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Research on Simulation System of Microgrids based on STM32

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Abstract

With the gradual depletion of traditional fossil energy and the increasing demand for electricity, finding new energy sources has become the only way for sustainable development. Microgrid is becoming an important auxiliary power for some developed and developing countries to solve the supply problem of energy system, which can not only effectively improve the overall utilization rate of renewable energy, but also improve the power supply reliability of the main grid. In this paper, the hardware circuit and software control of microgrid simulation system based on STM32 are studied and designed. The main circuit design of microgrid simulation system is based on STM32 single chip microcomputer as the main control core, and the pulse modulation signal SPWM is output through the software program of STM32F103CBT6 single chip microcomputer. The MOS driving circuit provides driving voltage and control signal to drive the inverter bridge to invert DC into AC. The inverter bridge is modulated by SPWM control technology, and the high-frequency signal in AC is filtered by low-pass filtering circuit, and finally the stable AC with a fixed frequency of 50 Hz is the output. By calculating the device parameters of the main control circuit and the full-bridge inverter circuit in the hardware unit circuit, and making appropriate selection of components, the specific model is determined, and finally the circuit design of the whole circuit is completed. The hardware circuit is designed rationally by Altium designer, and the software circuit is programmed by Keil. The influence of SPWM signal output by the circuit on the resistance load and its output waveform is analyzed comprehensively, and the influence of working frequency on the output waveform of the circuit is studied.

Keywords: Microgrid, STM32, Inverter, Full bridge inverter

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1. Introduction

Today, with the rapid development of society, energy consumption is also increasing, and the construction of smart grid will take some time. Facing the great challenge of power grid development and the growing demand for freight, the power supply of traditional large-scale power plants is decreasing day by day, and these natural fluctuations have led to the pressure of power grid on power supply [1-2].

In order to solve the defects of traditional energy network, microgrid was invented. Microgrid is a single system composed of small energy, energy storage elements, control elements and charges, and it is also one of the effective ways to transform from traditional energy network to smart grid, which effectively improves the utilization efficiency of renewable energy, and can also be used as an effective supplementary energy network to improve the reliability of energy supply. Until today, microgrid is gradually becoming an important auxiliary power for some developed and developing countries to solve the supply problem of energy systems, which can not only effectively improve the overall utilization rate of renewable energy, but also serve as an effective supplementary energy network to improve the power supply reliability of the main energy network [3].

In recent years, the global temperature has increased year by year and the rainfall has decreased, which has led to forest fires in almost all states in the southeast coastal areas, Tasmania, Western Australia, and Northeast China, and almost all states have experienced forest fires. In fact, environmentalists have already paid attention to the reserves of non-renewable energy, such as the destruction of surface soil by coal and oil and the accelerated melting of glaciers by greenhouse gases [4-5]. Therefore, nuclear energy, solar energy and other clean energy sources have begun to attract people's extensive attention, solar panels have gradually appeared in front of the public, and windmill power supply equipment has also been distributed one after another. However, in the early days, these distributed power supply devices were small in capacity, low in stability and low in power quality. Since the United States proposed to incorporate all micro-network concepts into DG in the 1990s, the potential benefits of DG were gradually recognized [6-7].

In this paper, the unit circuit of microgrid simulation system with STM32 single chip microcomputer as the core is deeply studied

2. Overall scheme design of the system

2.1 System composition block diagram

The main control chip of the control circuit is STM32F103CBT6. The chip has the functions of liquid crystal display and key adjustment, and has the advantages of high performance, low cost, and low energy consumption. The MOS driving circuit chip is UCC21520DW. The chip has first-order transmission delay and pulse width distortion, and provides driving voltage and control signal to drive the inverter bridge to invert DC into AC. The single-phase full-bridge inverter circuit chooses IRF540N, which has excellent technical indexes in voltage resistance, frequency characteristics and power loss. When the inverter is connected to the grid, it will introduce harmonic components that will affect the operation of the circuit, which will distort the waveform of the inverter output, so LC filter circuit is selected to filter out the harmonic components in the output signal.

The detection circuit takes ZMCT103C and ZMCT101B as the core and uses LM324 to measure the effective values of AC voltage and current at the output end. The display circuit adopts LCD1602, which can display the collected voltage, current and frequency at the same time, and occupy less pins of the control chip. The key circuit is used to control the operation of the microgrid simulation system, so as to complete the measurement of the output AC signal. The auxiliary power supply circuit control chip selects EUP3482ADIR1. The output voltage of the chip ranges from 0.923 V~20 V to 20 V, and it can output current 2A. The output type can be adjusted, and it can be rectified synchronously. Simple switch control is built without loop compensation.

The structural block diagram of microgrid simulation system is shown in Figure 1.

