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Research Article

The Design of the Parallel Switching Power Supply System

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Abstract: This study introduces a parallel switching power supply system which is controlled by C8051F020 MCU. The system consists of DC/DC converter, voltage-controlled constant current source circuit, over-current protection circuit and auxiliary power supply. TPS54331 is used to constitute a highly efficient DC/DC converter, reducing the input DC voltage to supply the voltage-controlled constant current source circuit. The parallel current-sharing of the system is realized by the voltage-controlled constant current source circuit. The output current of the two parallel power supply can be adjusted by changing the control voltage. When the output current exceeds the set value, the system starts over-current protection circuit to cut off the power and delays to restore power automatically after a certain period of time. The test results show that the system is stable and reliable, easy to control and has a function of over-current protection and automatic recovery.

Keywords: C8051F020 MCU, DC/DC converter, over-current protection, parallel current-sharing, voltage-controlled constant current source

INTRODUCTION

With the development of power electronic technology, power supply system is widely used in computer, industrial instrumentation, military, aerospace and other fields, involving all walks of life in the national economy. But in practice, single power's output parameters (voltage, current, power, etc.) often can't meet requirements or malfunction, causing power reduction of the system or the entire system collapse (Wang, 2005; Shen, 2007). These practical problems put forward higher requirements for the supply way of the power system and then make it from centralized to distributed development. Distributed power supply system uses small power modules and large scale integrated circuit as the basic components, constituting an intelligent high-power power supply with the latest theoretical and technological achievements such as the zero voltage, zero current technology (Zhang and Ren, 2009). The parallel power supply system is an important developing direction for distributed power supply. This parallel power supply system, particularly in applications that require high power, has the advantage of covering a wide range of power and reducing development costs (Stefan, 1996; Gao *et al*., 2011).

The current-sharing technology is the core of the switching power supply operating in parallel (Pano *et al*., 1997; Zhang and Cao, 2002). To make a rational allocation of the load output current in the parallel module, so far, a variety of different current control methods have been proposed, researched and developed (Luo *et al*., 1999; Ali *et al*., 2009). In the study of John and Arthur (1994), output voltage droop characteristics in droop method were proposed, but the voltage regulation of the system was poor with this method. In the reference (Rajagopalan and Xing, 2002), the authors used the master-slave control method to control the current-sharing of paralleled DC-DC switching converters. The system, however, won't work if the master module broke down. Zhang (2006) introduced the averaged current automatic current sharing method and its characterizes in the reference. These traditional current-sharing methods always use analog control, their bandwidth allowing a wide range and there are a lot of integrated chips can realize control. However, the principle of current-sharing in the traditional scheme is too complex, there needing too many components in the actual design. Besides, the contradiction between the system stability and the transient response of load current-sharing is difficult to solve (Huang, 2011).

In this study, we introduce a parallel switching power supply system which uses C8051F020 MCU as the controller. TPS54331 is used to constitute a highly efficient DC/DC converter. The automatic or manual

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control of the DC/DC modules' current ratio can be easily achieved with voltage-controlled constant current stable. The current of parallel modules is controllable and the absolute value of every module's relative error is less than 2%. Besides, the system has a function of over-current protection and automatic recovery.

THE OVERALL DESIGN PRINCIPLE OF THE PARALLELED DC-DC CONVERTERS

The system mainly consists of DC/DC converter, constant current source circuit, voltage sampling circuit, C8051F020 MCU data processing analysis module, over-current protection circuit and keys, LCD display module. The system principle block diagram is shown in Fig. 1.

The design principle of the system: 24V DC voltage is supplied to the parallel switching power supply system through the relay over-current protection circuit. The DC/DC converter, with TPS54331 as the main chip, steps down the 24V DC and supplies the constant current source circuit. In the constant current source circuit, the output control signal of the C8051F020 microcontroller is compared with the internal current sampling feedback voltage signal of the constant current source and then controls the size of the source circuit. The design is simple in principle and easy to control. The output voltage of the system is constant current source circuit output current, realizes arbitrary current ratio. Voltage sampling circuit samples the output voltage and feeds back to the system, keeping the load output voltage stabile. When the load current exceeds the set value, the system starts over-current protection circuit to cut off the power and automatically recovers power supply after a certain period of time delay, to achieve the over-current protection and automatic recovery functions.

