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Simulation Design of Single-phase AC Electronic Load

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Abstract: *With the development of power electronics technology, a variety of power supplies are used in people's production and life. The characteristics of the power supply will greatly affect production and life. Therefore, it is necessary to conduct strict tests on the power supply. The traditional load has the disadvantage of consuming a lot of energy, and the AC electronic load solves the disadvantages brought by the traditional load.This paper takes single-phase AC electronic load as the research object. Based on the overall scheme design and topology research of the power electronic load system, the energy-consuming power electronic load is simulated first, the simulation model is constructed, and the main circuit is designed. Parameter, realize the load simulation function; further carry out the simulation research on the single-phase energy-fed power electronic load, the current generation unit design adopts PI+ repetitive control strategy, and the energy feedback unit adopts double closed-loop control strategy. After testing, the simulation current generation and energy are realized. The feedback function completes the overall simulation design of the single-phase AC electronic load.*

Keywords: *AC electronic load; energy feedback; repetitive control*

1. Introduction

In the era of energy shortage, researchers at home and abroad pay close attention to the aging test through the production and research of the more popular green energy-saving devices, and the aging test essentially discharges the power supply device according to the current situation specified by people [3]. Electronic load is an advanced technology. It is a combination of power electronic technology, microcomputer measurement and control technology and automatic control technology. The technology in people's lives can simulate various types of loads and various power electronic devices.

1.1 Introduction to Electronic Electronic Load

1.1.1 Definition of power electronic load

Energy-fed power electronic load, also referred to as power electronic load [2]. The power electronic load is composed of an input load analog converter and an output grid-connected converter using a PWM-controlled voltage source rectifier as the basic structure. The two converters are connected by DC support capacitors to form a back-to-back overall structure [3].

1.1.2 The development process of single-phase AC power electronic load topology

Today, with the rapid development of power electronic components, there are many new circuit topologies, which is the progress of science and technology [6]. AC electronic load, which is a device that can simulate a variety of loads. It quickly and accurately tracks the current and can feed back to the grid [3]. The following will briefly describe the development process of single-phase AC power electronic structure [3].

In the first stage, the auto-voltage regulator and inductor are connected in series between the AC power source and the large power grid [1]. American scholar Suresh Gupta[3][4] proposed UPS power aging test equipment. The equipment adjusts the magnitude of the voltage amplitude and the output reactive power [1].

In the second stage, Ayres CA[4][5] and other scholars proposed a new UPS aging test device. It is a device composed of AC/DC converter, Buck-Boost [1] converter and DC/AC converter. The UPS output current and the DC/AC converter output harmonic distortion rate are low, and the inverter current has a

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relatively high power factor, which is the advantage of the proposed circuit [4].

The third stage, after 2000, in the context of the development of control theory and strategy, the continuous improvement of basic devices in the field of power electronics, and the continuous maturity and improvement of digital control technology, Taiwan scholar Huang SJ[5] first Proposed a further AC/DC/AC topology device [5]. This kind of simulation device has a simple and easy-to-understand structure and flexible and feasible control .

The main circuit topology of the universal energy-fed electronic load is mainly dual PWM converters. The front-end load simulation unit of the main circuit topology of the single-phase energy-fed electronic load is responsible for realizing the function of simulating the load, controlling the current on the inductor, and connecting the latter to the grid. The inverter unit is responsible for realizing the grid connection of the power factor.

1.2 Control of Power Electronic Load

1.2.1 Control strategy of power electronic load

The electronic load can adopt a variety of control strategies in various application situations. The key to control is current control, and the performance of the entire system is directly affected by the dynamic performance of current control.

There are a variety of VSR control strategies. Whether to introduce current feedback is divided into indirect current control and direct current control [5].

Direct current control controls the stability of the DC bus voltage . This control strategy has good dynamic performance and compensates for errors caused by system parameter changes.

1.2.2 Control method of power electronic load

At present, the commonly used control methods include classical proportional integral control, hysteresis current control, predictive control, repetitive control, and parabolic current control.