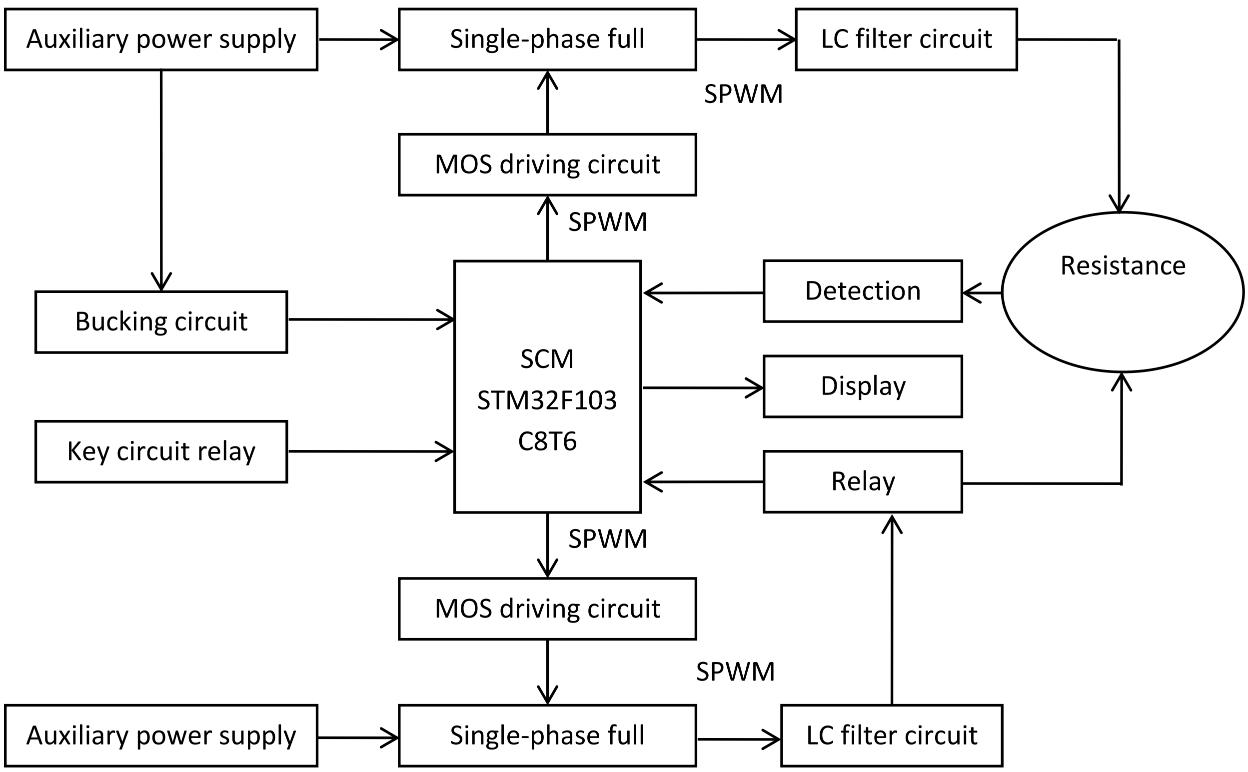

Figure 1. Block Diagram of the System Structure

2.2 System hardware circuit design

The pulse modulation signal SPWM is output by the software program of STM32F103CBT6 single chip microcomputer, and the driving voltage and control signal are provided by MOS driving circuit to drive the inverter bridge to invert DC into AC. The inverter bridge is modulated by SPWM control technology, and the high-frequency signal in AC is filtered by low-pass filtering circuit. Finally, the whole system is displayed on LCD screen. As the control core of the whole system, the main control circuit plays a key role in coordinating hardware and hardware work. The system has control function, which can automatically control and adjust the whole system, so that the hardware can run in the order required by software design.

2.2.1 Design of Single Chip Microcomputer Control Circuit

The core control circuit takes STM32F103CBT6 chip as the core, and the +5 V can be converted into +3.3 V to supply power to the single chip microcomputer through the regulated power supply chip EUP3482ADIR1. The reset circuit consists of resistor R16=10 KΩ, capacitor C6=0.1 μF and independent key S1, and its low-level reset time t = T=10 KΩ×0.1 uF=1 ms. Because the NRST pin remains low for more than 1ms, the single chip microcomputer can be effectively restarted.

The clock circuit is composed of 8 MHz high-speed crystal oscillator and 22 pF capacitor, which is multiplied to 72 MHz by the frequency multiplier inside the chip, and then generates SPWM signal with high precision, low distortion, and low harmonic. Capacitors C4 and C5 can fine-tune the frequency, and at the same time, a 22 μF capacitor is connected near the power supply terminal, which plays a role in filtering, reducing ripple interference and improving stability [8]. The schematic diagram of single chip microcomputer control circuit is shown in Figure 2.

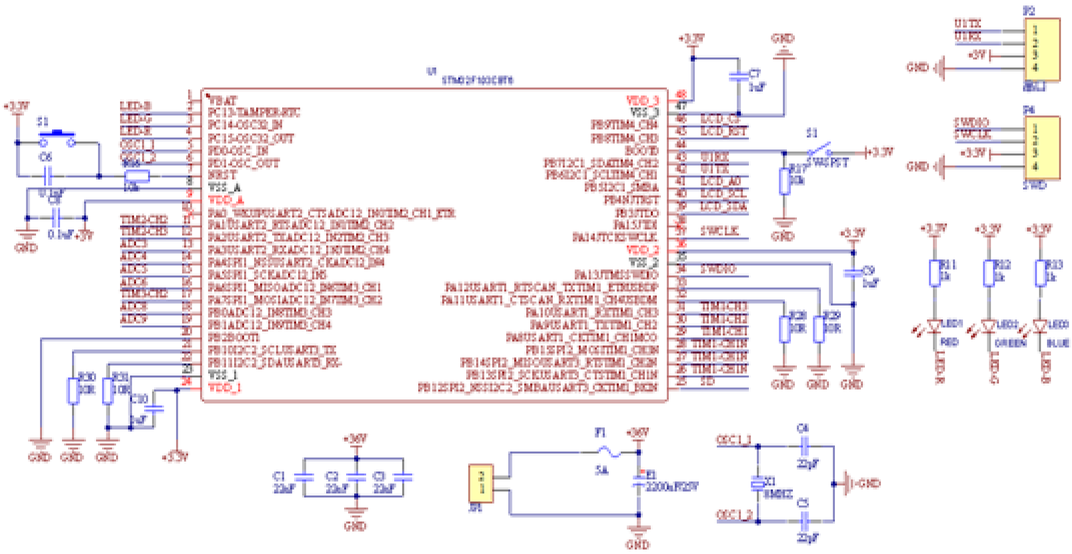

Figure 2. Schematic diagram of single chip microcomputer control circuit

2.2.2 Design of MOS driving circuit

MOS driving circuit chip is UCC21520DW, which is used to drive 5 MHz MOSFET and convert DC into AC with good transmission delay and pulse width distortion. The input end of the circuit is connected to the single chip microcomputer and powered by +3.3 V power supply, while the output end is connected to the inverter circuit and powered by +15 V power supply. 6-pin DT terminal capacitor has strong anti-interference ability. Pins 1 and 2 are the high input and low input of SPWM signal respectively, and pins 15 and 11 are the high output and low output of SPWM signal respectively [9].

