is needed. In terms of current control, the inductor current is controlled by a hysteresis controller and then passed through an LC filter to eliminate switching ripple. The state feedback of the capacitor voltage is adopted to suppress the resonance of the LC filter. The PI controller is used to control the output current of the LC filter. The current reference is added directly to the reference of the hysteresis controller. The whole system consists of two parts, hysteresis control and state feedback. The advantage of this method is that the output current switching ripple is small and the response speed is fast. Also suitable for uninterruptible power supply and other occasions. So I think it can be used in my charging pile design.(Kobayashi and Funato, 2008)

In summary, The hysteresis current control method can be used in the post-module of inverter grid connection. Hysteresis current control is widely used because of its simple control and fast response speed. Hysteresis current control has two functions. As a negative feedback closed-loop controller, it regulates the current so that the current is output according to the set value. The other function is to form a PWM wave and modulate the switching instruction to PWM wave. In addition, the hysteresis current control method has a small calculation amount and no complicated calculation process. By selecting different hysteresis widths to adjust the control accuracy, it has the characteristics of fast response speed and high accuracy. In addition, because the control accuracy and the switching speed are determined by the hysteresis width, it does not change with the current, so it has good stability.

CHAPTER 3

DESIGN OF DC BOOST CIRCUIT

3.1 Topological structure selection of DC boost circuit

The main circuit topology mainly completes the two functions of boosting and mode control. The DC boost is to boost the DC voltage output by the charging pile to the DC bus voltage; the three control modes of the load are to test the performance of the charging pile in different modes.

For DC boost, there are two main circuit topologies, one is DC-DC mode, and the other is DC-AC-DC mode. DC-DC boost circuit topologies mainly include Boost topology, Buck-Boost circuit, Cuk circuit, etc.; DC-AC-DC modes mainly include push-pull circuit, flyback circuit, and forward circuit.

In this paper, several classic DC boost circuit topologies are selected for comparative analysis, including: push-pull circuit, Boost topology, DC-DC boost converter with intermediate tapped inductor, Sepic chopper circuit, Zeta chopper circuit, and capacitive energy storage Cuk circuit.

3.1.1 Analysis of Push-Pull Circuit Topology

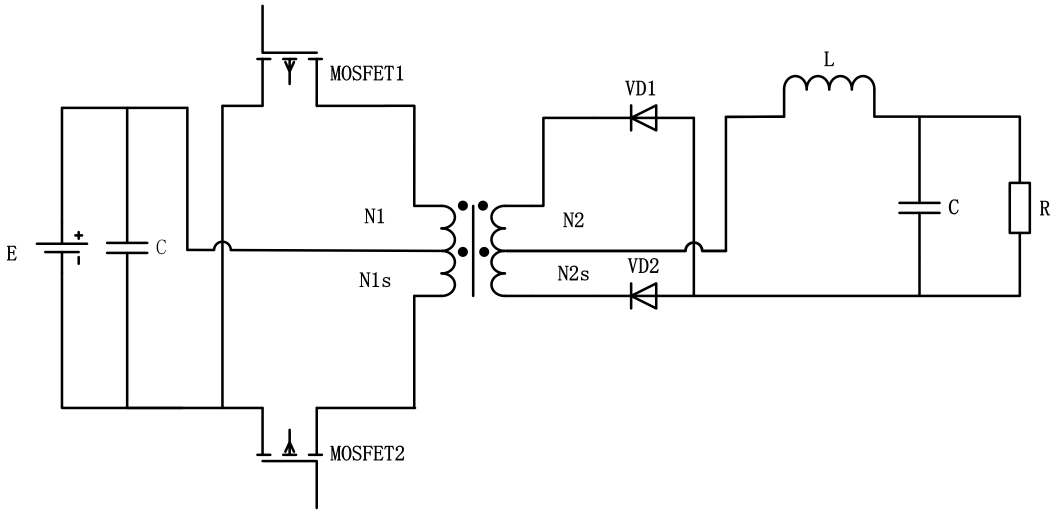

Figure 3.1: Push-pull circuit topology

Figure 3.1 shows the topology of the push-pull circuit. The characteristic of the push-pull circuit is that it has an isolated DC conversion topology and is used in occasions where the boost ratio is relatively high.

Through the alternate conduction of the two power switch tubes, alternating current voltages with opposite phases are formed across the windings N1 and N1S. When the MOSFET1 is turned on, its corresponding diode is turned on, forming a current loop. When the two power switch tubes are both turned off, the two corresponding diodes are both turned on, and the current is shared by half. When the switch tube is turned on, the inductor L accumulates energy, which makes the current increase. When the two switch tubes are both turned off, the energy on the inductor L is consumed on the load, so that the current gradually decreases. When selecting the switch tube withstand voltage, it should be greater than twice the power supply voltage E.

If both switching tubes are turned on, the primary winding of the transformer will be short-circuited. Therefore, an interlock circuit should be involved in the control to avoid this situation. The duty cycle of the switching tube is required to be ≤50%, and the dead zone of the switching tube Sufficient time should be reserved.

According to the characteristics of the inductor and circuit analysis, the following formula holds when the current is continuous in the inductor L:

$$\frac{U_o}{E}=\frac{N_2}{N_1}\frac{2t_{on}}{T} \tag{3.1}$$

among them:

U_O-----------The output voltage

T_{ON}--------------Duty cycle.

From equation (3-1), it can be analyzed that the push-pull circuit can achieve a larger step-up ratio by increasing the transformer ratio. In addition, this structural topology also has simple drive, high power, two-way excitation, and low energy consumption. Etc.

The disadvantage of this topology is that due to the transformer, it is easy to cause high-frequency oscillations of the voltage and current output by the circuit, which will damage the switching tube devices, bring safety hazards to the system itself and auxiliary devices, and the transformer efficiency is low. In addition, due to the existence of the transformer, the system volume becomes larger, the power density is lower, the structure is more complicated, the cost increases, and the maintenance is difficult.

The most important thing is that during the reserved dead zone period for the two switch tubes, the current will be discontinuous, which will not meet the constant current mode control of the system, so this topology does not conform to the design of the intelligent feedback load.

3.1.2 Boost DC boost chopper circuit topology analysis

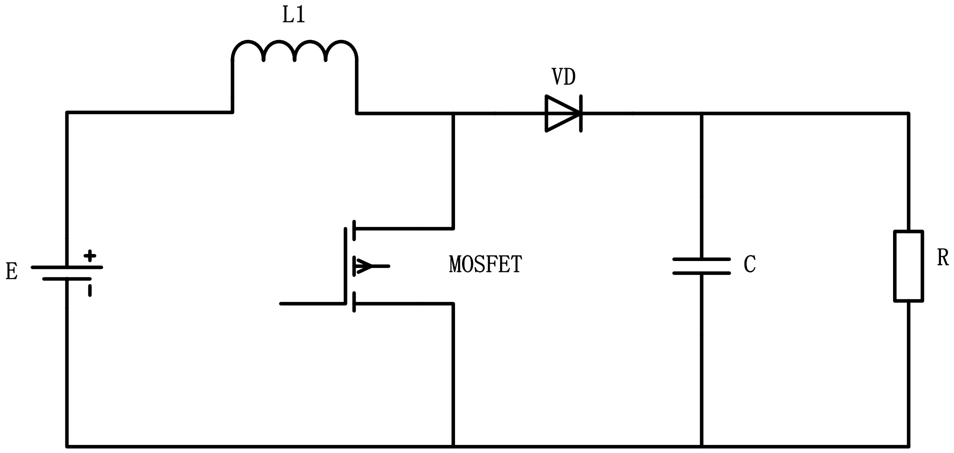

Figure 3.2: Boost DC boost chopper circuit

The Boost DC boost circuit topology is shown in Figure 3.2, which has the advantages of simple topology, fewer components, and clear functions.

The principle of this topology is simple. When the power switch is turned on, the power supply E delivers energy to the inductor L with a constant current I_1, and the capacitor C provides energy to the load R. Assuming that the value of the capacitor C is large enough, the voltage U_0 on the capacitor C remains constant. The on-time of the power switch in the cycle time is t_{on}, and the off-time is t_{off}. According to the law of conservation of energy, in the steady state, the energy released by the inductor L in the same cycle is equal to the stored energy, namely

$$E_i I_1 t_{on} = (U_o - E_i) I_1 t_{off} \tag{3.2}$$

Simplified

$$U_o = \frac{E_i}{1-\alpha} \tag{3.3}$$

among them:

$\alpha = \frac{t_{on}}{T}$ ------The duty cycle of the switch tube.

The principle of the Boost DC boost circuit is shown in formula (3-3). The boost principle is realized by the energy storage of the inductor L and the principle that the capacitor voltage cannot change suddenly.

According to theoretical calculations, when the duty cycle α is infinitely close to 1, the boost ratio will tend to be infinite. However, in engineering practice, due to the internal resistance of the inductor, the limited capacitance of the capacitor and the loss of the power switch, the boost ratio will suffer Restriction, usually Boost circuit duty cycle is less than or equal to 0.88, that is, boost circuit magnification is not less than or equal to 7.33.

Due to the simple structure of the Boost circuit, only one power device is used, the switching loss is less, the efficiency is higher, and the control algorithm is simple, so it is still widely used. However, because the power-on switch is always in a hard-switching state, as the power increases, the diode will have reverse recovery loss and cause EMI interference, which is an urgent problem to be solved.

3.1.3 Topological analysis of DC-DC boost converter with middle tapped inductor

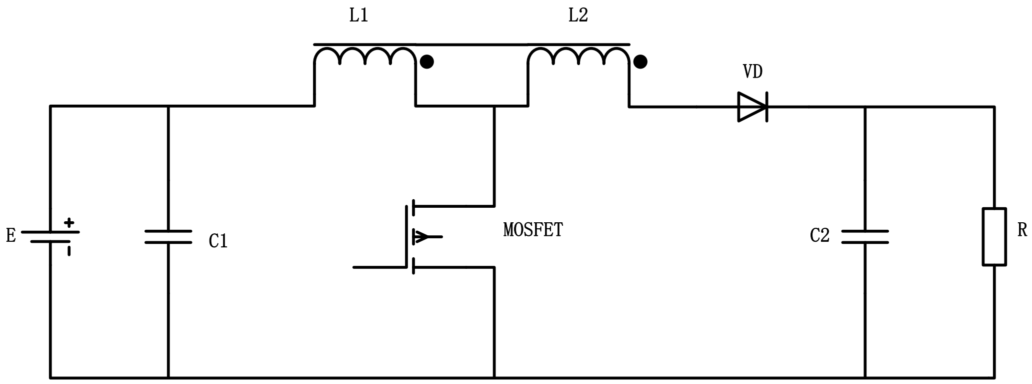

Figure 3.3: DC-DC boost converter with middle tapped inductor

The topological structure of the DC-DC boost converter with a middle tapped inductor is shown in Figure 3.3. This topology is an improvement through the Boost DC boost circuit. Its control law and principle are basically similar to those of Boost. In order to solve the problem of increasing the circuit The boost ratio issue introduces coupled inductors.

Function of inductor: it is an energy converter that converts electric energy and magnetic field energy. When MOS switch is closed, inductance converts electric energy into magnetic field energy and stores it. When MOS is disconnected, inductance converts stored magnetic energy into electric field energy. After superposition with input power voltage, the energy is filtered by diode and capacitor to obtain smooth DC voltage and provide it to load The output voltage is higher than the input voltage, which is the completion of the step-up process.

It is known that the magnetic flux of the inductance remains constant during the period. From this, the boost ratio M of the DC-DC converter with a center-tapped inductor can be derived as

$$M = \frac{1+N\alpha}{1-\alpha} \qquad （3.4）$$

among them:

$N = \frac{N_2}{N_1}$ ------The turns ratio of the two inductors

α ------ Switch tube duty cycle

Inductance value $\frac{L_2}{L_1} = \left(\frac{N_2}{N_1}\right)^2$, The coil turns of the inductors L_1 and L_2 are N_1 and N_2, respectively. Through the mutual inductance of the inductance, the boost ratio is 1+ND times higher than that of the Boost circuit, which solves the problem of insufficient voltage ratio of the Boost circuit.

Because the inductor actually has leakage inductance, and the higher the power level, the greater the loss of the system, resulting in lower efficiency of the system. At the same time, the volume of the inductor is larger, and the energy density is lower, causing the system to increase in size, structure, and cost. Shortcomings such as rising, make the use of this structure has a specific occasion.

3.1.4 Sepic chopper circuit

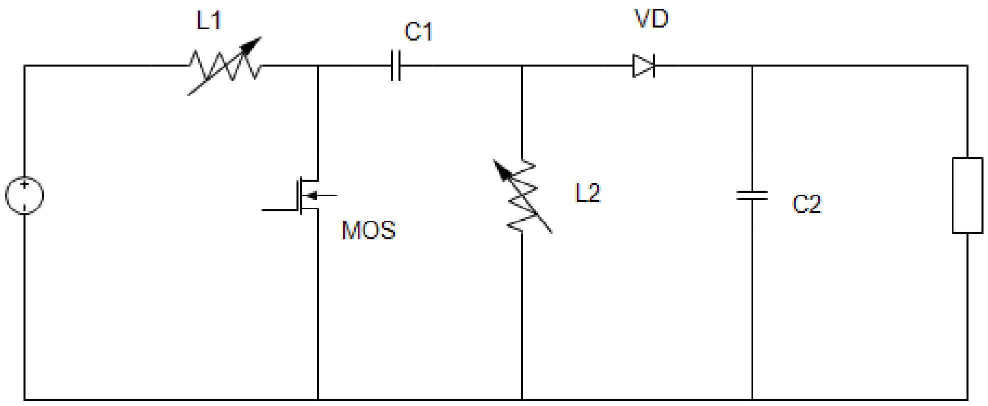

Figure 3.4: Topological structure of Sepic chopper circuit

When MOS is on, E-L1-MOS circuit and C1-MOS-L2 circuit conduct electricity at the same time, L1 and L2 store energy. The energy stored in C1 transfers to L2 when MOS is on.

When MOS is in off state, E-L1-C1-VD-load (C2 and R) circuit and L2-VD-load circuit conduct electricity at the same time. At this stage, E and L1 not only supply power to the load, but also charge C1.

SEPIC circuit features:

·It is not easy to use: two inductors, one capacitor and one transistor and one diode should be added to the charge pump circuit.

·High efficiency.

·High EMI and output ripple.

·It can be used for boosting and depressurizing.

·It can be used in high output current.

·The price is the highest due to the large number of components to be matched.

Because it has high EMI, and the number of components to be matched is large, and the price is high, it is not selected as the pre-stage circuit.