Repetitive control is a relatively common control system, which realizes the non-static control of the output by the control system [7]. The PI control algorithm is simple. Qi Yan adopts direct current control strategy and PI+ repetitive control algorithm in the control of current generating unit. The response speed of repetitive control is slow [9].

2. Analysis of Working Principle of Power Electronic Load

In order to accurately control the amplitude and phase of the input current, on the input side of the AC electronic load, the power supply under test is presented as a load characteristic; this article explains the structural design of the energy-fed electronic load, and explains the electronic load simulation side and The principle of operation on the grid-connected inverter side.

2.1 Overall Scheme Design of Power Electronic Load System

1) Simulate the load unit circuit to simulate various loads and test the performance of the power supply.

2) The energy feedback unit circuit realizes the electric energy feeding network. The control quantity can be represented by the DC bus voltage and grid-connected current, and the front-end electric energy is fed back to the grid through the reactor, thus achieving energy saving.

2.2 Topological Structure of Power Electronic Load

The main circuit topology is shown in Fig.1, which controls the input current i1, output current i2 and bus voltage Udc to achieve the function of power electronic load. Among them: the load simulation under various conditions is achieved by controlling the input current i1.

S11~S14 are the main switching devices of the load analog converter, L1 is the input inductance, and r1 is the parasitic resistance of the input converter. It takes into account the damping effect caused by the wire itself and the connection joint, the switch conduction loss and the dead zone effect, etc. Effective resistance, S21~S24 are used as the main switching devices of the grid-connected converter, and L2 is used as the output inductor of the grid-connected converter. Same as above, r2 is the parasitic resistance of the grid-connected converter.

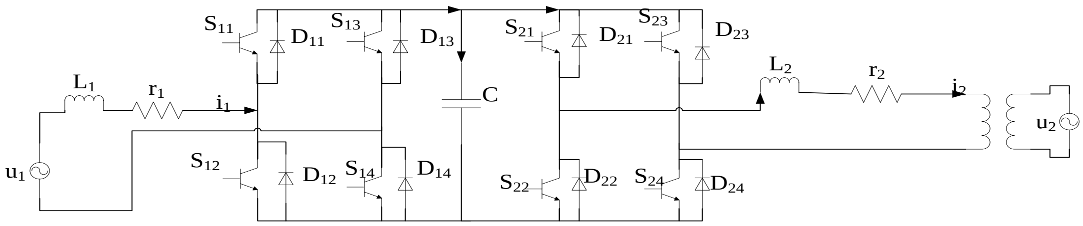

Fig.1 Topological structure of the main circuit

3. Main Circuit Parameter Design and Simulation Study of Energy-consuming Electronic Load

This article mainly studies the single-phase energy consumption AC electronic load. According to the technical standards of the energy-feeding electronic load, the design method of inductance parameters and filtering parameters are analyzed. And this chapter simulates energy-consuming electronic loads.

3.1 Design of AC Side Inductance

The role of inductance in this system is as follows:

(1) The power supply voltage is isolated from the AC side voltage;

(2) To achieve the purpose of adjusting the power factor;

(3) Eliminate the influence of PWM harmonic current on the AC side.

3.2 Design of DC Energy Storage Capacitor

The most important thing in the structure of the entire power electronic load is the capacitor on the DC side, which can carry out energy transmission and energy storage. The specific effects are as follows:

(1) It acts as a buffer and balances the energy exchange between the two parts ;

(2) Stabilize the DC bus voltage to make the system work in a normal state;

(3) The large-capacity capacitor eliminates the control of the front and rear stages and prevents voltage fluctuations caused by changes.