There is a driving resistor between the gate and the transistor, according to the formula:

$$2\frac{\sqrt{LC}}{C} < R_g \quad (1)$$

It is calculated that Rg=10 Ω.

C47 is the source capacitance of the transistor gate, according to the formula:

$$C > \frac{2Q_g}{(V_{CC} - 10 - 1.5)} \quad (2)$$

According to the data sheet, Qg is 30 nC and VCC is +15 V. Therefore, C>0.17 uF, where C=0.22 uF. The schematic diagram of MOS drive circuit is shown in Figure 3.

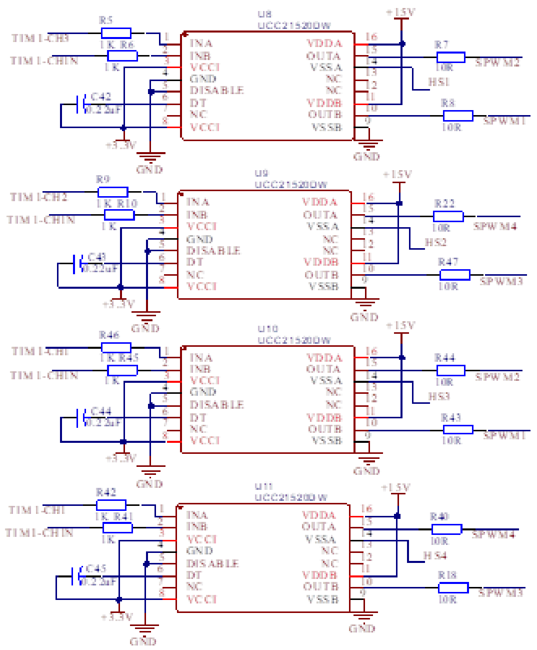

Figure 3. Schematic diagram of MOS drive circuit

2.2.3 Design of single-phase full-bridge inverter circuit

The core chip of the circuit is IRF540N. Compared with other transistors, IRF540N has excellent technical indexes in terms of withstand voltage, frequency characteristics and power loss. During normal operation, the MOS driving circuit provides driving voltage and control signal to drive the inverter bridge to invert DC into AC, and the two switches in the same phase conduct alternately, thus realizing 180 conduction mode. After the power supply is turned on, each transistor in the circuit is turned on once every 60 and turned off after 180. In addition, in order to avoid circuit damage caused by two transistors conducting at the same time, a short dead time is established between the two transistors [9].

When the inverter is connected to the power grid, harmonic components will be introduced into the large power grid, which will lead to waveform distortion of the inverter output. Therefore, LC filter circuit is selected to filter out the harmonic components in the output voltage. In order to make the filtered output waveform closer to sine wave, it is necessary to reduce not only the lower harmonics in the reverse output voltage that are higher than the cutoff frequency, but also the cutoff frequency that is lower than the lowest harmonic frequency in the SPWM output voltage. Therefore, the filter inductance L2 is 1 mH and the filter capacitor C11 is 2.2 uF.

Design of filter inductor: The ripple of inductor current is taken as 0.2 of the average inductor current, and in order to ensure continuous flow, volt-second balance is,

$$L \times \frac{di_L}{T} = \frac{1}{2} \times (V_S - V_O) \tag{3}$$

Where, VS is the maximum input voltage when the system is stable, and its value is selected as +36 V, VO is the rated output line voltage of 24 V, and T is the switching period, taking 10μs. Substitute, L=1 mH in parameter calculation.

Design of filter capacitor: The cut-off frequency of LC filter is designed to be 10% of the switching frequency fS, and good filtering effect can be obtained according to the formula,

$$10\% \times f_S \geq \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

When substituting parameters to calculate C≥1.5 μF, due to the single-phase full-bridge inverter structure, the capacitance of the filter capacitor C=2.2 μF. The schematic diagram of single-phase full-bridge inverter circuit is shown in Figure 4.