3.1.5 Zeta chopper circuit

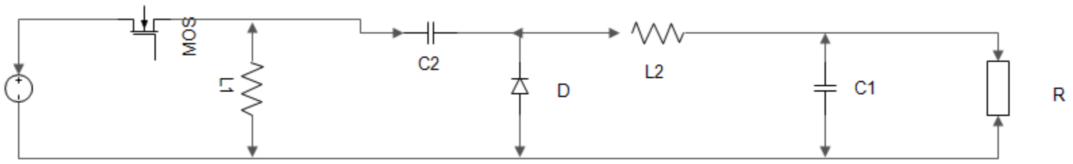

Figure 3.5: Topological structure of Zeta chopper circuit

The basic working principle of the circuit is: when the controllable switch MOS is in the on state, the power supply stores energy to the inductance L1 through the switch MOS. When MOS is in off state, L1 forms an oscillation circuit through D and C2, and its stored energy is transferred to C2 until the current of oscillation circuit is zero. After all the energy on L1 is transferred to C2, D turns off and C2 supplies power to load R through L2. If the conduction ratio α is changed, the output voltage can be higher than or lower than the supply voltage. When $0 < α < 1 / 2$, it is depressurization, when $1 / 2 < α < 1$, it is boosting.

Because the input current of the Zeta circuit is not continuous, it cannot meet the constant current mode in the design, so it is not selected as the pre-module.

3.1.6 Topological analysis of capacitive energy storage Cuk circuit

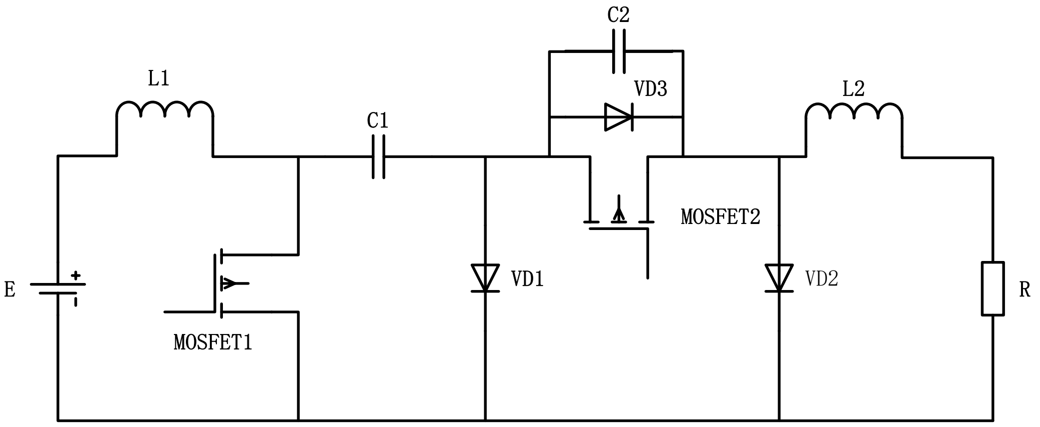

Figure 3.6: Topological structure of Cuk circuit

The characteristic of the Cuk converter is that the input and output current ripples are small. Through the coupling of the input and output inductors, the current ripple is further reduced, and the effect of higher power density can be achieved. The scholar Edson Adriano Vendrusculo proposed a new type of Cuk circuit topology in 1996, as shown in Figure 3.6. Its characteristics are remarkable. Two MOS transistors can independently control the input and output current, which is beneficial to subsequent current control; The absorbing capacitor realizes soft switching, reduces the loss of the power switch tube, and improves the overall efficiency of the system.

The input and output voltage relationship of the Cuk circuit is:

$$U_{\mathrm{o}} = E\frac{\alpha}{1-\alpha} \tag{3.5}$$

among them:

α ------ MOS tube duty cycle;

U_{o} ------ Circuit output voltage.

The newly added MOS2 tube and VD2 form another set of charging circuits, which can be charged when the capacitor C_1 is not charged. At this time, according to the charge balance of capacitor C_1:

$$I_i(1-\alpha_i) = I_o\alpha_{\mathrm{o}} \tag{3.6}$$

among them:

α_i ------ Duty cycle of MOS1 tube;

α_{o} ------ Duty cycle of MOS2 tube;

I_i, I_o ------ Average value of input and output current.

The input and output currents are controlled by α_i and α_{o} respectively. The necessary condition for this circuit topology is that the duty cycle of MOS1 tube ≥ the duty cycle α_{o} of MOS2 tube.

According to the law of conservation of energy and ignoring circuit losses, we get:

$$I_iE = I_{\mathrm{o}}U_o \tag{3.7}$$

$$\frac{U_{\mathrm{o}}}{E} = \frac{\alpha_o}{1-\alpha_i} \tag{3.8}$$

From equations (3-7) and (3-8), the boost ratio formula of the Cuk circuit with capacitor energy storage is obtained, which theoretically proves that its structure can realize the DC conversion function.

In addition, the soft switching function of the power switch tube is realized through the buffer capacitor C2, and the switching loss is reduced. The output current increases the voltage to U2 by charging the capacitor C2, so that the diode VD2 is turned on, and the voltage U2 of the capacitor C2 applies a reverse voltage to VD1. When the MOS1 tube is turned off, its terminal voltage is 0. Before the MOS1 tube is turned on, the buffer capacitor C2 is discharged to zero voltage through the input current. The zero-voltage conduction of the MOS2 tube is obtained by the law that the MOS1 tube is turned on after a period of delay, but the conduction of the MOS1 tube does not have the characteristic of zero loss at this time. Another disadvantage is that there are two diodes in the circuit, which increases the loss; the circuit structure is relatively loaded, and the control signal is complicated.

Capacitor energy storage type Cuk circuit also has many advantages such as small output energy ripple and stability. In addition, two power switch tubes are matched to meet a certain boost ratio, which meets the requirements of DC converters in the circuit topology.

From the perspective of control, the capacitive energy storage type Cuk circuit has multiple power switch tubes, which can realize flexible control of input and output currents. Based on this, it is brought when the load is controlled in three modes of constant current, constant voltage and constant power. Not small and convenient, so this circuit topology is a better choice than this design.

This overall design makes full use of the advantages of this topology to design an intelligent feedback load that meets the requirements, realize the control switching of different modes, and the detection of the load characteristics of the charging pile.

3.1.7 Comparative analysis and summary

Based on the above discussion, the advantages and disadvantages of the four topologies are obtained, as shown in Table 3-1.

Table 3.1: Performance comparison of six DC-DC boost circuits

Type	**Typical output power (W)**	**Energy storage element**	**Input/output voltage relationship**	**Characteristic**
Buck Chopper	0-1000	Single inductor	0≤output≤input	The current input needs to be continuous, the input voltage is higher than the output voltage, and the output voltage polarity does not change when stepping down
Boost Chopper	0-5000	Single inductor	Input ≤ output	The current input needs to be continuous, the input voltage is lower than the output voltage, and the output voltage polarity does not change when boosting
Buck-boost chopper	0-150	Single inductor	Output≤0	The input and output currents are discontinuous
CUK converter		One capacitor and two inductors		Both input and output current are continuous
SEPIC converter		One capacitor and two inductors		Input current is continuous
ZETA converter		One capacitor and two inductors		The output current is continuous

Table 3 clearly shows the characteristics of various topologies. It can be seen from the table that the capacitive energy storage type Cuk circuit has better characteristics except for the slightly complicated circuit topology and lower boost voltage. In line with the requirements of this system, the capacitive energy storage type Cuk circuit is selected as the front-end structure of the intelligent feedback load for voltage boosting and different mode control of the load.

In addition, the MOS tube is selected as the power device switching tube. The MOS tube has the advantages of high switching frequency, positive temperature coefficient, and good thermal stability. It is a better choice to apply to this system.

3.2 Design of control strategy of DC boost circuit

The system needs to implement 3 load modes: constant current mode, constant voltage mode, and constant power mode. In the constant current mode, it means that the load performs constant current feedback and is not controlled by the load voltage to detect the constant current characteristics of the charging pile; in the constant voltage mode, it means that the feedback load is not controlled by the load current and keeps the voltage unchanged. Feedback is used to detect the constant voltage characteristics of the charging pile; in the constant power mode, the load keeps the output power unchanged to detect the power output by the charging pile.

3.2.1 Closed-loop feedback adopts PID link

Analyzing the three load modes, in essence, it is necessary to maintain certain parameters unchanged, and a negative feedback closed-loop control system is required. In order to improve control accuracy and control stability, a proportional, integral, and derivative control system, namely PID control, is introduced.

The main characteristics of PID control are: easy-to-understand, easy-to-implement, and wide application range, which can meet more than 95% of the control objects and requirements; the controller is suitable for most objects and has strong universality, to be precise, It is not sensitive to parameters, has a wide range of application and reliable control. The charging pile load in this system is a common load. The PID controller can follow the voltage, current and power changes of the load, quickly adjust the PWM to adapt to the changes in the outside world, and achieve better control.

The specific control algorithm is to collect the voltage and current information, and then compare with the reference value to generate the difference, modulate it through the PID link, and send it to the PWM controller to control the switch on time and sequence of the power device to make the difference The absolute value becomes smaller, and the actual value is consistent with the reference value.

3.2.2 The concrete realization plan of the three control strategies

The following takes one of the three modes of constant current control mode as an example to illustrate how the controller implements the load mode.

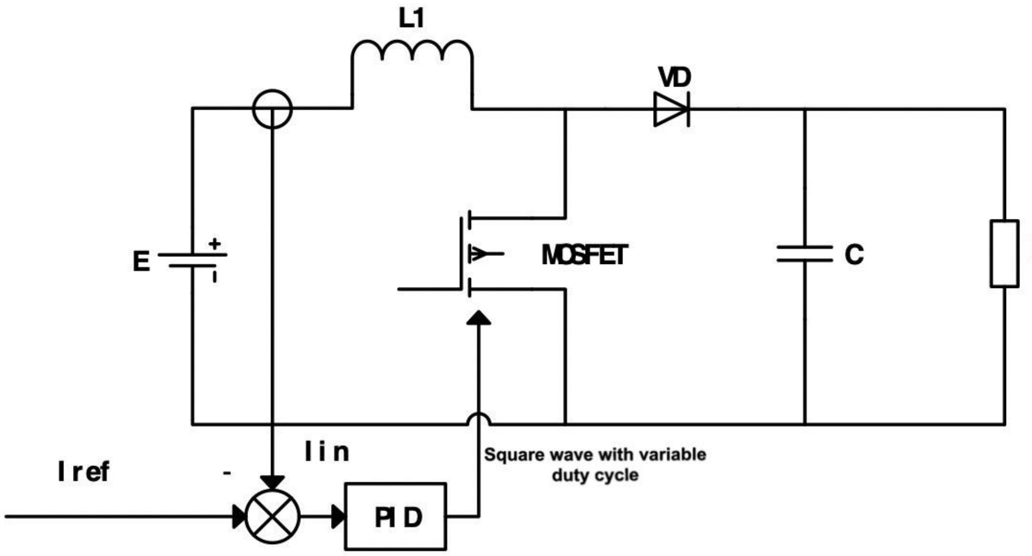

Figure 3.7: Constant current control circuit diagram

Figure 3.7 is a simple control model of the DC boost circuit as an example. The input current I_{in} is collected and compared with the reference current I_{ref} to obtain the error value, and then modulated by the PID link to control the duty cycle to make the system output The input current of is consistent with the reference current, realizing constant current control.

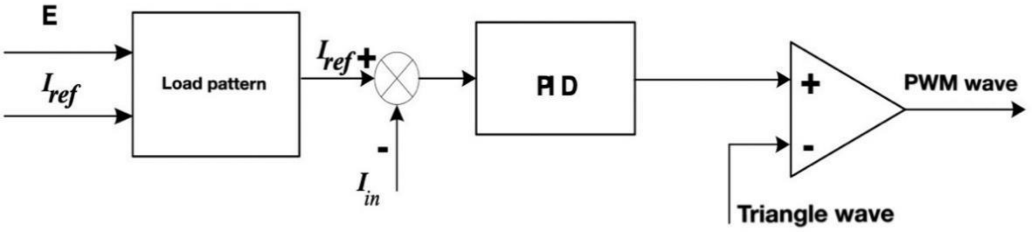

Figure 3.8: DC boost circuit control strategy

According to the above-mentioned realization of constant current control, the other two control modes can be obtained, as shown in Figure 3.8, both of which compare the set value with the sampled value, then modulate the error to obtain the control value, and then send it to the PWM control system , Adjust the parameters to achieve consistency between the set value and the reference value.

A. Constant current control: The error value is formed by sampling I_{in} and setting I_{ref}, and through PID modulation, the PWM switching device is controlled to turn on and off to adjust the current.

B. Constant voltage control: By collecting the voltage, comparing with the set voltage, get the error, through PID controller modulation, control the conduction law of the PWM switching device, realize the minimum error, and then make the actual voltage consistent with the set voltage effect.

C. Constant power control: The expected power P/power supply instant voltage U is the instant reference current I_{ref}. Compared with the measured current I_{in}, the PID controller controls the switching tube to turn on and off.

Finally, the realization and switching of the three control modes are formed, which meets the various mode requirements for detecting the load of the charging pile.

3.3 Overall analysis and simulation verification of capacitive energy storage Cuk circuit

3.3.1 Circuit design parameter analysis

In this design, the capacitor energy storage type Cuk circuit is used to realize the DC boost function in the front stage of the intelligent feedback load. The boost principle has been described above, and several important parameters need to be determined through theoretical analysis. The function of the inductor L1 is to store energy to achieve voltage pumping. If the value of L1 is too small, the stored energy will not meet the boosting requirements. If it is too large, the overall system inertia will be too large and the response time will be too long. The performance cannot be detected; the capacitor C1 plays the role of energy storage and voltage retention, if C1 is too small, it will not play the role of voltage maintenance, and if C1 is too large, it will not transmit the voltage change; C2 is used to realize the soft switching function of MOS2 tube It should not be too large; the role of the inductor L2 is to stabilize the output current, and a relatively large inductor value should be selected. The selection of parameters needs to be balanced according to actual needs, and a compromise is selected when a variety of needs are considered. In the constant current mode, the current stability requirements are higher, and the voltage stability requirements are higher in the constant voltage mode. The constant power mode requires that the current change trend is opposite to that of the voltage. In the case of taking these three modes into consideration, the three cases are selected. In addition, assuming that the equivalent impedance of the latter stage is R, an appropriate value is selected through theoretical analysis.

The specific parameter settings are as follows:

In order to meet the boost ratio of the system, the duty cycle of the MOS1 tube should be within a certain range, resulting in a lower limit of the output current. This system is 35A, so the power level of this system is at least 1500W. The boost ratio is about 7.3, so the output current I_0 is about 5A.

The inductor L1 needs to meet two conditions: make the input current continuous and meet the voltage pumping requirements. According to the condition of continuous current:

$$L_1 \geq \frac{E^2 \alpha_i T}{2P_{\min}} \tag{3.9}$$

among them:

E------------DC power supply voltage;

α_i-----------Duty cycle;

T-------------work cycle;

$P_{\min}$--------------The minimum power output of the power supply.