On the other hand, considering the instantaneous energy relationship, the following formula can be realized:

$$P_1 - P_2 = U_{dc} i_{dc} = \frac{1}{2} C \frac{dU_{dc}^2}{dt} \tag{1}$$

$$U_{dc}^2 = U_{dco}^2 + \frac{2}{C}\int (P_1 - P_2)dt = U_{dco} + \frac{2}{C}\int (u_1 i_1 - u_2 i_2)dt \tag{2}$$

Among them, Udc0 represents the stable value of the bus voltage, and the above formula can be extended to obtain the following formula:

$$\begin{aligned} U_{dc}^2 = U_{ds}^2 + \frac{2}{C}[(U_1 I_1 \cos\varphi - U_2 I_2)t - \\ \frac{1}{2\omega_1} U_1 I_1 \sin(2\omega_1 t + \varphi) + \frac{1}{2\omega_2} U_2 I_2 \sin(2\omega_2 t + 2\theta)] \end{aligned} \tag{3}$$

In steady-state operation, the active power reaches equilibrium, and the following formula can be obtained:

$$U_{dc}^2 = U_{dcc}^2 - \frac{1}{2\omega_1 C} U_1 I_1 \sin(2\omega_1 t + \varphi) + \frac{1}{2\omega_2 C} U_2 I_2 \sin(2\omega_2 t + 2\theta) \tag{4}$$

Write it as and then expand it to the Taylor series, ignoring the infinitesimal quantity to get the

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following:

$$U_{ds} = U_{d0}\sqrt{1+\xi} = U_{dc0} + \frac{1}{2}\xi U_{dc0} + \Delta U_{dc} \tag{5}$$

$$\Delta U_{dc} = \frac{1}{2}\xi U_{dco} = \frac{1}{CU_{dco}}\left[-\frac{1}{2\omega_1}U_1 I_1 \sin(2\omega t + \varphi) + \frac{1}{2\omega_2}U_2 I_2 \sin(2\omega_2 t + 2\theta)\right] \tag{6}$$

Maximum pulsation of ΔUdc:

$$\Delta U_{dc} = \frac{1}{2}\xi U_{dc0} = \frac{1}{CU_{dc0}}\left[\frac{1}{2\omega_1}U_1 I_1 + \frac{1}{2\omega_2}U_2 I_2\right] \tag{7}$$

According to the above formula, the lower limit of the capacitance value:

$$C = \frac{U_1 I_1 + U_2 I_2}{2\omega \Delta U_{dem}} \geq \frac{U_1 I_1 + U_2 I_2}{\omega \times 10\% \times U_{dro}^2} = 1094\,(\mu F) \tag{8}$$

When considering the selection of the capacitance value, it should be considered that the response speed of the current loop is affected by the capacitance value, and the capacitance value should be appropriately smaller. However, when the system is working in a stable state, the voltage fluctuation cannot be large, and a stable state must be maintained, and this value is higher than the voltage peak value, and the capacitance cannot be too small. Take the capacitance C=2200μF.

3.3 Simulation Research of Energy-consuming Power Electronic Load

3.3.1 Establishment of simulation model

In classic PI current control, the inductor current is the feedback signal of the current inner loop. Compare the output with the carrier. It controls the current average value to track the current command value. The functions of each calibration link of the PI controller are as follows:

Integration link: The main function is to eliminate static differences. The integral intensity is determined by the integral constant. The smaller the overshoot of the closed-loop system, the slower the response speed of the system .

In the practice of the control system, PI controllers are mostly used to improve and improve the steady-state performance of the control system. Therefore, in this paper, the MATLAB simulation adopts the PI control method for simulation.

(1) Modeling of single-phase PWM rectifier control loop

According to the previous theoretical analysis and research, the simulation operation of the system is carried out below, and the simulation model shown in Fig.2 is obtained by using MATLAB simulation software:

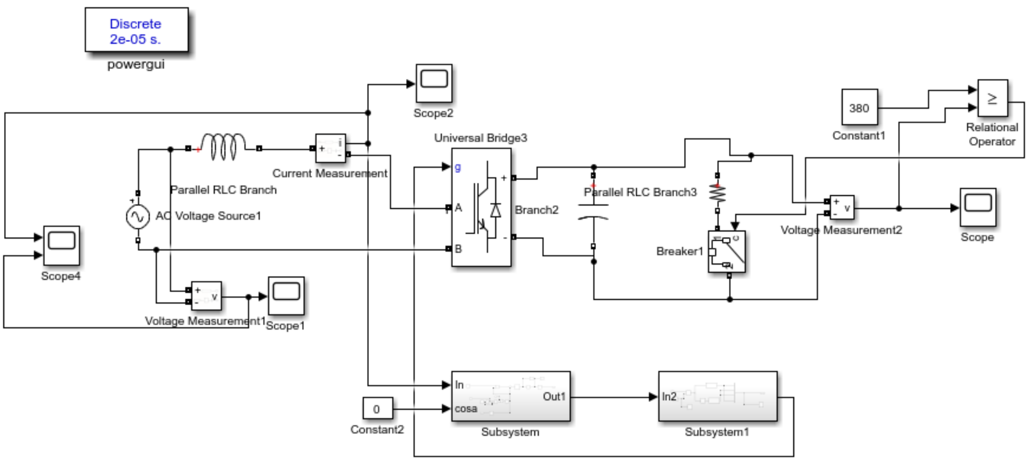

Fig.2 MATLAB simulation model

(2) Control simulation model

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The internal structure of the control system (Subsystem) is shown in Fig. 3.

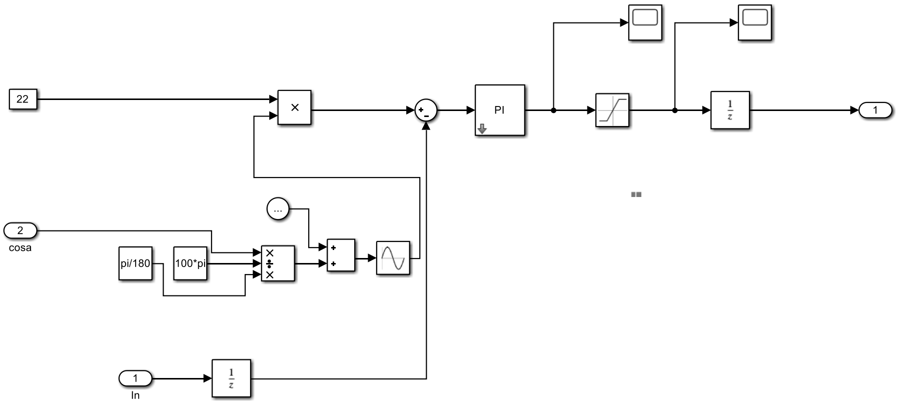

Fig.3 Control system module

(3) PWM generation module model

The internal structure diagram of the PWM generation module is shown in Fig.4 below. The required square wave is selected by synthesizing and comparing the carrier triangle wave signal with a certain frequency and the standard sine signal generated by the control system in the adjustment circuit of the modulation wave.

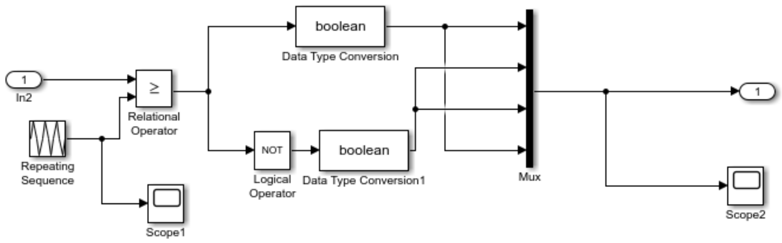

Fig.4 Control system module

3.3.2 Analysis of simulation results

(1) R=10Ω, Un=220V, In=22A. In Fig.5, the current on the input AC side is a standard sine wave, and the voltage on the AC side is in phase.