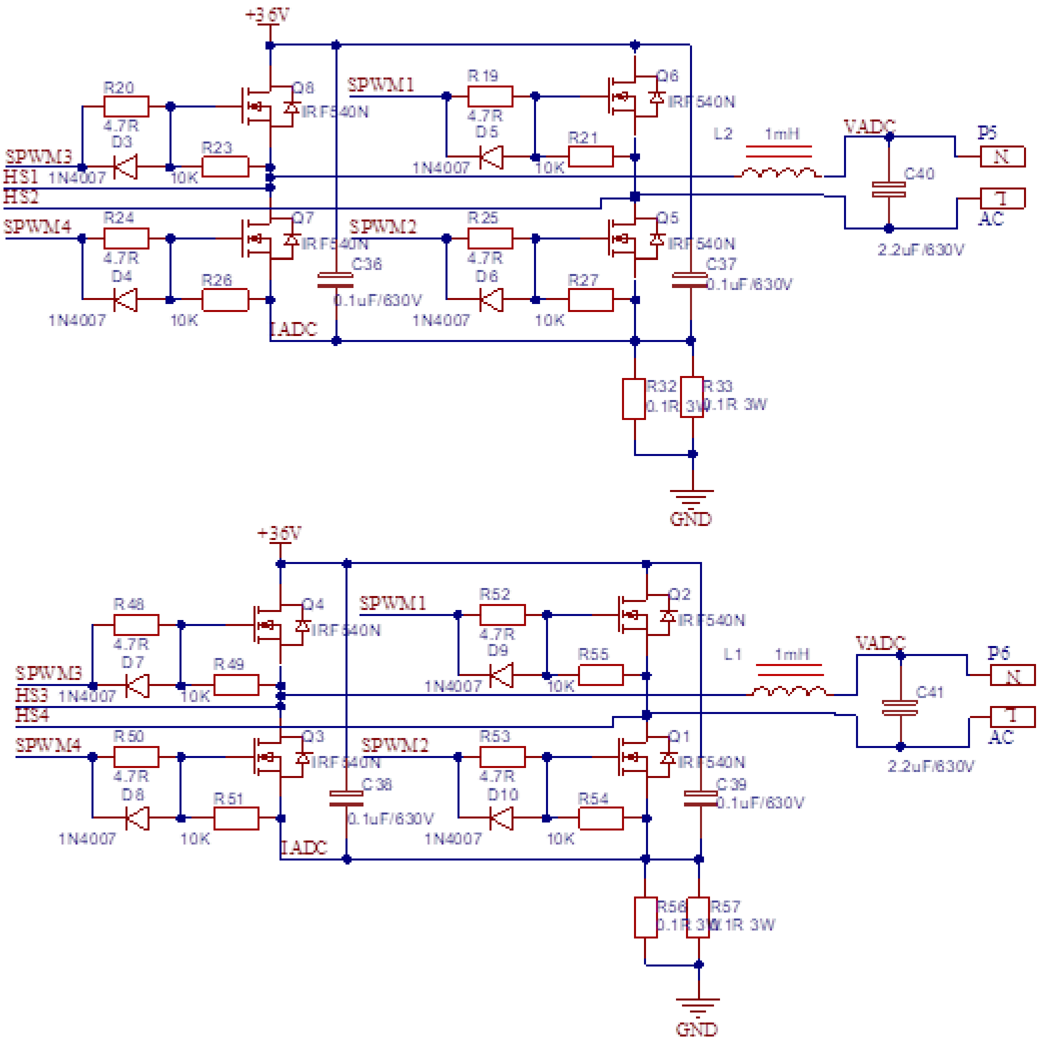

Figure 4. Schematic diagram of single-phase full-bridge inverter circuit

2.2.4 Detection circuit design

The output current of the inverter is measured by current transformer ZMCT103C, and the zero-crossing comparison circuit composed of operational amplifier LM324 and peripheral devices convert 50 Hz sine wave into AC line current. The rated input current of the transformer is 5 A, the output current is 5 mA, the transformation ratio is 1000 : 1, the maximum AC line current output by the inverter is 2 A, the output current is 2 mA according to the transformation ratio relationship, and an AC voltage of 240 mV can be obtained by selecting 120 Ω as the sampling resistor R64.

The voltage transformer ZMCT101B is used to measure the AC line voltage and phase of the inverter. The rated input and output currents of the transformer are 2 mA, the transformation ratio is 1000 : 1000, and the maximum AC line voltage output by the inverter is 24 V. The input resistance R65=10 KΩ is determined by backward calculation from the rated input current of 2 mA. At this time, the output current of the transformer is 2 mA, and an AC voltage of 240 mV can be obtained by selecting 120 Ω as the sampling resistor.

The AC voltage is rectified by the rectifier circuit to obtain pulsating DC. Finally, the DC voltage is amplified by the co-directional amplifier and sent to the AD conversion channel for further work. The schematic diagram of the detection circuit is shown in Figure 5.

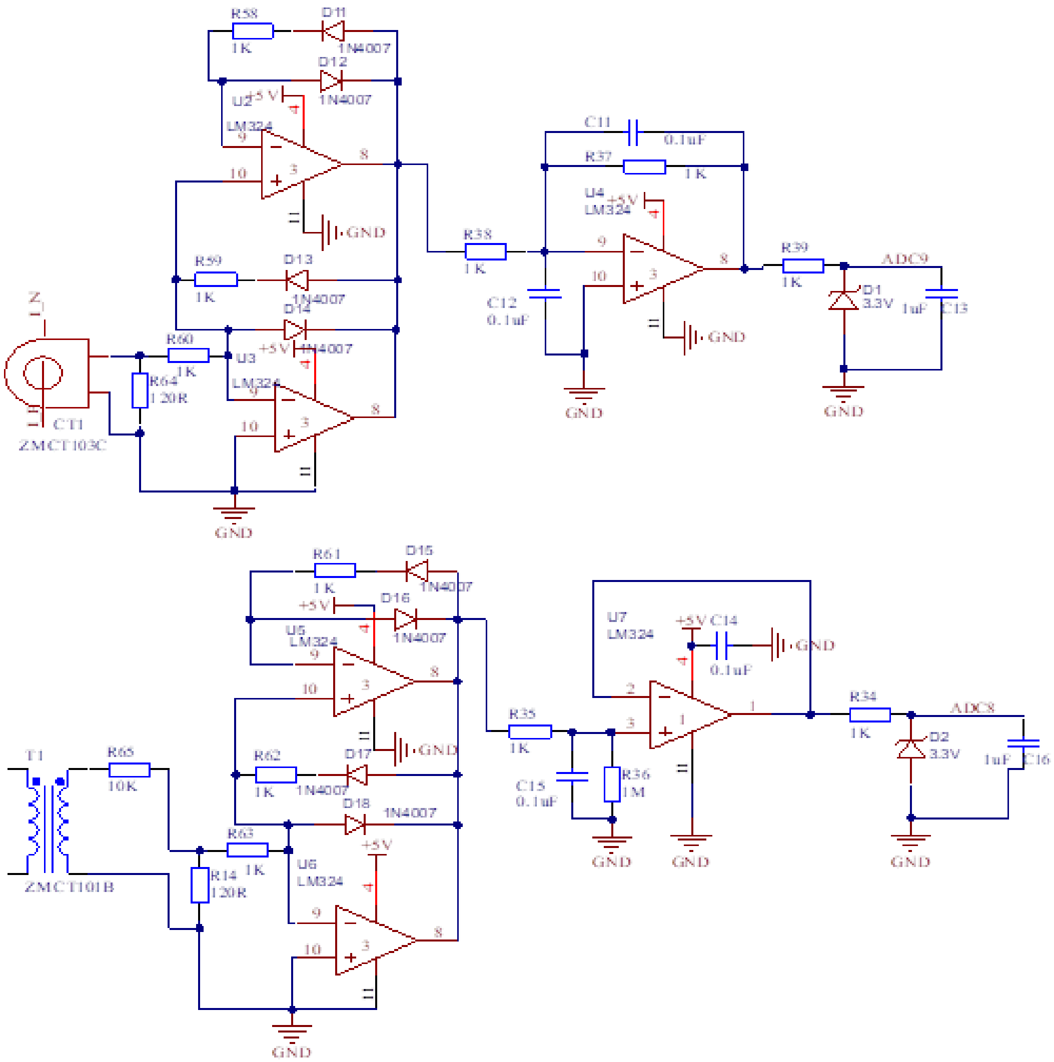

Figure 5. Schematic diagram of detection circuit

2.2.5 Auxiliary power supply circuit design

The control chip of the auxiliary power supply circuit is EUP3482ADIR1. The output voltage and current of the chip can be continuously adjusted in the circuit and can be rectified synchronously. There is a simple switch control inside the chip, and the switching frequency is 340 KHz, so there is no need for loop compensation. The power supply circuit can provide +5 V and +3.3 V power supplies for the SCM STM32F103CBT6, the driver module, the inverter module, the detection module, the LCD module, and the key module through step-down.