At this time, it can be obtained that L1 is greater than or equal to 0.07mH. In addition, in the constant current mode, the fluctuation of the current is less than or equal to 2%, and the fluctuation formula of the inductor current is:

$$\Delta i_{L_1} = \frac{E}{L_1} \alpha T \tag{3.10}$$

among them:

Δi_{L_1}-----------------The fluctuation range of the input current.

According to the design requirements: $35 \times 2\% = 0.7A$, $L_1 = 4.32\text{m}H$ after calculation.

When selecting the parameters of the capacitor C_1, the voltage U_{C1} of the capacitor C_1 needs to be approximately equivalent to the output voltage U_d. According to the characteristics of the capacitor:

$$C_1 \geq \frac{P_{\max}}{100\pi U_{c_1} \Delta U_{c_1}} \tag{3.11}$$

among them:

$P_{\max}$ ------------ Maximum power output

U_{c_1} -------------- Capacitor C_1 voltage

Can get $C_1 \geq 1200\mu F$

The inductor L_2 is used to limit the ripple of the output current, and it needs to meet:

$$L_2 \geq \frac{U_{c_1} T}{4\Delta I_o} \tag{3-12}$$

among them:

ΔI_o ---------- Output current fluctuation range.

So get $L_2 \geq 0.035H$

Capacitor C2 is a buffer capacitor, used to realize the soft turn-off of the MOS2 tube. If it is too large, the delay of the switch tube will be too large, take $C_2 = 1\mu F$

Based on the above analysis and calculation, the final parameters are as follows:

The inductance L1 is 0.05H (it is smaller in the constant voltage and constant power mode), the capacitor C1 is 1200μF, the inductance L2 is 0.4H, and the capacitor C2 is 1μF.

In addition, the equivalent resistance R of the subsequent circuit of the intelligent feedback load is determined based on the power and output voltage of the subsequent circuit, and the equivalent resistance is:

$$R = \frac{U_d}{I_o} = 70\Omega \tag{3-13}$$

Then set the output equivalent impedance to 70Ω. At this time, the main circuit of the intelligent feedback load and the corresponding electrical parameters are determined.

3.3.2 circuit analysis of three control strategies

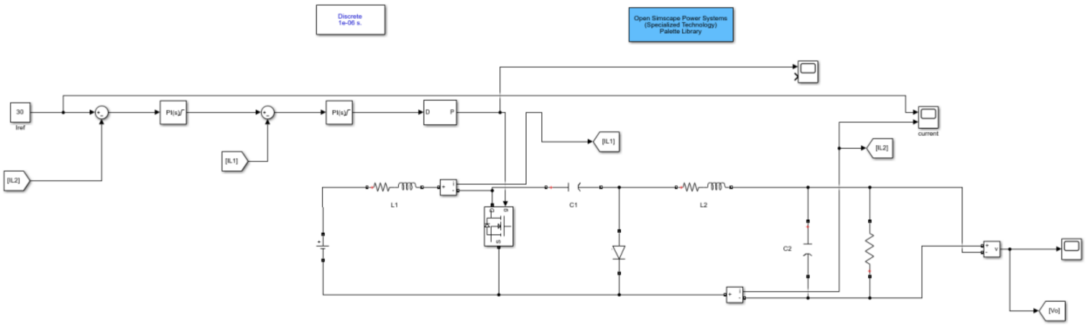

Figure 3.9: constant current mode control strategy of DC boost circuit

Figure 3.9 shows the control circuit in the constant current mode. The MOS1 tube modulates through the PID control link through the negative feedback signal error, and transmits it to the PWM control to turn on and off to achieve the purpose of stabilizing the input current to the desired value; Among them, the PID parameter debugging is mainly based on the current and voltage waveforms, whether there is overshoot, oscillation, etc., through the modification of Kp and Ki parameters, the rapidity and accuracy of system adjustment and response time are achieved. In this design, the parameters of the two PID regulators are set to Kp=1 and Ki=0.1.

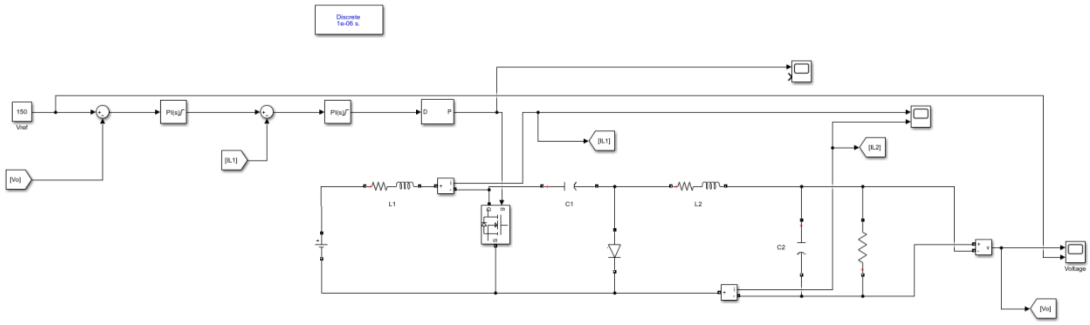

Figure 3.10: constant voltage mode control strategy of DC boost circuit

Figure 3.10 shows the control circuit in constant voltage mode. The control principle is basically the same as that in constant current mode, except that the control algorithm is different. Obtain the voltage collection information, compare it with the set voltage, and adjust the error to achieve the consistency between the set voltage and the actual value.

Figure 3.11 shows the control circuit in constant power mode, and its working principle is basically the same as that in constant current mode, so won't repeat it here.

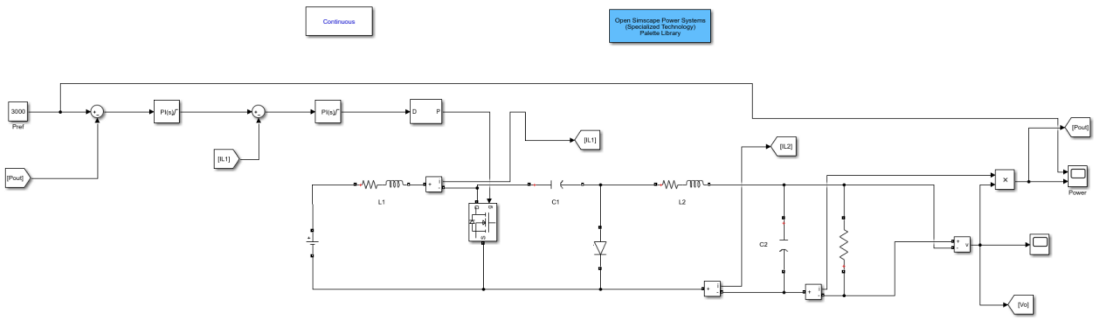

Figure 3.11: constant power mode control strategy of DC boost circuit

3.3.3 Overall Simulink simulation verification of DC boost circuit

In order to verify the selected main circuit structure and whether the calculated parameters are achievable, the Simulink tool in Matlab is used for simulation research. Matlab software is a mainstream simulation software, which has great advantages in system simulation, and its simulation speed and accuracy are relatively prominent. Simulink is a graphical simulation, which can be quickly started for those who initially use simulation software. It supports discrete and continuous, linear, and nonlinear simulations, with a high degree of visualization and a wide range of applications.

The capacitor energy storage type Cuk circuit simulation model built with Simulink tools is now in constant current mode as shown in Figure 3.12.

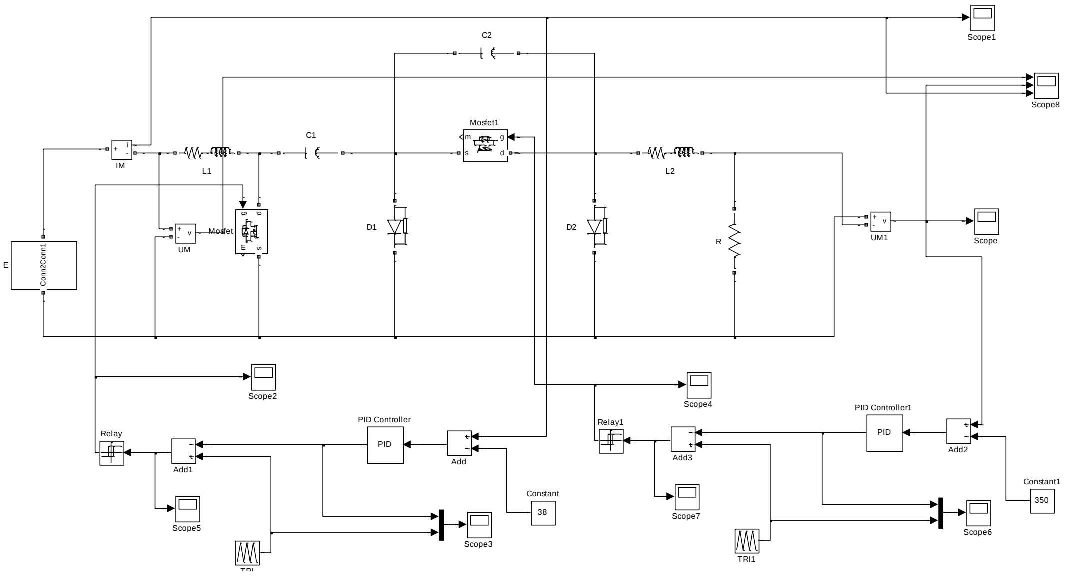

Figure 3.12: The capacitor energy storage Cuk circuit model taking constant current control as an example

Figure 3.13 shows the power supply to be tested, which is based on the maximum value of 6 sine waves with a phase difference of 60°.

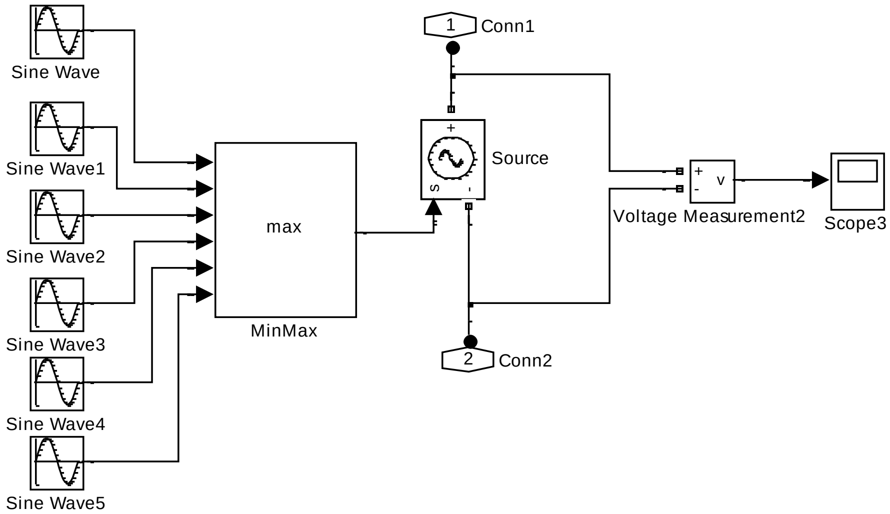

Figure 3.13: Internal topology of equivalent power supply

Set the system according to the above parameters, and the simulation result waveform is shown in Figure 3.14-3.16.

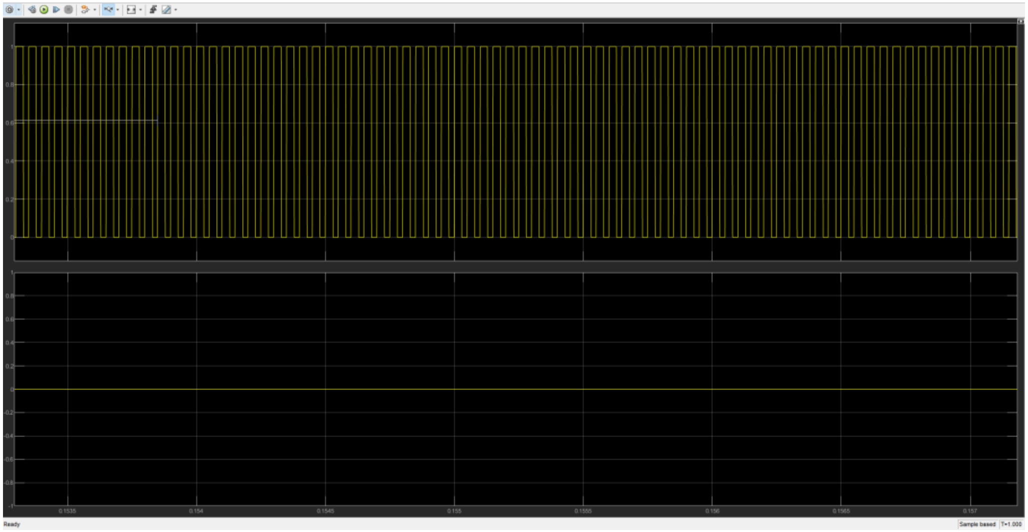

Figure 3.14: The power supply voltage of the circuit in constant current mode

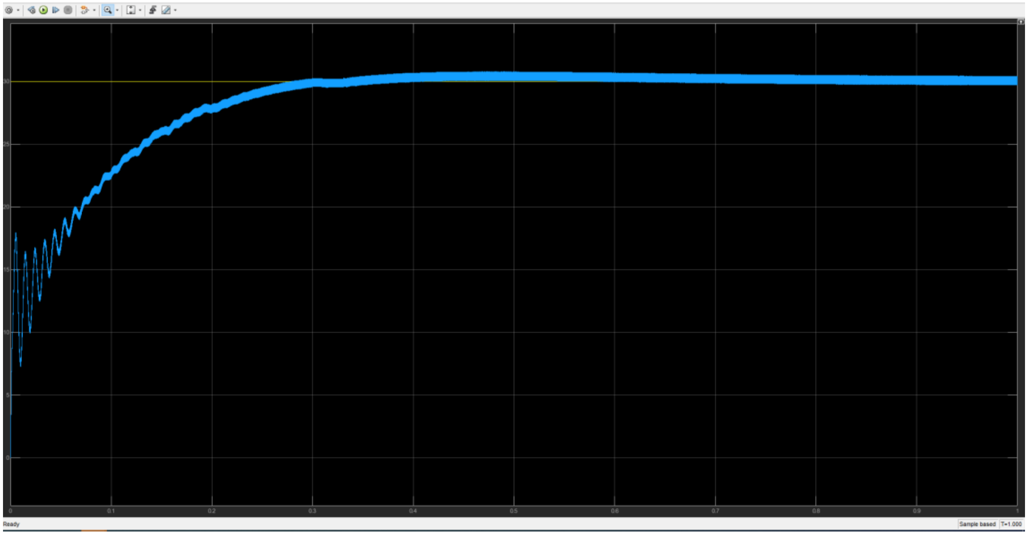

Figure 3.15: Input current of the circuit in constant current mode

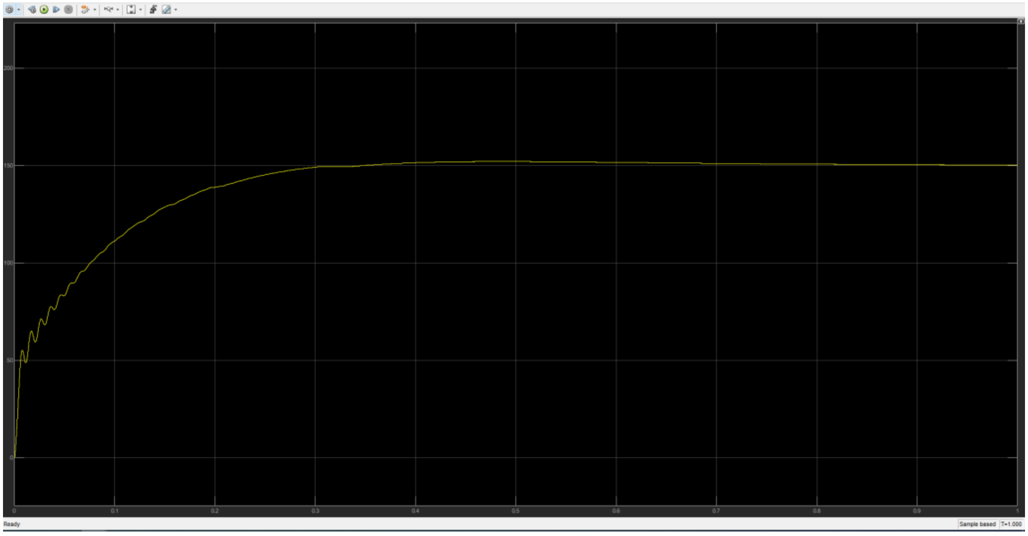

Figure 3.16: The output voltage of the circuit in constant current mode

Figure 3.14 shows the power supply voltage. Figure 3.15 shows the input current waveform. It can be seen from the results that the input current can still remain stable near the set expected current value under the fluctuation of the power supply under test, and the fluctuation does not exceed 2%. Figure 3.16 shows the bus voltage of the power supply. It can be seen that this system can stabilize the bus voltage, and the voltage fluctuation is small and the fluctuation is less than 5%.