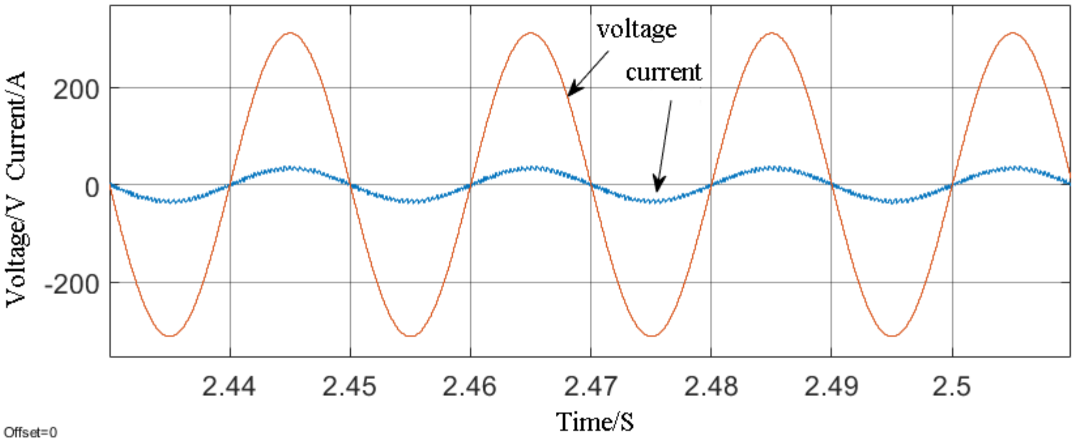

Fig.5 The voltage and current waveforms on the input AC side

R=5Ω, Un=220V, In=44A. In Fig.6, the current on the input AC side is a standard sine wave, and the voltage on the AC side is in phase.

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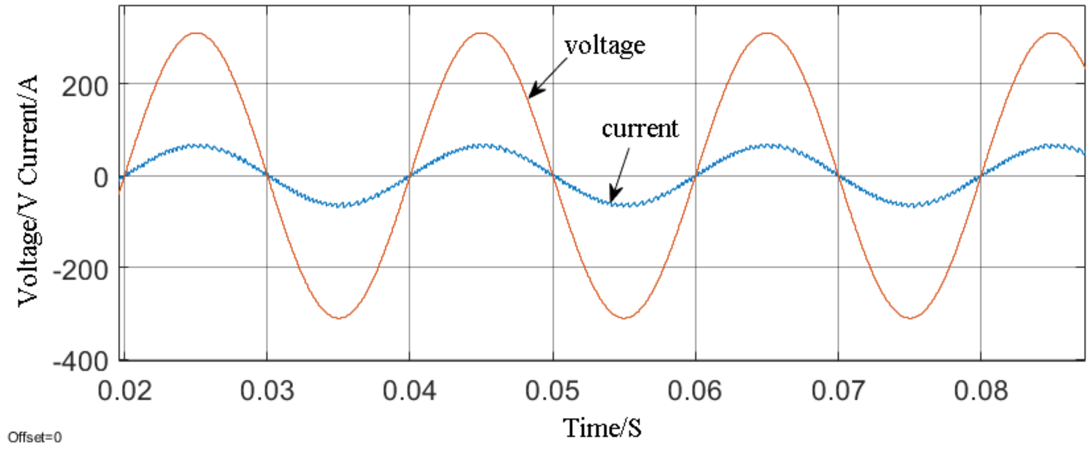

Fig.6 The voltage and current waveforms on the input AC side

(2) The output load is a resistive load:

φ=30°, λ=0.866, R=1.73Ω L=3.18mH. Fig.7 shows the simulation results. The current on the input AC side is a standard sine wave, which lags behind the voltage on the AC side.