The auxiliary power supply circuit is shown in Figure 6.

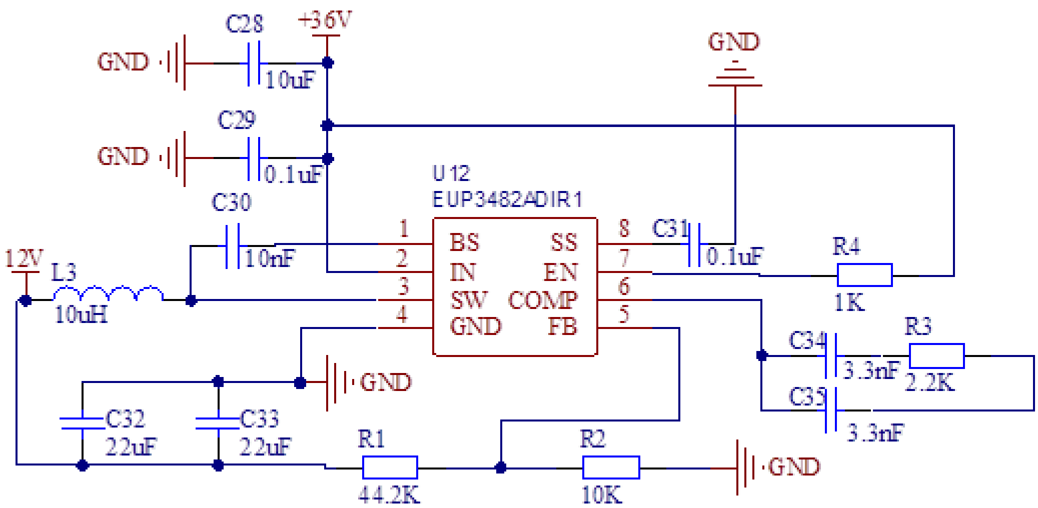

Figure 6. Schematic diagram of auxiliary power supply circuit

2.3 System software design

2.3.1 Main program design

When the main program starts, all variables are initialized. If a key is pressed, the key subroutine is executed, otherwise, the voltage and current output are collected by AC part, the processed data is sent to LCD1602 for display through STM32, and the protection SPWM control subroutine is executed at the same time. Finally, the collected voltage and current values are compared with the set upper and lower limit values. When the data exceeds the limit value, the protection subroutine is executed, otherwise, the system is initialized, and so on, and the loop is infinite.

The flow chart of the main program of the system is shown in Figure 7.