However, it can be concluded from the figure that the longer rise time of the system is due to the consideration of steady-state errors and the prevention of system oscillations, while sacrificing a little speed. In addition, the rest of the performance is in line with the system's indicators, while verifying the correctness and feasibility of the main circuit topology and control strategy.

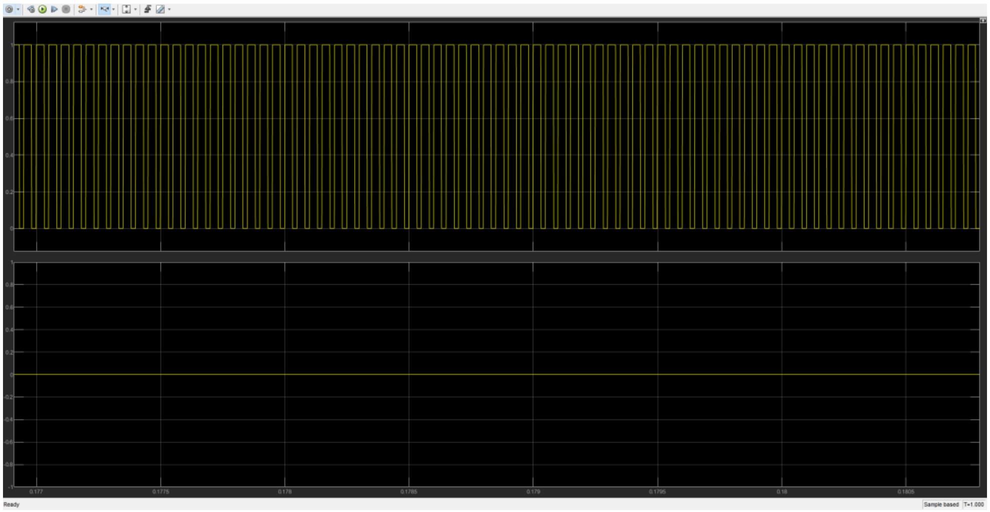

Figure 3.17: The power supply voltage of the circuit in constant voltage mode

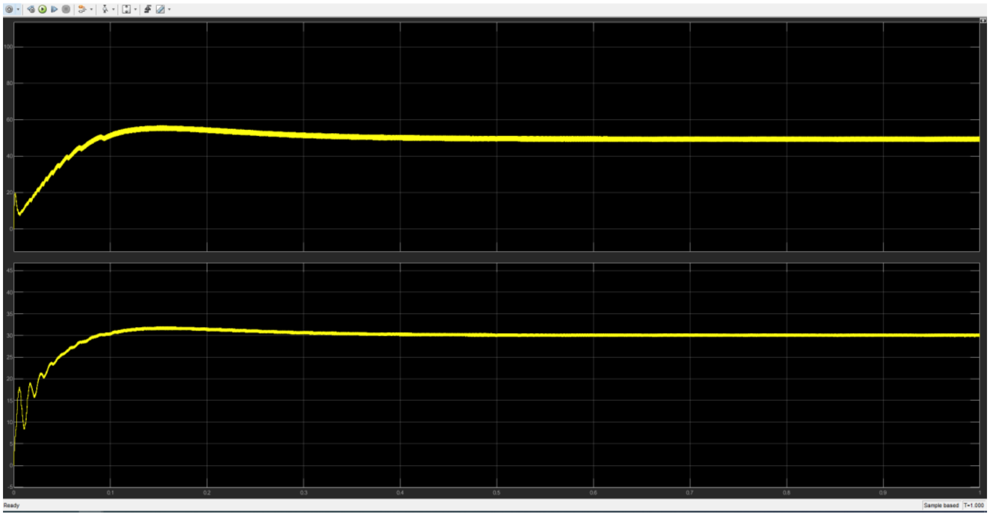

Figure 3.18: Input current of the circuit in constant voltage mode

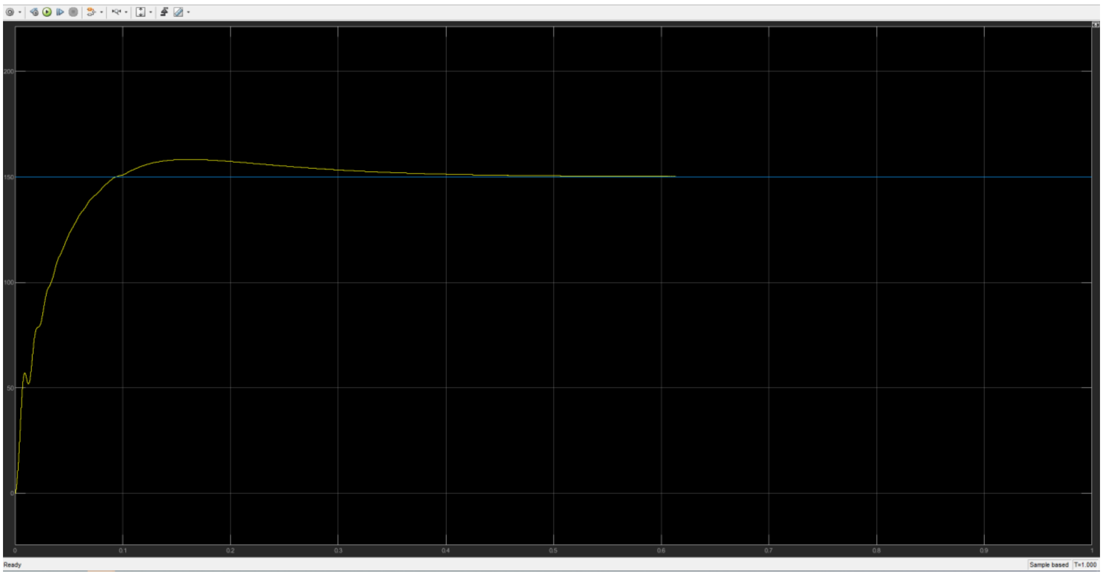

Figure 3.19: The output voltage of the circuit in constant voltage mode

The waveform of the constant voltage mode is shown in Figure 3.17-3.19, and the control law can be obtained through the waveform. It can be seen that the voltage is at a relatively stable level, and the fluctuations in the steady state are controlled within 3%, which meets the system design requirements, can achieve the function of constant voltage control mode, and realizes the feasibility of controlling constant voltage.

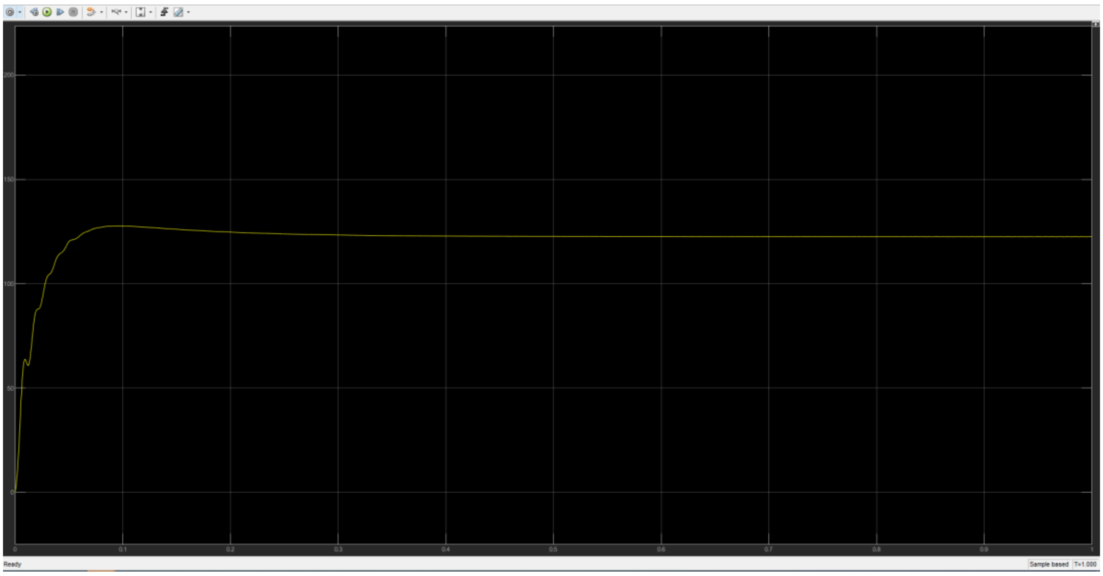

Figure 3.20: The output voltage of the circuit in constant power mode

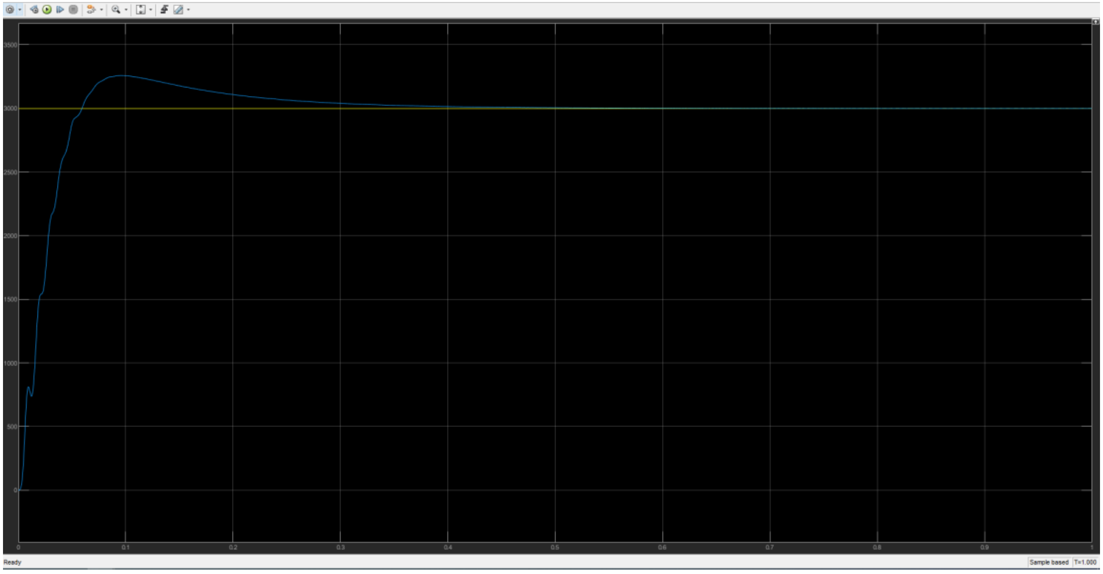

Figure 3.21: The output power of the circuit in constant power mode

It can be seen from Figure 3.21 that the output power is in a stable state, with small fluctuations. In the steady state, the up and down fluctuations are controlled within 2%, which meets the design requirements of the constant power control mode. It verifies the main circuit topology and the control algorithm for the constant power mode. Correctness and feasibility.

3.4 Summary of this chapter

At the beginning of this chapter, six traditional typical DC boost circuit topologies were analyzed and compared. On this basis, the advantages and disadvantages of each topology were compared. Then, according to the requirements of this design, the Cuk circuit with capacitor energy storage was selected as the system. The topological structure of the front-level circuit determines the parameters of the components in the topological structure of the main circuit; at the same time, according to the load characteristics and mode requirements, the control algorithm model and circuit are designed and analyzed. Finally, the whole is analyzed by Simulink in Matlab. The previous circuit was simulated and analyzed, and the simulated waveform was obtained, which verified the correctness and feasibility of the previous circuit structure and control algorithm.

CHAPTER 4

DESIGN OF INVERTER GRID-CONNECTED CIRCUIT

The grid-connected inverter is a power electronic converter that converts the energy on the DC bus of the previous stage into AC, and then transmits it to the grid.

In addition, in order to enter the grid in an orderly and controllable manner, it is necessary to comply with relevant standards when connecting to the grid, mainly the requirements for phase, frequency, power quality and other parameters:

(1) During normal operation, the voltage deviation of the grid-connected system should meet the requirements of GB/T 12325, and the specific value is that the deviation is not more than +7%, -10% of the grid's rated voltage;

(2) Frequency requirements when the system is connected to the grid. According to the regulations of GB/T 15945, when grid-connected, the maximum allowable deviation of the inverter is ±0.5Hz;

(3) The power quality of the grid-connected system. According to relevant national standards, the total current harmonics are not more than 5% of the inverter's rated output, and the limit for single harmonics is also specified;

(4) When the system is connected to the grid, the DC component output by the inverter should not exceed 1% of its AC rating.

In order to comply with relevant standards and improve the quality of grid connection, it is necessary to design a reasonable inverter topology and control algorithm.