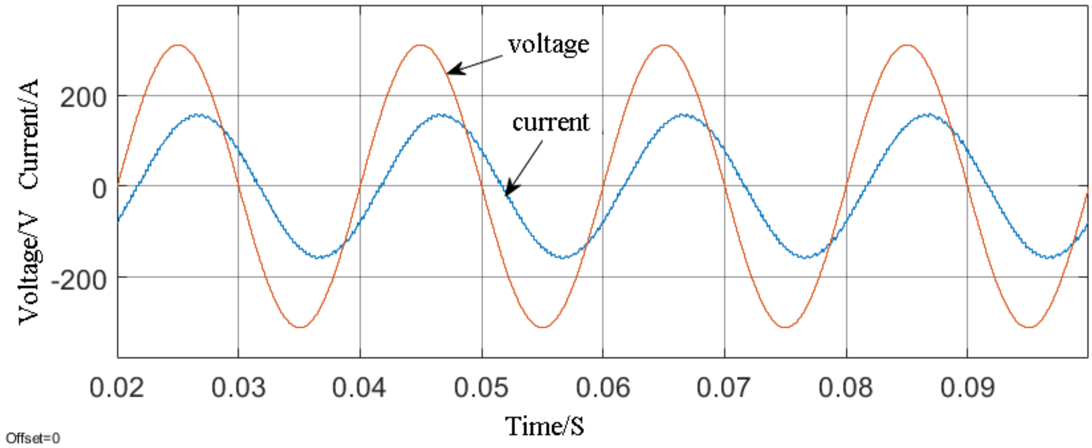

Fig.7 The voltage and current waveforms on the input AC side

φ=45°, λ=0.5, R=1.41Ω L=4.50mH. Fig.8 shows the simulation results. The current on the input AC side is a standard sine wave, which lags behind the voltage on the AC side.

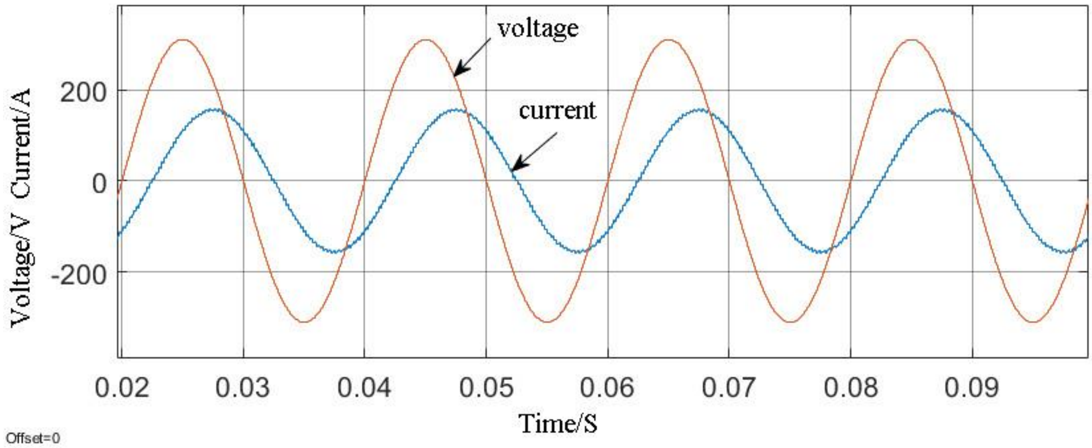

Fig.8 The voltage and current waveforms on the input AC side

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4. Summary

With the rapid development of power electronic technology design, traditional power supply testing methods consume a lot of energy. Based on the related literature of electronic load, this paper focuses on the simulation and experimental research on the design and control of single-phase AC electronic load. The main conclusions are as follows:

(1) Utilizing the characteristics that the rectifier can fully control the current and can operate in four quadrants, the general-purpose energy-feeding electronic load uses a dual PWM converter as the main circuit topology.

(2) Closed-loop control is performed on the AC side current of the energy-consuming load analog converter, and the PI control strategy is adopted to enable the load analog converter to simulate real typical pure resistive loads and resistive inductive loads.

(3) The “PI+repeat” regulator is used to design the AC side current closed-loop control system of the pre-load analog converter of the energy-fed system, which can simulate the real typical linear load and compare it with the output waveform under the PI control strategy.

(4) The design of the double closed loop control system of the DC bus voltage outer loop and the inner loop of the feeder current is carried out on the downstream energy feedback unit of the system. The proportional regulator is used to design the inner loop of the feeder current and the PI regulator is used to The external loop of the DC bus voltage in the middle of the system is designed.

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