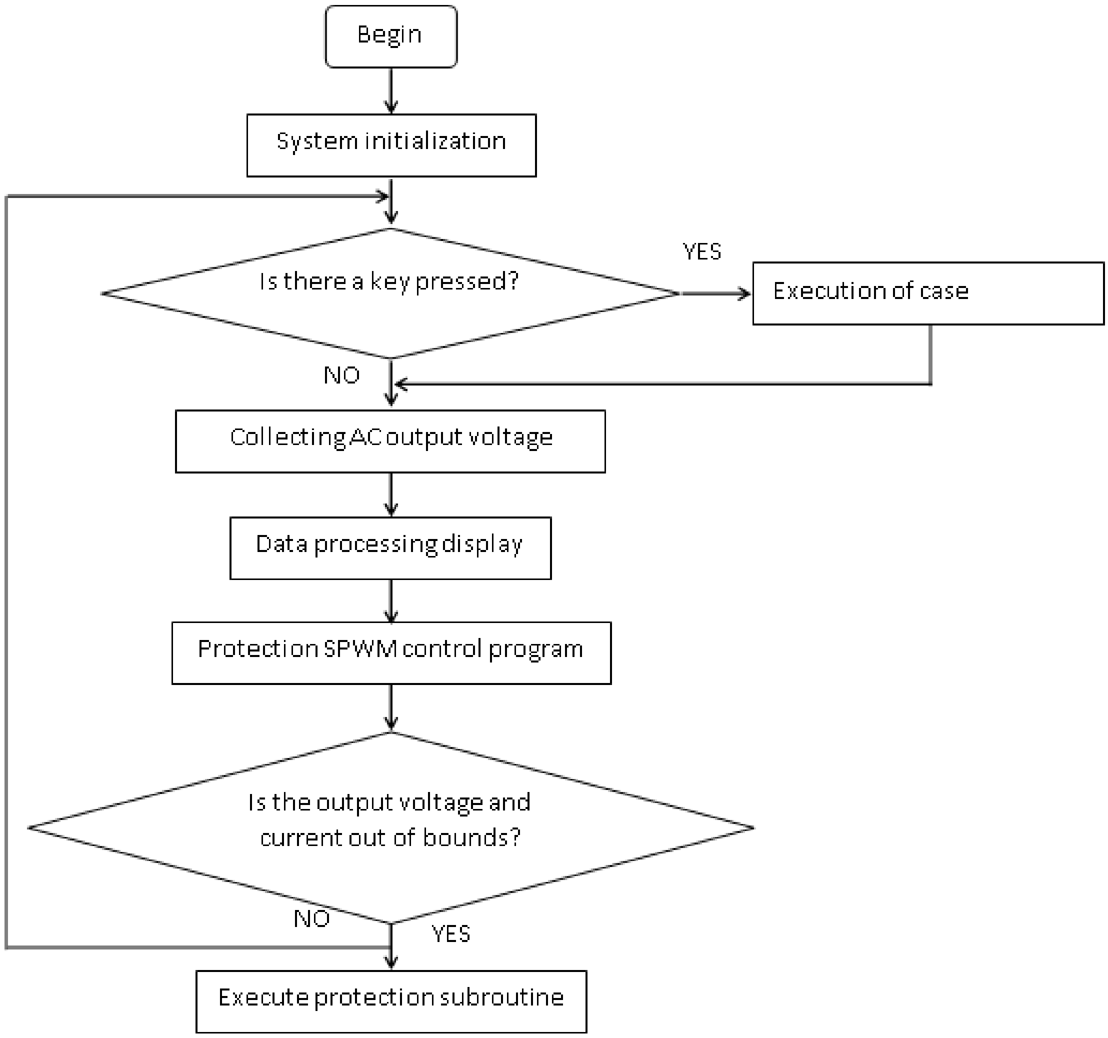

Figure 7. Flow chart of the main program

2.3.2 Control circuit programming

Firstly, the port is initialized, and the signal is sampled and processed according to the period of system establishment, and then the processed signal is sent to the post-circuit. The system controls the main inverter to work in the voltage-stabilizing mode, uses the voltage transformer to measure the line voltage, and realizes the symmetrical phase voltage with stable output amplitude through dq coordinate transformation and PI adjustment. The slave inverter is controlled to work in steady current mode, and the line current is measured by current transformer. After the voltage phase of AC bus is obtained by PLL, the output voltage and current are adjusted by PI algorithm at the same frequency and phase, and the current sharing of the two inverters is realized at the same time. PLL phase-locked loop realizes the output voltage synchronization of two inverters, and according to the output current of the main inverter, the current instruction of the slave inverter is given, and PI regulation is adopted to control the output current of the slave inverter to realize current distribution.

The flow chart of the control circuit program is shown in Figure 8

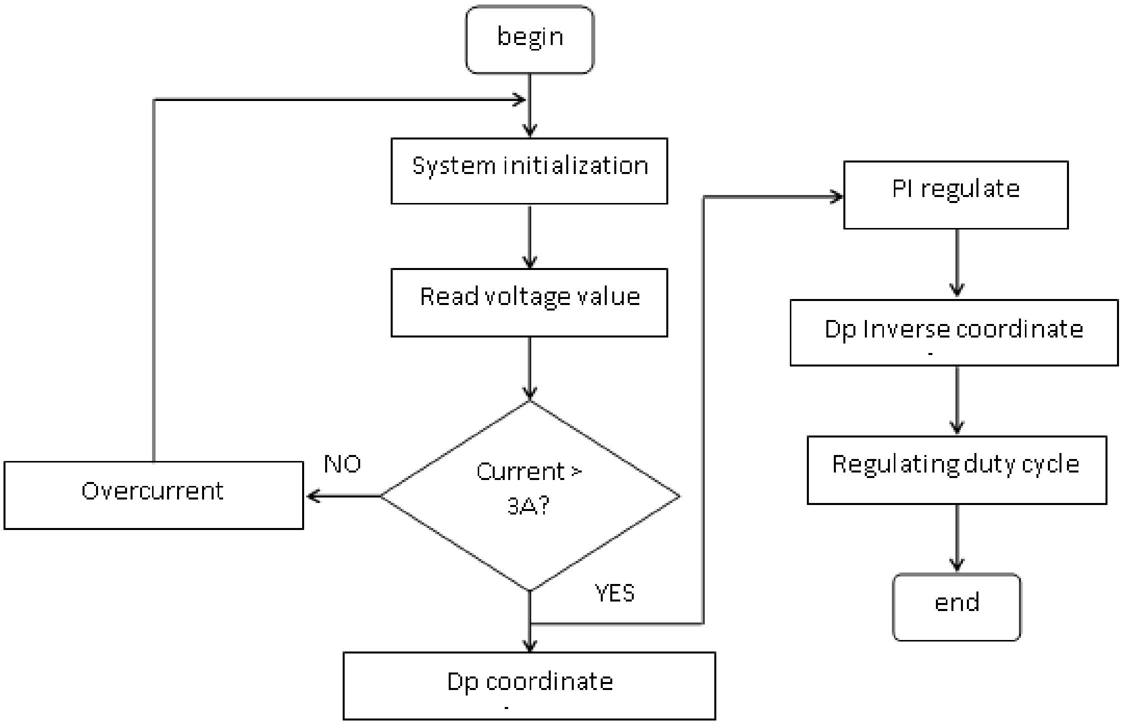

Figure 8. Flow chart of the main controller program

2.3.3 Program design of detection circuit

When the program starts, it first checks whether the AD conversion is completed. If the conversion is completed, it will clear the conversion completion flag bit, otherwise, it will wait for the data to be updated. After the zero clearing is completed, it is checked if the bus voltage and bus current are currently collected, and the corresponding data is processed after the judgment is accurate. Finally, the data is updated, and the overall operation is completed.

The program flow chart of the detection circuit is shown in Figure 9.