4.1 Circuit topology design of grid-connected inverter

4.1.1 Structure of grid-connected inverter

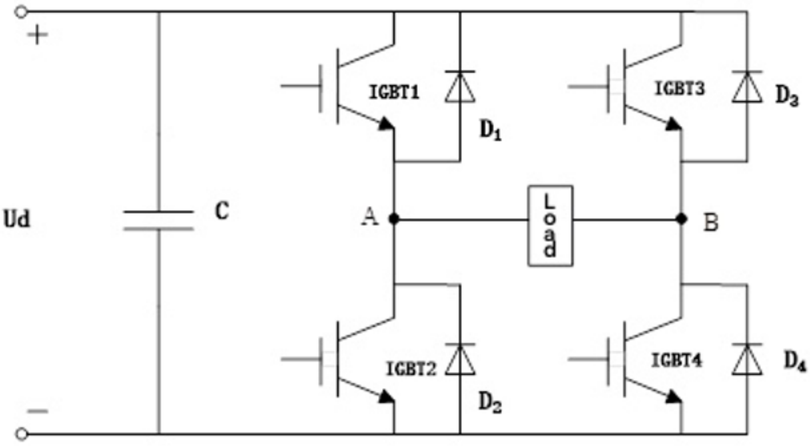

Figure 4.1: Inverter circuit structure diagram

This system is illustrated by the single-phase full-bridge topology, as shown in Figure 4.1.

Single-phase full-bridge inverter topology is the most widely used topology at present. It is characterized by simple structure and easy control. It consists of 4 switch tubes, divided into two groups, namely 1, 3 groups and 2, 4 groups, alternately Turning on realizes that DC becomes AC, and its output waveform is a square wave of DC bus voltage value. The disadvantage of this topology is that it uses more devices, but because of its simple and reliable structure and easy realization of various functions, it is used as the main structure of the inverter circuit.

MOS tube has the advantages of high switching frequency and low power consumption, but the voltage level is low. In order to prevent damage to power devices due to excessive voltage, insulated gate bipolar transistors (IGBT) are selected as switching elements to design inverter circuits.

4.1.2 Selection of filter

The output of the full-bridge inverter circuit is a square wave with the same amplitude as the DC bus, which needs to be filtered to get a better sine wave. At the same time, due to the existence of higher harmonics of the IGBT switching frequency, the output of the inverter cannot be satisfied. The power quality required by the power grid requires a filter to filter the high-order harmonics and the square wave output by the SPWM. In addition, the filter also has the functions of phase, active and reactive power exchange, etc., which can be summarized as follows:

(1) Affect the response time and dynamic performance of the inverter current,

and also affect the grid-connected power, system loss and bus voltage;

(2) It can be used as a physical isolation grid and inverter, through the control of the inverter to change the output voltage and phase, to achieve the inverter grid-connected amplitude and phase to match the grid;

(3) Suppress the high frequency harmonic current of the inverter, realize the sine wave at the output end, and control the power factor and grid connection;

(4) While ensuring that the inverter output meets the national standards, it can also obtain a certain damping characteristic for the grid transmission reactive power according to the actual operating conditions and improve the stability of the system.

In the structure of the filter, a single inductor is the simplest structure, and can achieve better results and smooth the output current, but the effect on higher harmonics is poor and cannot meet the actual needs of the system, so this system uses inductors Capacitive filter, as shown in Figure 4.2.

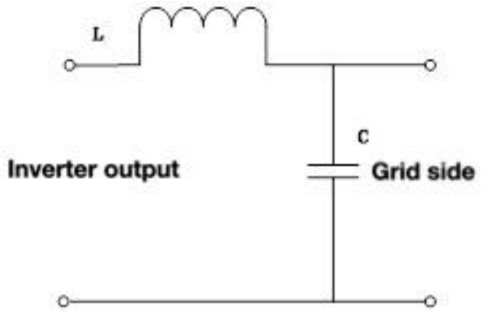

Figure 4.2: LC filter structure diagram

The LC filter has good current-voltage conversion performance and can reduce current noise. It is often used in independent power supply. The following is a theoretical analysis to discuss the problem of filter design. Inductance L can play a role in hindering the current, smooth the current waveform, and have good filtering performance for low-order harmonics. Capacitor C is the current high-order harmonic generation loop, Good harmonic filtering performance. In an ideal situation, when the values of L and C are large enough, the output of the inverter is a sine wave without any deformation, but in practice, the response speed, operation stability, and fundamental voltage of the inverter need to be considered. It is necessary to select the appropriate value for design to achieve the best effect due to problems such as dropout, active power loss, current harmonics and resonance.

According to the theory of resonance, it can be concluded that the resonant frequency of the system is $f0 = \frac{1}{2\Pi\sqrt{LC}}$, and the inverter needs to avoid the resonant frequency; at the same time, the carrier frequency of the system needs to be greater than the resonant frequency, so a low-pass filter is designed to eliminate the resonant frequency. At the same time, reserve some margin. According to Table 1, the switching frequency of the IGBT should be: $\frac{1}{20ms} = 0.00005Hz$. So the resonance frequency needs to meet:

$$5f_s < f_0 < 0.5f_c \qquad (4.1)$$

Among them: f_s is the fundamental frequency of 50Hz; the equivalent carrier frequency is set to 8kHz, and the result is:

$$250 < \frac{1}{2\Pi\sqrt{LC}} < 4000 \qquad (4.2)$$

Simplify further to get:

$$1.6*10^{-9} < LC < 4*10^{-7} \qquad (4.3)$$

At the same time, LC needs to be less than the switching frequency of IGBT, Considering the final setting, the capacitance C is 300μF and the inductance L is 1mH. $LC=3*10^{-7}$，Less than 0.00005 Hz.

4.1.3 Application of grid-connected transformer

The current filtered by the filter meets the grid-connected conditions, but for grid safety and the requirements of related standards, the inverter needs to be electrically isolated from the grid. The so-called electrical isolation means that the two circuits are not directly connected in the wiring. In other words, the two circuits are insulated from each other while ensuring that the two circuits maintain the relationship of energy transmission.

This design uses ordinary transformers for electrical isolation. The transformer transfers energy through electromagnetic. The primary side and the secondary side of the transformer are not electrically connected, and the two sides do not affect each other, which ensures the safety of the power grid. When the primary side of the voltage transformer is energized, an alternating magnetic flux will be generated in the iron core, and the alternating magnetic flux will generate an alternating voltage on the secondary winding, and then the energy will be consumed through the secondary side loop. This is the working principle of the transformer and the principle of electrical isolation between the primary and secondary windings.

4.2 Control strategy design of inverter circuit

The control of the inverter plays a vital role in this system. The inverter has two main functions. One is to maintain the bus voltage and realize the DC bus in a constant range. To achieve this function, the energy delivered by the front stage of the system can be output to the grid in time to achieve energy transmission balance; Second, make the voltage and current waveforms delivered to the power grid a sine wave to ensure the quality of the delivered energy and ensure that no harmonic pollution and reactive power are generated on the power grid.

When the system is connected to the grid, when the energy delivered by the front stage of the system is less than the energy of the inverter connected to the grid, the multi-grid power will reduce the DC bus voltage, and finally the bus voltage will shut down under voltage; When the delivered energy is equal to the grid-connected energy of the inverter, the DC bus voltage will be constant within a certain range to stabilize the bus voltage; when the energy delivered by the front stage of the system is greater than the grid-connected energy of the inverter, more The power will increase the DC bus voltage, and eventually the bus voltage will overvoltage and stop. For the inverter, the grid-connected voltage of the inverter should be slightly higher than the peak value of the grid voltage, but too high or too low is harmful to the system itself, too low will make the grid unsuccessful, and too high will It is harmful to the components of the inverter itself.

This system uses a direct control current control algorithm, that is, the grid-connected current is used as the control object, and the control target is that the grid-connected current is in phase with the grid voltage, forming a standard sine wave, and the power factor is 1. There are two main control modes for the inverter grid-connected current: hysteresis current control mode and fixed switching frequency current control mode. The hysteresis current control is simple and easy to implement. The fixed switching frequency control mode has the characteristics of later The filter is easy to design. This system design chooses a relatively simple current control scheme with hysteresis comparison.

4.2.1 Hysteresis current control mode

Hysteresis current control is widely used due to its simple control and high corresponding speed. The hysteresis current control plays two roles, as a negative feedback closed-loop controller to adjust the current, so that the current is output according to the set value; the other role is to form a PWM wave, which modulates the switching command. The schematic diagram of its work is shown in Figure 4.3.

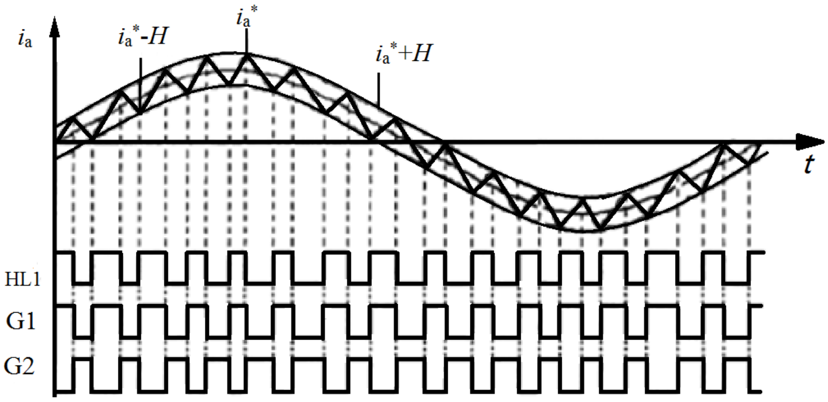

Figure 4.3: Schematic diagram of hysteresis current control

It can be seen intuitively from the above figure that the reference current signal i_a* and the actual current i_a are in an envelope, and the actual current changes with the reference current, and the variation range is ±H. By selecting different H values, different duty cycles will be obtained. Compared with the PWM wave, it also gets a different control schedule. When H is too small, the control will be too frequent, and the power device will be damaged due to too fast switching frequency; when H is too large, it will not play the role of current follow-up, the output error will become larger, and the system performance will not meet the standard.

The hysteresis current control method has a small amount of calculation and no complicated calculation process. It has the characteristics of fast response speed and high accuracy by selecting different hysteresis widths to adjust the control accuracy. In addition, since the control accuracy and switching adjustment speed are determined by the hysteresis width and will not change with the current, the stability is good.

According to the above analysis, the hysteresis width is an important parameter. After theoretical analysis and simulation tests, and at the same time according to the requirements of the actual system, when the hysteresis width is selected as 0.1A, it is most in line with the current system, so the hysteresis width is selected as: H=0.1A.

4.2.2 Voltage and current common control scheme

According to the previous analysis, the hysteresis current control is selected as the control of the inverter, and the inverter needs to stabilize the DC bus. So there are currently two control targets, both the current and the DC bus are controlled as control objects.

The purpose of hysteresis current control is to make the current integrated into the grid follow the command current, and the source of the command current is the voltage of the grid and the reference rated impedance. The control of the bus voltage is for the balance of power. When the grid-connected power is consistent with the power provided by the bus, the bus voltage will remain constant, thereby stabilizing the entire system. The grid-connected power is controlled by changing the grid-connected current. Achieve the balance of the entire system.

The specific control strategy flowchart is shown in Figure 4.4.

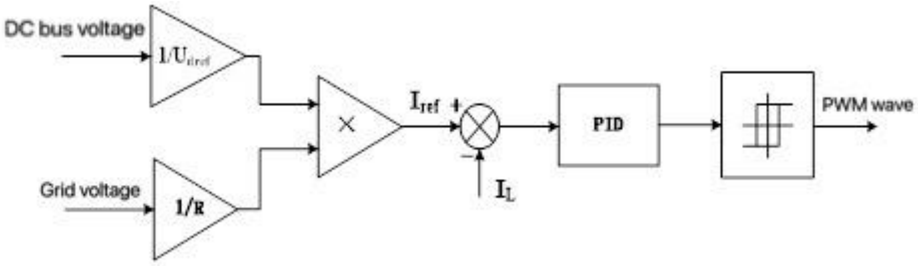

Figure 4.4: Specific control strategy of inverter grid connection

As can be seen from the above figure, the grid voltage is compared with the rated impedance, that is, the grid-connected command current. At the same time, the current bus voltage is compared with the reference voltage to obtain the gain coefficient, which reflects the change of the bus voltage, and then the two values are phased. Multiply to obtain the mixed value of the two control targets, compare it with the actual current to obtain the current control error, enter the PID control link, adjust the control signal, obtain the control signal, enter the hysteresis comparator, and obtain the PWM wave pair The power switch tube performs control, and the error value becomes the smallest, that is, the difference between the actual grid-connected current and the reference current is within the hysteresis width to realize the grid-connected system.

4.3 Overall analysis and simulation verification of the inverter circuit

4.3.1 Overall analysis of inverter circuit

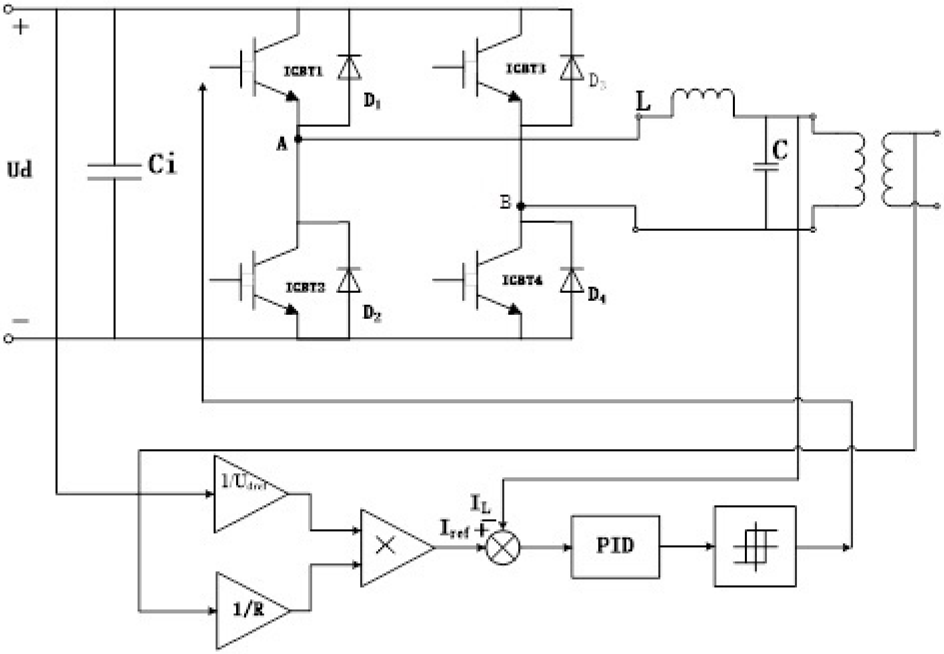

Figure 4.5: General diagram of inverter control

Figure 4.5 shows the overall circuit diagram of the system inverter, from which the relationship between the control system and the main circuit topology can be seen. Among them, Ci is a filter capacitor, which is used to filter out the fluctuation of the bus voltage. The selection principle for Ci is: if the selection is large, the change of the bus will not reflect the real power change, and it will also make the response time of the system longer; If it is small, the filtering effect of Ci will not be reflected and the effect is not obvious. In general engineering, choose 1000μF. On the grid-connected side, there is LC filtering, which has been discussed in the previous article. The transformer is used as electrical isolation, and the ratio of 1:1 is selected. The PID parameters are selected as Kp=1 and Ki=0.1.