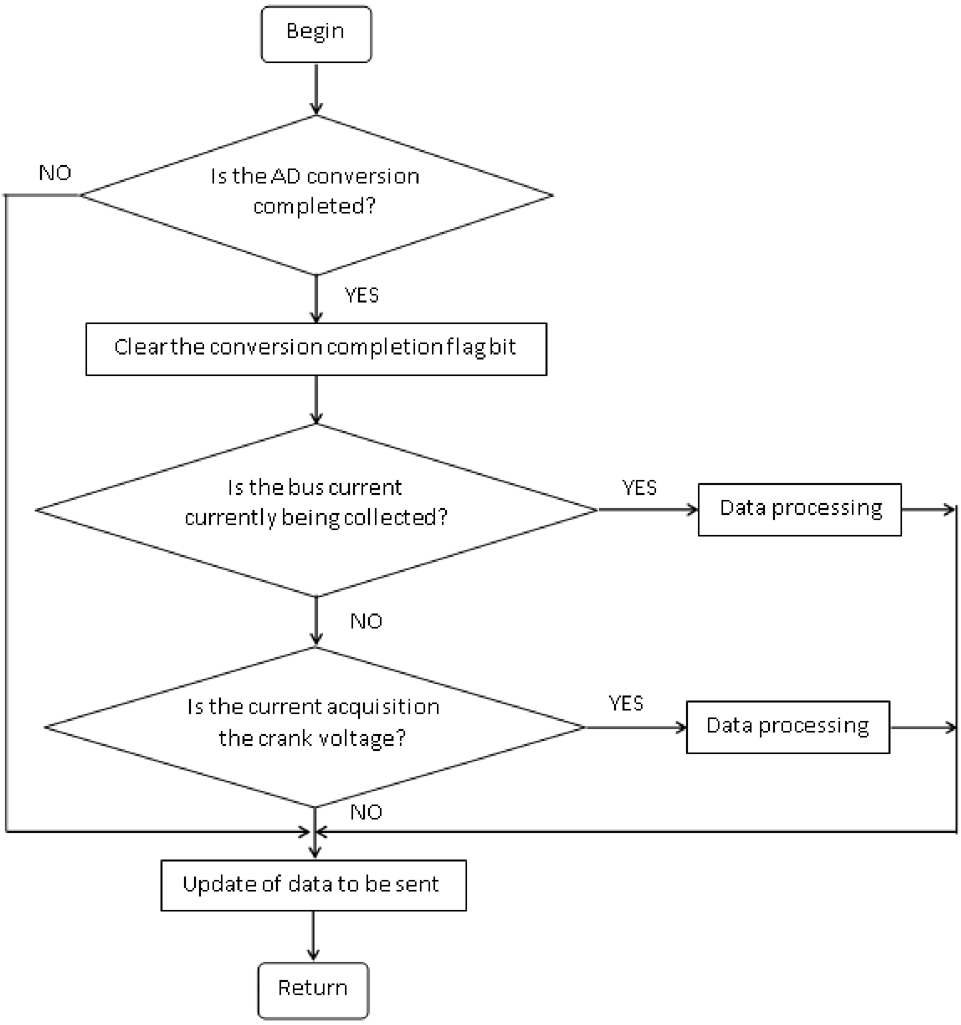

Figure 9. Flow chart detection circuit

2.3.4 Programming of LCD circuit

First, the LCD1602 is initialized, and then it is checked whether a key is pressed. If a key is pressed, it is scanned and judged to determine the key value, otherwise it is initialized again. The key value is converted into ASII code, stored in the register, and then it is judged whether the key is released. If the key is released, it is checked whether the seventh bit is 0, otherwise it is checked again. When the seventh bit is 0, a command is written to the LCD1602 to display the voltage and current values and complete the overall operation of the display circuit; otherwise, continue scanning to determine the key values.

The program flow chart of LCD circuit is shown in Figure 10.