4.3.2 Overall Simulink simulation verification of the inverter circuit

According to the above theoretical analysis, simulation verification is carried out for the selected parameters and control algorithm of this design to verify the correctness of the theory and prove the feasibility of the scheme. Use the graphical simulation tool SIMULINK in the simulation software MATLAB for simulation.

As shown in Figure 4.6, the main circuit topology of the inverter connected to the grid and the corresponding auxiliary circuit are built in MATLAB. Since the electrical isolation transformer cannot reflect the isolation effect in the simulation, the transformer is omitted. At the same time, when inverting, the stability of the bus voltage is required, so a stable voltage source is used instead of the DC bus in the simulation. The selection of the component parameters of the topology is carried out according to the previous article, and the powergui module is selected in the simulation, which can analyze the system's active power, reactive power, and current harmonics.

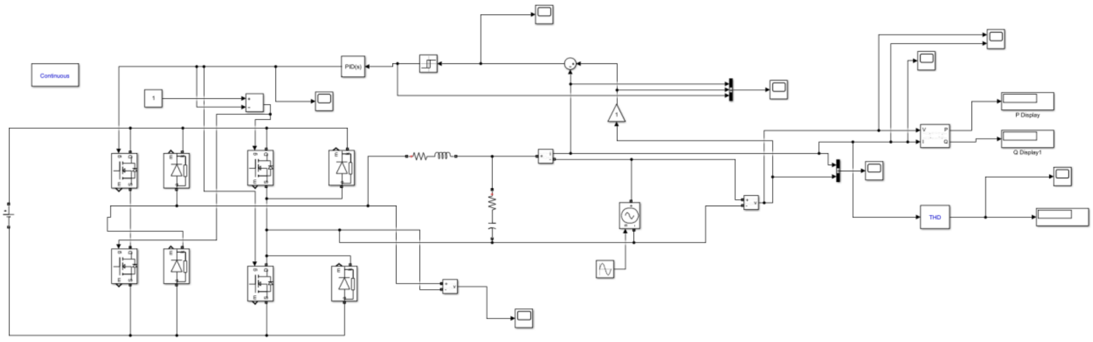

Figure 4.6: The overall simulation diagram of the inverter circuit system

After running the simulation model, the grid-connected voltage and current of the inverter are shown in the figure.

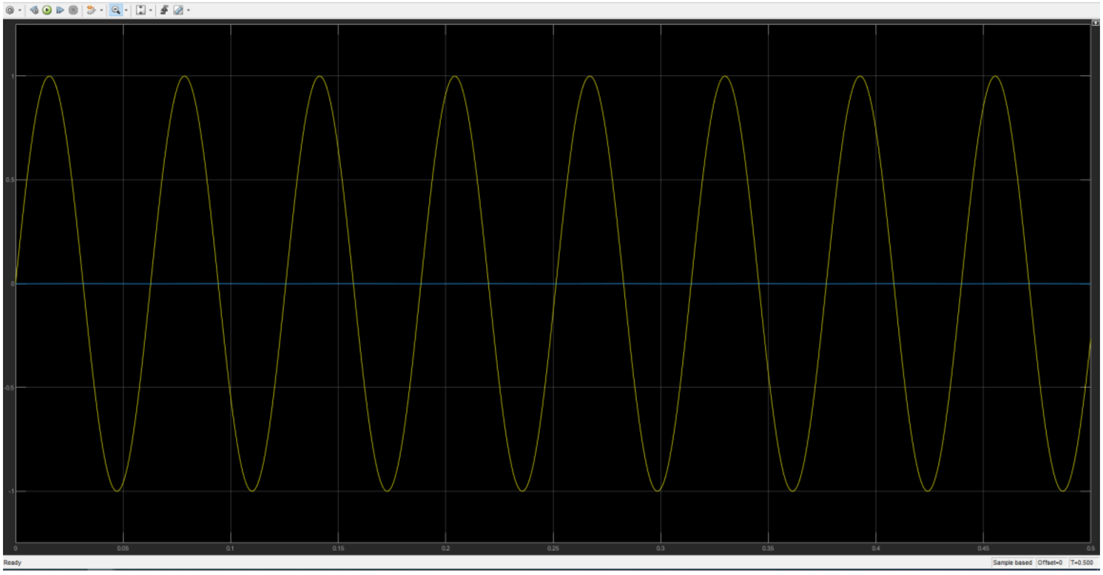

Figure 4.7: Grid voltage and grid current waveform

Since the grid current waveform is not obvious enough, a separate screenshot of the current waveform is as follows.

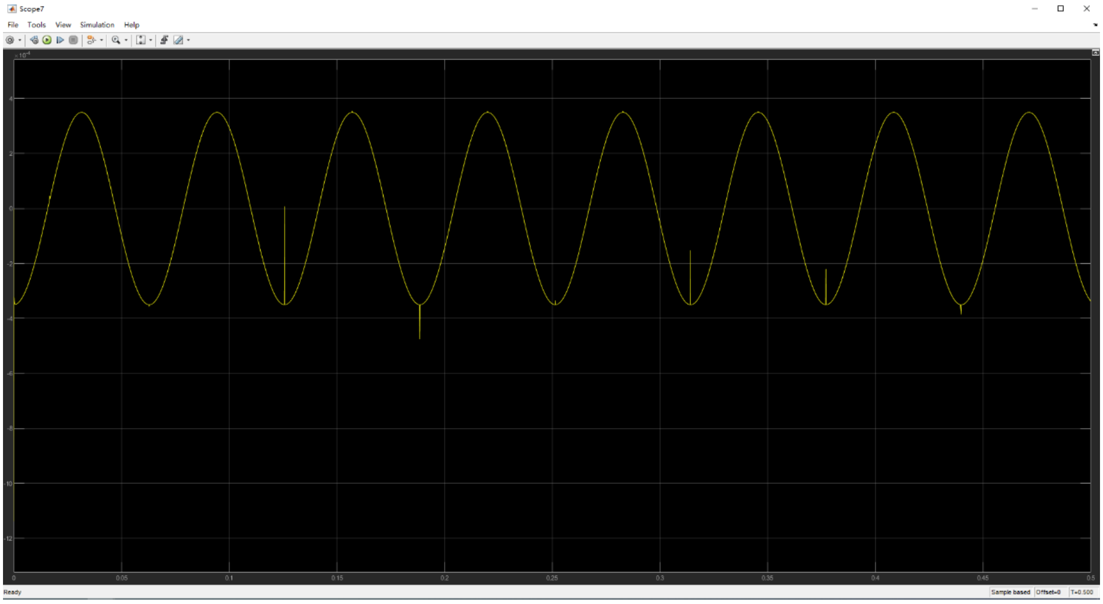

Figure 4.8: Grid current waveform

From the waveform analysis, the grid-connected voltage and current have good sine wave characteristics, which can realize the energy transmission from the grid-connected inverter to the grid.

The power factor of the grid-connected is analyzed below. The calculation formula of power factor is as follows:

$$\lambda = \frac{P}{S} \tag{4.4}$$

among them:

P---------------- active power;

S-----------------apparent power.

And the relationship among the three is:

$$S^2 = P^2 + Q^2 \tag{4.5}$$

From the above analysis, the power factor reflects the proportion of reactive power in the total power. It can be seen that the power factor can reflect the proportion of active power in the total power, and it is also a response to the phase difference between voltage and current. When it is close to 1, the overall characteristics of the circuit show impedance properties, the current and voltage are synchronized, and the reactive power is close to zero. The power factor is 1 analyzed by the tool, which meets the system requirements.

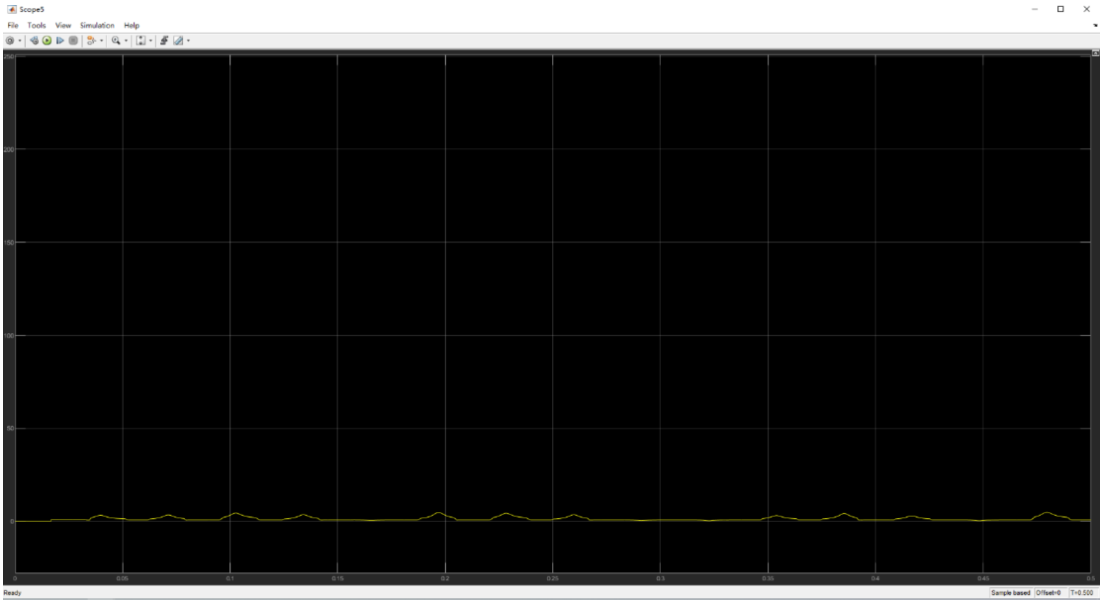

Figure 4.9: THD waveform of current harmonic total distortion rate

According to the definition of harmonics, the formula is as follows:

$$THD = \frac{I_h}{I_1} 100\% \tag{4.6}$$

among them:

I_h---------The effective value of the total harmonic current;

I_1----------The effective value of fundamental current.

Harmonic reflects the quality of the current connected to the grid. When the current waveform presents a perfect sine wave characteristic, the waveform is the fundamental waveform without other frequency waveform components. Through the harmonic analysis in the powergui tool, 50Hz is selected as the fundamental frequency, and the harmonic analysis of the current waveform is performed. As shown in Figure 4.9, the data obtained is that the total current distortion rate is maintained at about 0.01, which is in line with the system design.

4.4 Summary of this chapter

This chapter selects the parameters of the grid-connected inverter and related auxiliary circuits according to the system requirements and indicators, and explains the corresponding principles; when selecting the control algorithm, the characteristics of the hysteresis current controller and related parameters are obtained through theoretical analysis. The selection principle is analyzed, and the hysteresis control with DC bus and grid-connected current as the control object at the same time is analyzed. Finally, simulation analysis is carried out according to the above theoretical analysis, and the correctness of the selected parameters and control algorithm is verified through the simulation model. , Analyze the quality of grid connection, harmonics and power factor meet the system requirements.

CHAPTER 5

SYSTEM OVERALL ANALYSIS AND SIMULATION VERIFICATION

In the previous article, theoretical analysis and simulation experiments were carried out on the DC boost topology and grid-connected inverter, and their corresponding topologies. Both of them can meet their respective needs. This chapter will connect the two parts as a whole. Analyze and demonstrate.

5.1 Overall system analysis

The intelligent feedback load of the charging pile consists of two-stage circuits, as shown in Figure 5.1.

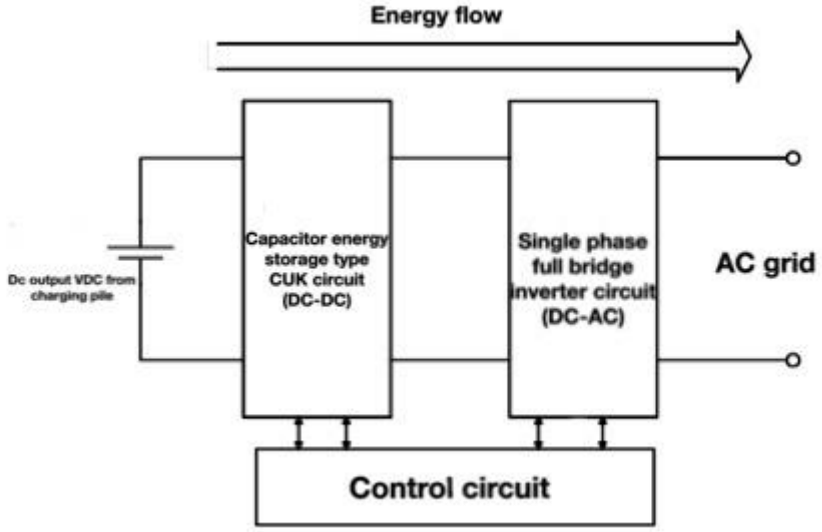

Figure 5.1: Overall block diagram of the system

The system is composed of a previous stage voltage boost part and a back stage inverter part. The energy flow direction is the direction of the measured DC load to the grid.

First analyze the DC boost circuit, as shown in Figure 5.2. According to the previous analysis, the circuit has two functions. According to the different requirements of the load, it can realize the three control modes and the switching between the modes; as the front-stage structure, it boosts the voltage of the load and realizes the grid connection for the latter stage. Make energy reserves.

Figure 5.2 shows the detailed control flow and topology of the DC boost.

According to the demand reference quantity of the control mode as the command current, command power, and command voltage, the three modes are switched and controlled by selecting the control module to generate the corresponding duty cycle to achieve the purpose of following the command.

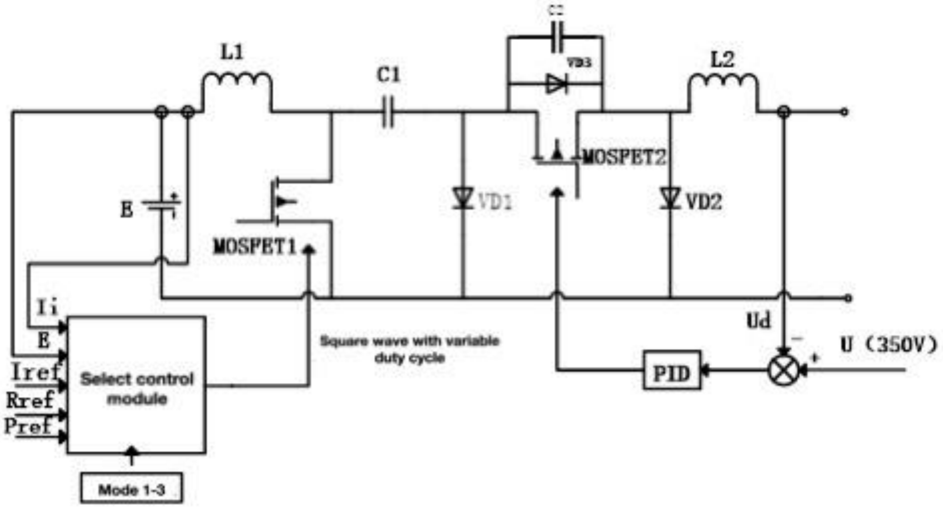

Figure 5.2: General diagram of the system's pre-stage booster circuit

In order to further explain the control of mode switching, as shown in Figure 5.3 is the structure diagram of the selection control module. The principle is: according to the mode selection, the internal automatic switching is performed, the corresponding command is calculated according to the different input terminals, and then the command is carrier wave, the PWM wave is obtained through the hysteresis comparator, and the switch tube is controlled to obtain the function of following the command.

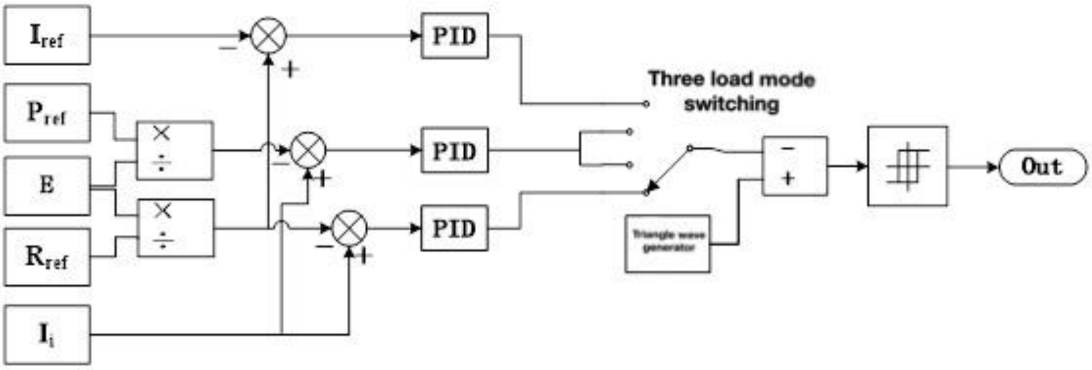

Figure 5.3: Select the internal control principle of the control module

The principle of DC boost has been explained in the previous article, and the corresponding circuit parameters have been given in the upper level and demonstrated through simulation. The connection point of the front-stage boost and the rear-stage inverter is the DC bus, so the DC boost has a vital connection with the subsequent DC bus. The output of the previous stage corresponds to the input of the subsequent inverter. In order to be successful, the bus voltage needs to be stabilized at a value higher than the grid amplitude, which is controlled by the MOS2 tube of the previous circuit and the current of the subsequent stage.

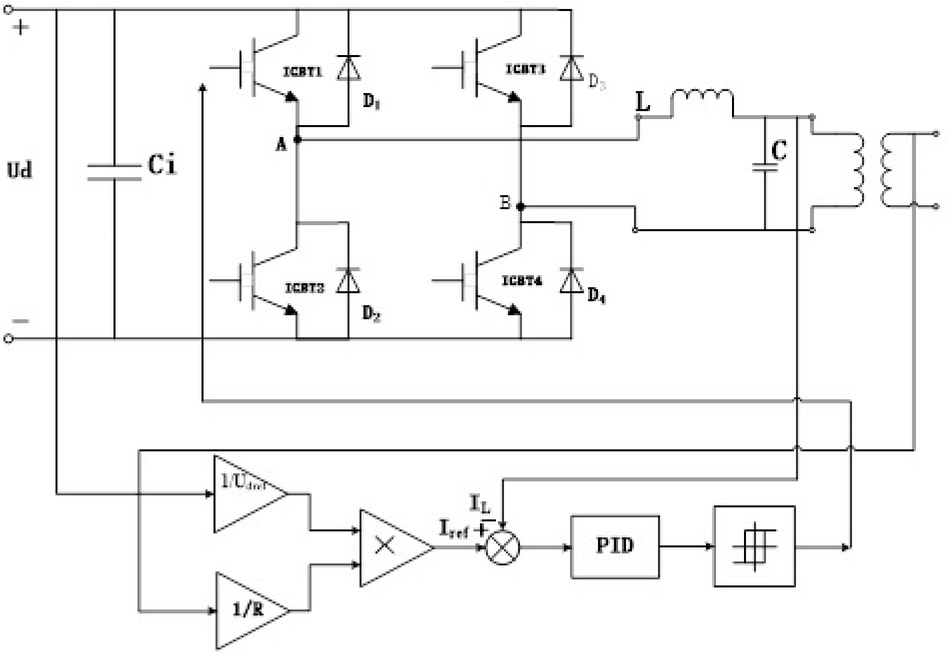

Figure 5.4: System post-control general diagram

The overall structure of the back-stage circuit inverter is shown in the figure above, and its basic control strategy has been described above. The front stage and the back stage are connected through Ud. The load collects energy to the DC bus through the boost circuit, and the inverter feeds back to the grid side through the DC bus. The energy collection and grid-connected energy need to achieve a dynamic balance. The stability of the bus bar plays a vital role.

5.2 System simulation verification

In the previous article, each module has been simulated individually, and the effect meets the system design requirements, and finally the overall system simulation is performed through the connection of each module.

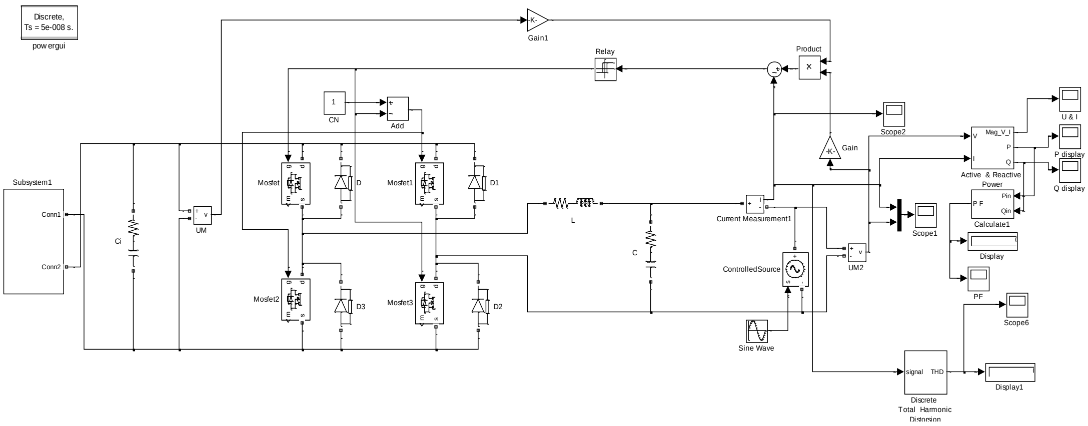

Figure 5.5: System Simulink simulation analysis overall diagram

Figure 5.5 shows the simulation diagram of the entire system. The DC boost module is packaged into sub-modules in Subsystems1, leaving only two output terminals to connect with the downstream inverter, and connect to the grid through the oscilloscope that comes with the simulation software Display of voltage and current waveforms.

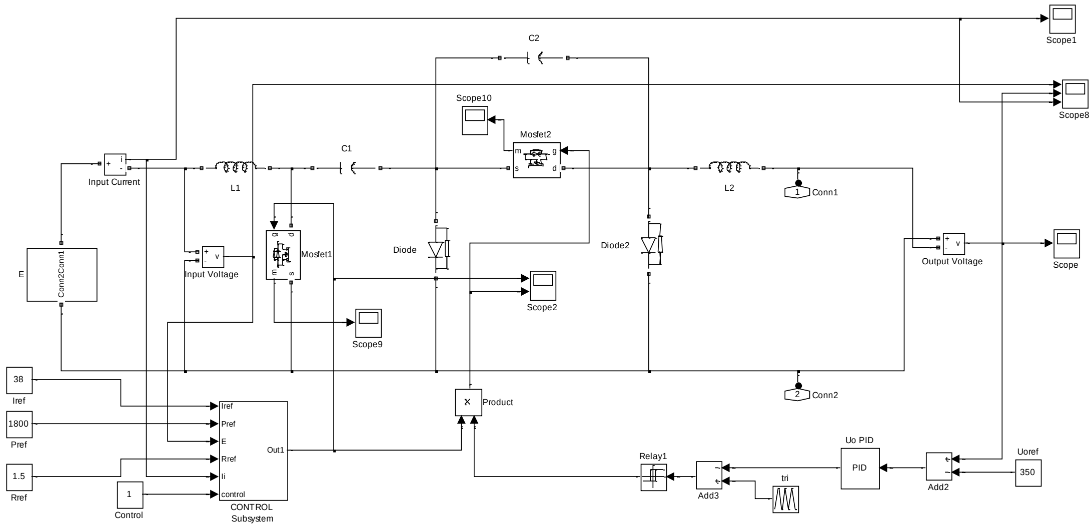

Figure 5.6: Circuit diagram of the capacitor energy storage type Cuk in the sub-module

Figure 5.6 is an expanded view of the internal structure of Subsystems1. The measured power supply is replaced by three-phase uncontrolled rectification; in the simulation, in addition to the control of the MOS2 tube based on the DC bus voltage, it also needs to consider that the duty cycle cannot be larger than that of the MOS1 tube, so a multiplication is added Controller for control. The control of different modes of load is implemented through CONTROL Subsystems. The module is encapsulated and the input and output of the module are reserved. The internal structure is shown in Figure 5.7.

The internal control has been explained in detail in the previous article, so It will not repeat it here.

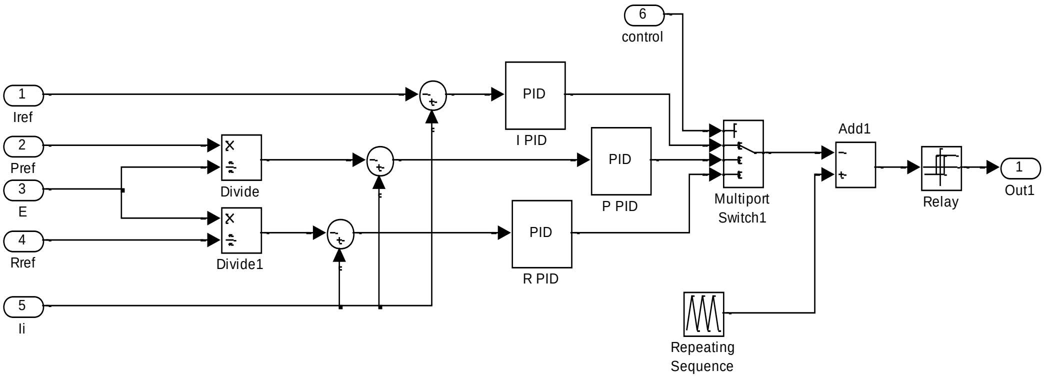

Figure 5.7: The control structure in the CONTROL Subsystems module

The above is the topological diagram of the simulation structure of the entire system. The simulation is carried out below, and the simulation results are analyzed, taking the constant current mode as an example.

Basic simulation parameters: simulation duration: 0.5s; algorithm: discrete, ode23t; simulation step: default; control cycle: 5e-8s. The topology-related parameters and PID parameters are described in Chapter 2 and Chapter 3. The device parameters not described are simulated according to the default settings:

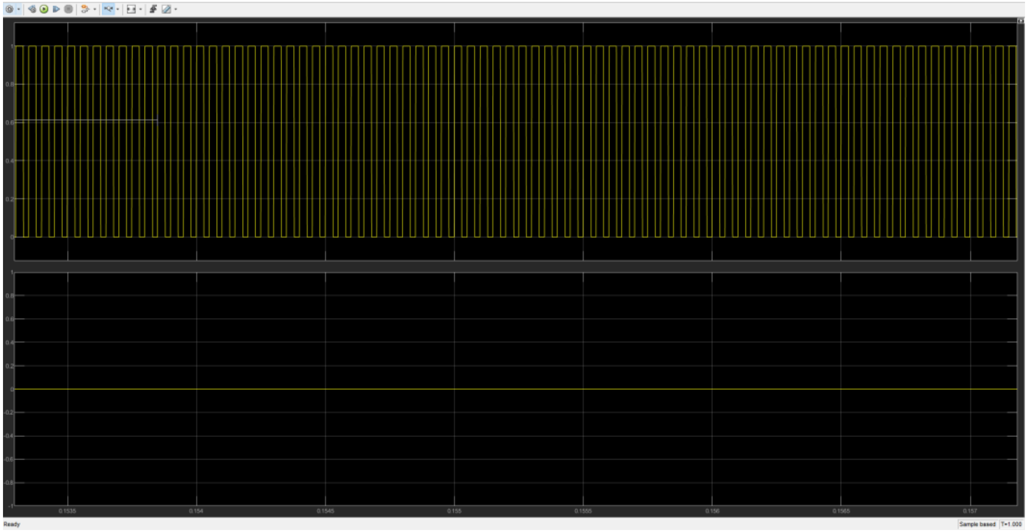

Figure 5.8: The power supply voltage of the circuit in constant current mode

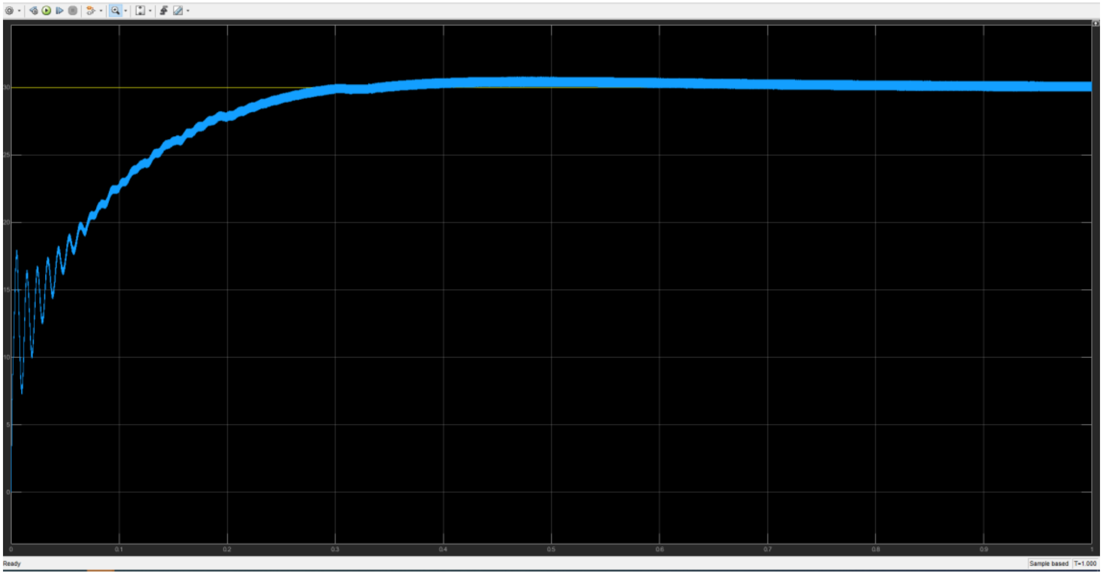

Figure 5.9: Input current of the circuit in constant voltage mode

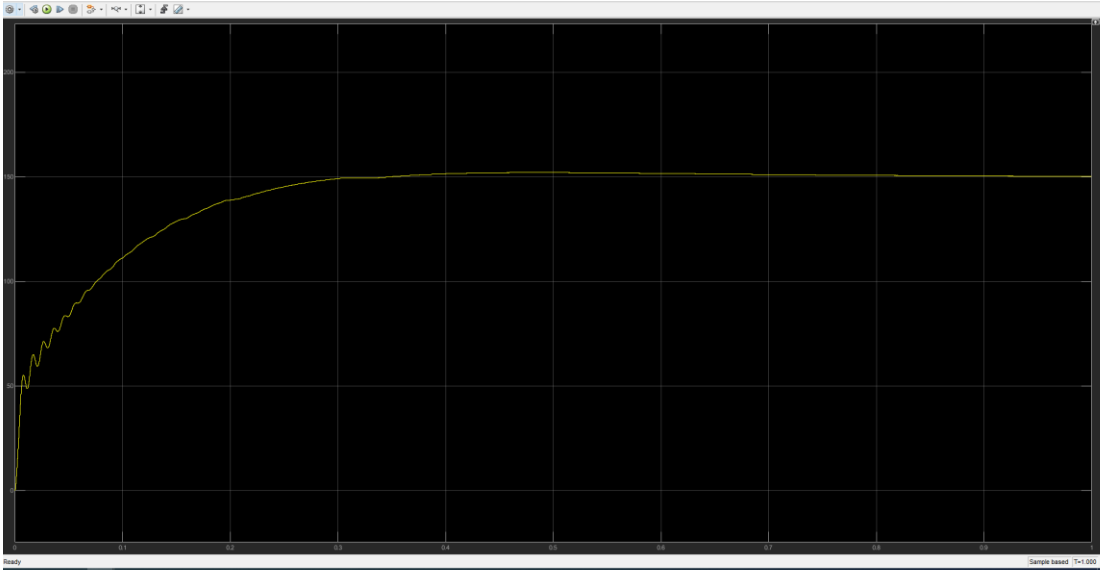

Figure 5.10: The output voltage of the circuit in constant voltage mode

Figure 5.8 is the voltage output waveform of the tested power supply, Figure 5.9 is the current waveform, and Figure 5.10 is the voltage waveform of the DC bus. It can be drawn from the figure that the voltage of the tested power supply fluctuates greatly, but the output current is very stable and meets the design requirements of the system. The disadvantage is that the DC bus has a fluctuation of about 4% during the start-up phase, and the dynamic time is longer. The current dynamic response time is longer, but it can basically meet the design requirements of the system.

Change the CONTROL setting in the CONTROL Subsystems module to switch to constant power mode for verification. The constant power mode is that the output power is a constant value. Because the calculation is more complicated and the amount of data is large, the simulation time is small, but it can still reflect the control law and control effect. The simulation waveform is as follows:

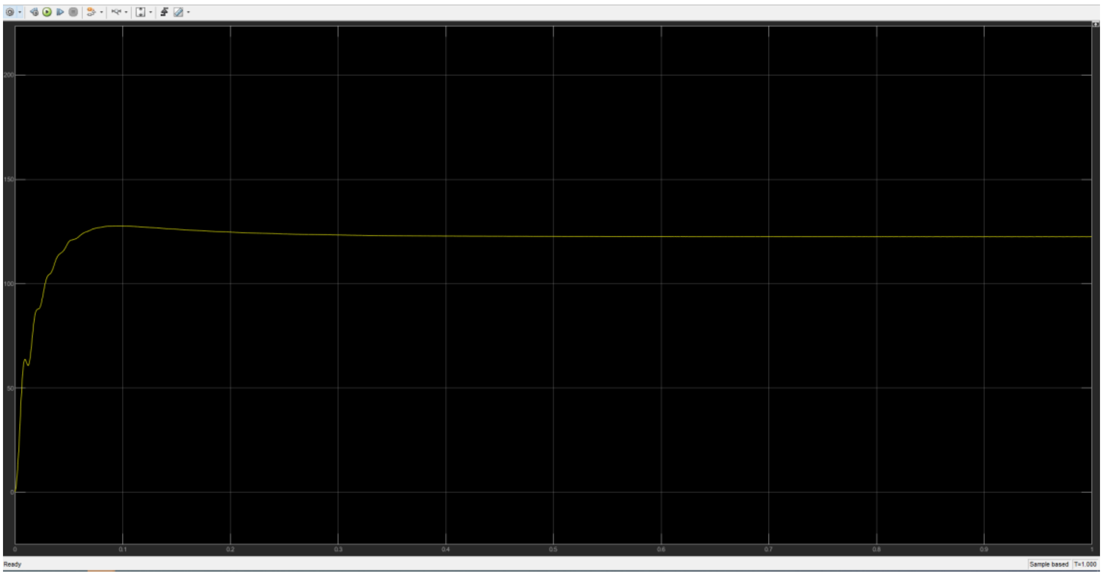

Figure 5.11: The output voltage of the circuit in constant power mode

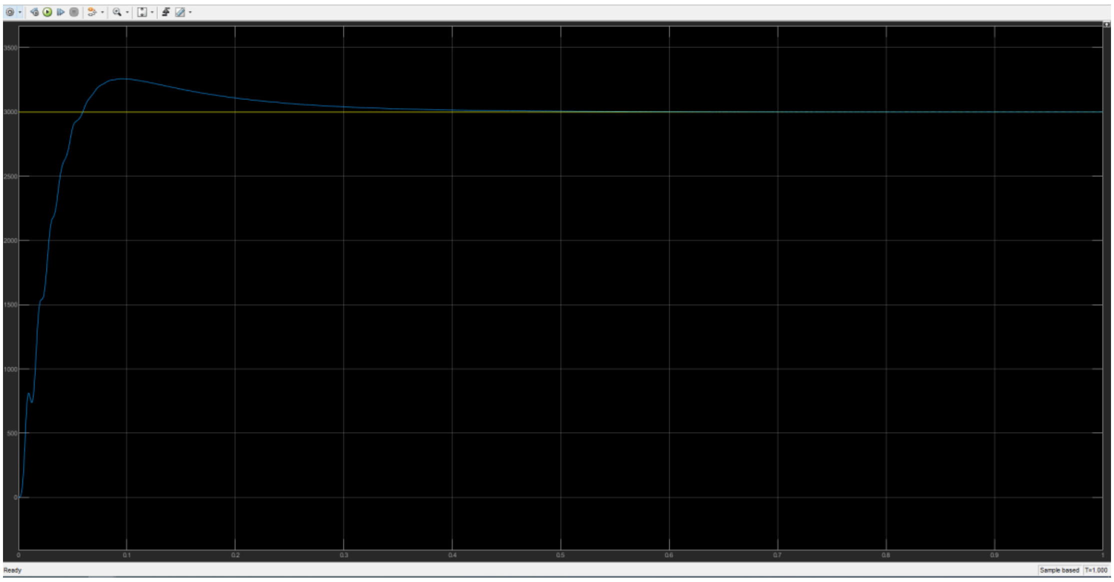

Figure 5.12: The output power of the circuit in constant power mode

It can be seen from the figure that the output power waveform is basically stable, conforms to the system control requirements, and satisfies the system error.

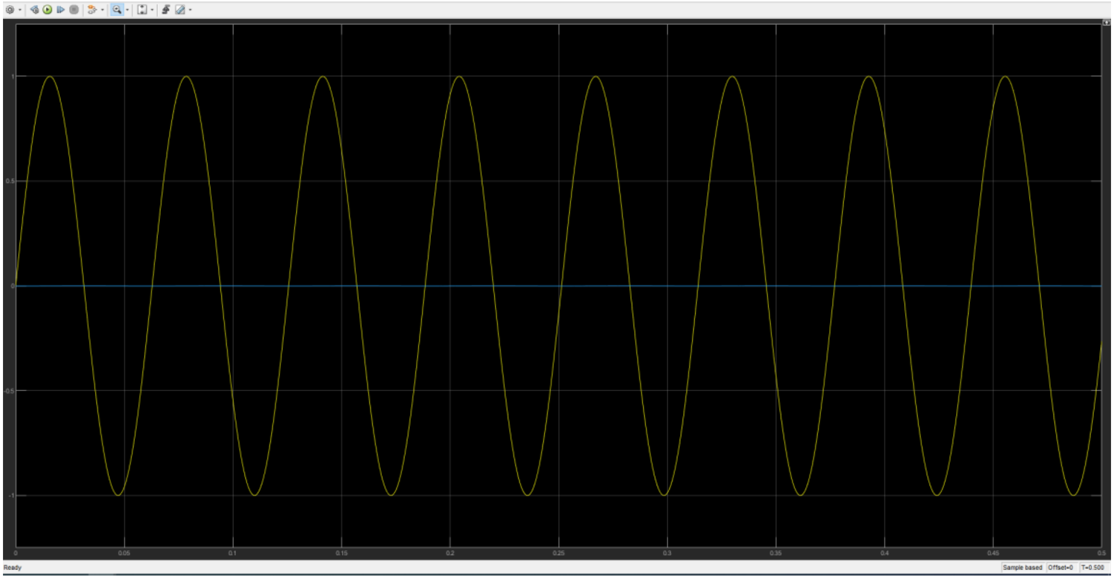

Figure 5.13: Grid-connected voltage and current waveform

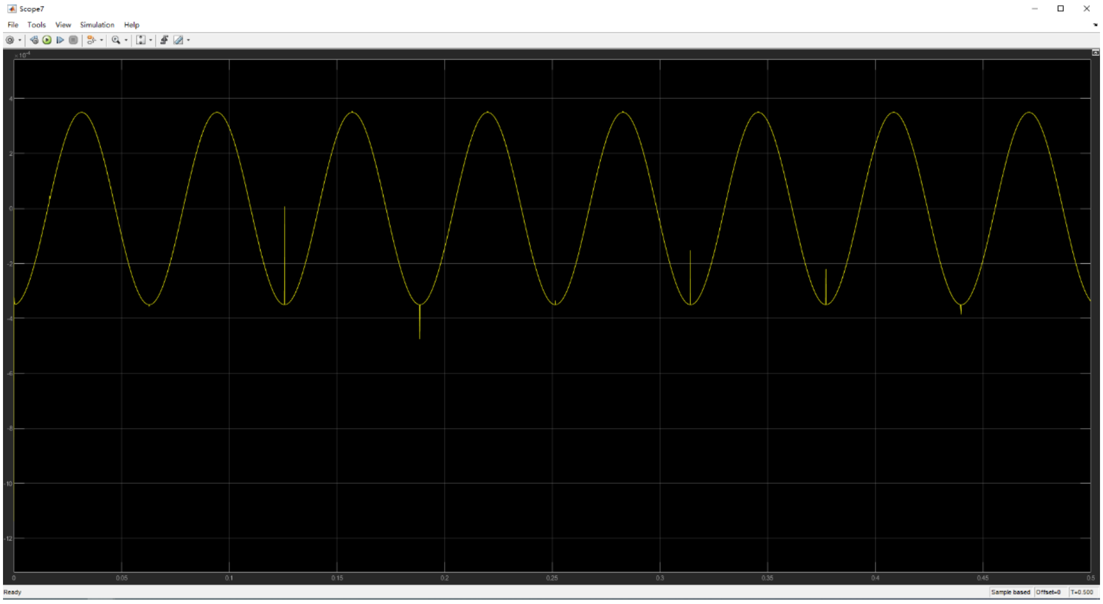

Figure 5.14: Grid-connected current waveform

It can be seen from the figure that the grid-connected current presents a very standard sine wave. Through the analysis tool that comes with the simulation software, it can be concluded that the power factor and grid harmonics meet the grid-connected requirements.

Based on the above analysis and the conclusion of the third chapter, the design of the system is verified by simulation. From the simulation waveform and effect, the design can basically meet the feedback function, and can switch three control modes to meet the basic requirements of various indicators.

5.3 Summary of this chapter

This chapter integrates the theoretical analysis and simulation of the previous chapters, connects each module, realizes the connection of the entire system, and conducts a simulation analysis of the overall system. Through the simulation waveform, it is concluded that the overall system design can meet the basic indicators.

CHAPTER 6

CONCLUSION AND DISCUSSION

6.1 Conclusion

This design is designed for the test of charging piles. The charging piles have constant voltage, constant current, and constant power operation modes. The intelligent feedback load needs to meet the output characteristics of the charging pile, so the intelligent feedback load needs to have three control modes. The design is divided into a pre-stage boost module and a post-stage inverter module. Through the analysis of the main topology circuit structure of each module, and the mainstream control method, the theoretical analysis and simulation verification of each module are carried out. The main conclusions of this design are as follows:

Through the analysis of the charging pile, the performance requirements required for the front-end DC boost are obtained, and finally the capacitive energy storage type Cuk circuit topology is selected through comparison. At the same time, according to the characteristics of the charging pile, the front-level control mode and the control algorithm are determined, and the control circuit construction and parameter selection are completed, and the selected topology and control algorithm are simulated and analyzed. It is concluded that the device parameters and control algorithm can meet the design requirements.

Through the analysis of the previous stage, the topological structure of the subsequent inverter module was determined, and the full-bridge inverter circuit and auxiliary circuits were selected, including isolation transformers, filters, etc., and the control algorithm was determined. The correctness of the selected main control circuit and device parameters is verified by simulation.

Finally, the two modules are connected as a whole for verification, and the grid-connected voltage, current, and power are specifically analyzed through waveforms. The final conclusion can achieve the basic design indicators.

6.2 Recommendations

Although this article has achieved the above results, due to the limited time, there are many areas for improvement. The details are as follows: The charging pile generally adopts three-phase four-wire system for power supply. This design is single-phase grid-connected, and the feedback load should be realized in three-phase four-wire system. Grid-connected under the wire system, this design is single-phase grid-connected; the power and voltage levels of the system design are small, which cannot fully meet the voltage range of the charging pile, and the voltage range of the feedback load needs to be expanded later; the response time of the system is long, Can not fully meet the requirements of the response time of the charging pile; at the same time, the control algorithm is not optimized enough, and the output waveform fluctuates greatly, which requires subsequent improvement; the theoretical analysis is not enough, and the simulation depth cannot reach the actual use environment. The above topics need further study and research.

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