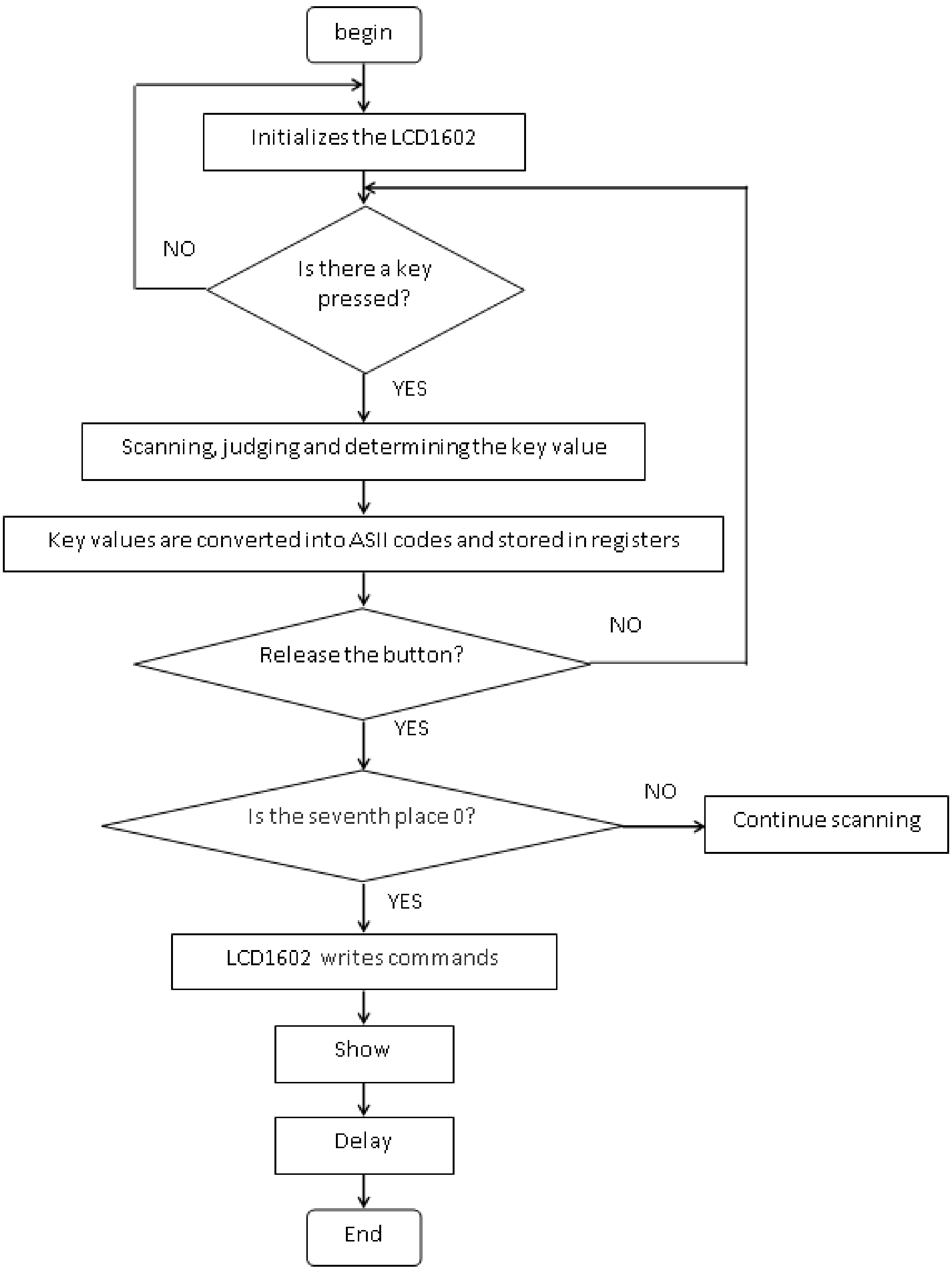

Figure 10. Program flow chart of LCD circuit

3. Results and Discussion

3.1 Overall system test

Test of microgrid simulation system is done in grid-connected state. The DC power supply is used to supply power to the inverter, and the voltage is set to +36 V. The grid-connected inverter is controlled to make the two inverters work together, and the 8 Ω resistance load is connected. The output voltages of the no-load and the connected load are measured by voltmeter. The test results are shown in Figures 11 and 12.

Figure 11. Test results of inverter connected to the grid with no load

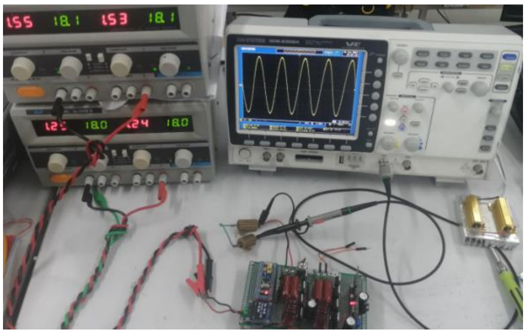

Figure 12. Test results of inverter connected to grid and connected to load

As shown in Figure 13, the actual current of the device is 2.77 A. When the circuit is in the state of grid-connected operation, and two inverters provide AC power to the 8 Ω resistance load at the same time, and the output voltage, output current and output frequency of the LCD screen are 24.10 V, 2.714 A and 50.07 Hz respectively. The circuit is connected to an oscilloscope, and the output voltage is 24.3 V, the frequency is 49.99 Hz, and the sine wave is displayed.

The sine wave waveform of grid-connected inverter is shown in Figure 13.

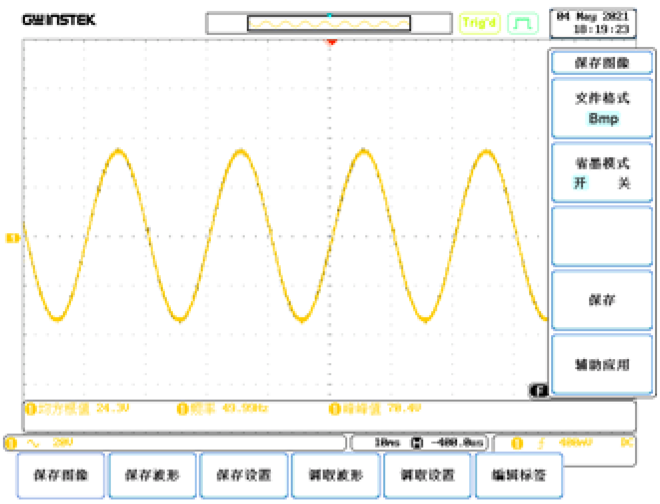

Figure 13. Sine wave of inverter in grid-connected state

3.2 Test result analysis

3.2.1 Analysis of system efficiency

The test data of 1~3 times in the measurement times are the output voltage, output current and overall efficiency of the system corresponding to the input voltage of +36 V when the simulation system is running alone. The output voltage, output current and overall system efficiency are tested corresponding to the input voltage of +36 V when the system is connected to the grid for 4~6 times. Table 1 shows the system efficiency test data.

Table 1. System Efficiency Test Data

Number of Measurements	Input Voltage/V	Incoming Current/A	Output Voltage/V	Output Current/A	Efficiency/%
1	36	1.44	24.12	1.933	89.9
2	36	1.41	24.15	1.915	91.1
3	36	1.48	24.09	1.923	87.4
4	36	2.21	24.10	2.914	88.3
5	36	2.27	24.13	2.951	87.1
6	36	2.24	24.11	2.927	87.5

The experimental test results show that when the system works independently, and when the input voltage is +36 V, the input current is 1.41 A and the input power is 50.76 W, the output voltage, the output current and the output power of the system are measured to be 24.15 V, 1.915 A and 46.25 W respectively at full load, from which the overall efficiency of the system is calculated as 91.1%. When the system is connected to the grid, the overall efficiency is 87.1% when the maximum output current of the system is 2.951 A. Compared to the system running alone, with the increase of system output current, the overall efficiency of the system gradually decreases, mainly due to the increase of line loss and internal loss of switch tube during grid-connected transmission.

3.2.2 Analysis of grid-connected output current

The output currents of different inverters of the system at full load are measured by current testing instruments. Table 2 shows the test data of 1~3 times.

Table 2. Grid-connected output current test data

Number of Measurements	Output current of Inverter 1/A	Output current of Inverter 2/A	Absolute Error/A
1	1.46	1.53	0.07
2	1.44	1.53	0.09
3	1.49	1.55	0.06

The experimental test results show that when the simulation system is connected to the grid, the output power of inverter 1 and inverter 2 is evenly distributed according to the ratio 1 : 1, and the effective value Io of the load line current changes back and forth between 1 and 3 years, and the output line currents of the two inverters remain within a certain error range, not exceeding the error range of 0.1 A, which meets the design requirements.

4. Conclusion

The proposal of this paper studies the flexible, large, and diverse grid-connected problem of distributed power sources. Studying the reliable supply of various energy forms to the load is an effective way to study the active distribution network and make the traditional power grid transition to the smart grid. The micro-grid technology would be researched further to find a solution to the effective use of energy. In the whole design process, the steps from the determination of design scheme, the establishment of system framework, the design of unit system to the overall circuit design, as well as the wiring and welding of physical circuit and the adjustment of simulation test, have deepened the understanding of microgrid simulation system.

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