SPECIFIC ANALYSIS AND DESIGN OF THE SYSTEM HARDWARE CIRCUITS

DC/DC converter: The module steps down the 24V DC input voltage to provide power for the voltage-controlled constant current source circuit behind. Using a dedicated DC/DC buck converter chip TPS54331, the circuit is shown in Fig. 2. C1, C2, C3 are decoupling capacitors. R1, R2 divide the input voltage to enable the TPS54331 chip. C5 is a bootstrap capacitor. L1, C8 constitute an LC filter and filters for the output voltage. C6, C7, R3 are frequency compensation components. The output voltage is divided by R4 and R5 and

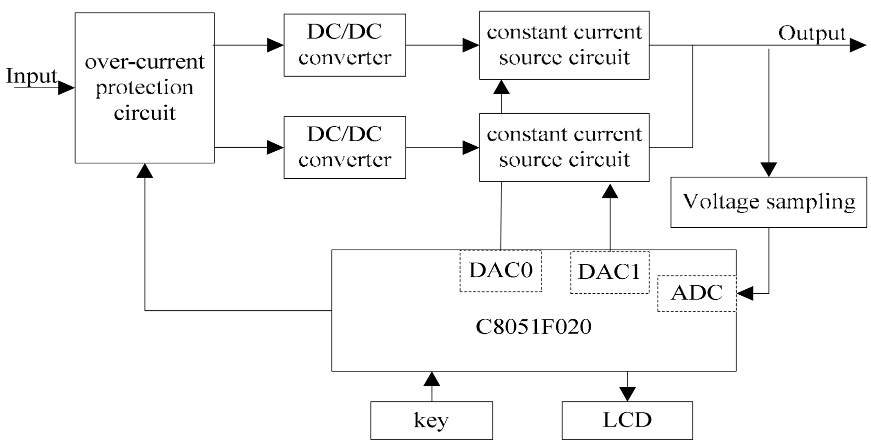

Fig. 1: The system principle block diagram

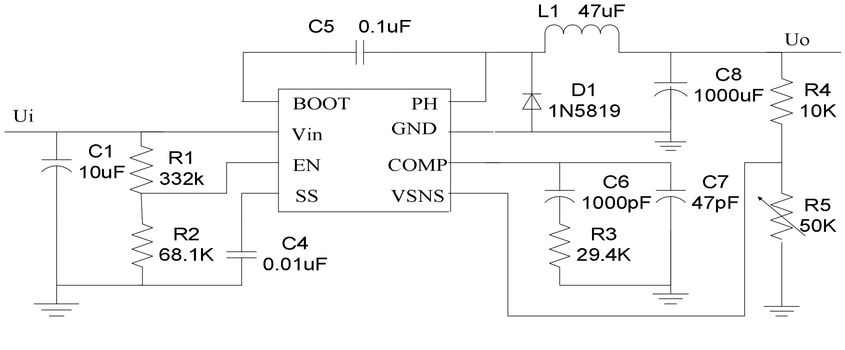

Fig. 2: DC/DC converter circuit

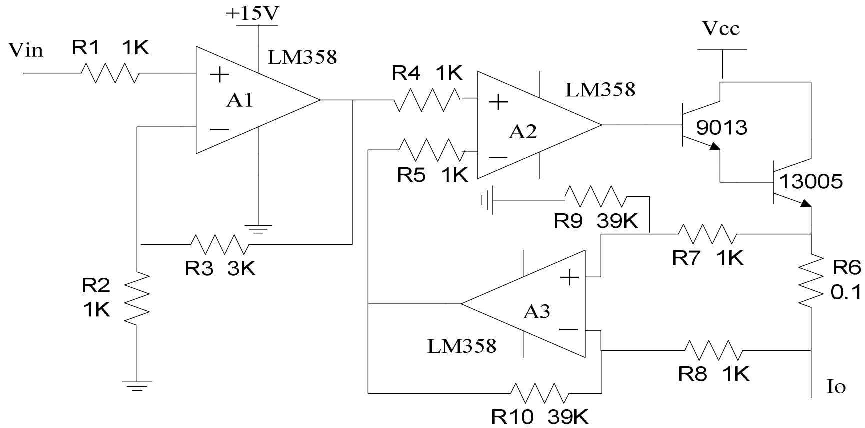

Fig. 3: Constant current source circuit

then sent to the VSNS port of the chip, forming a negative feedback. By adjusting the sliding rheostat, the output voltage can stay in the set voltage value.

Constant current source circuit: The constant current source circuit realizes the current-sharing between the parallel switching power supply modules of the system. The design of the circuit uses a voltage-controlled constant current sources circuit (He, 2004), including a control signal amplifying circuit, a current sampling and amplifying circuit, a voltage comparing circuit and a current amplifying circuit. The scheme is shown in Fig. 3. The output voltage of DC/DC converter is used as the power of the constant current source circuit, namely V_{cc} in Fig. 3. V_{in} is the voltage control input port, controlled by MCU. I_o is the current output port of the constant current source. R6 is a 0.1 ohm current sampling resistor. In the circuit design, in order to prevent the resistance change caused by high current, thereby affecting the output current, four 0.1 ohm resistor are paralleled every two and then series, to improve the stability of the output current.

The control signal amplifying circuit is constituted mainly by A1 amplifier. The circuit magnification is:

$$Au = 1 + \frac{R3}{R2} = 4 \tag{1}$$

The current sampling and amplifying circuit is constituted mainly by A3 amplifier. R6 is a sampling resistor. Setting its voltage drop for ΔU, the output voltage of A3 is:

$$U_O = \frac{R10}{R8}\Delta U = 39\Delta U \tag{2}$$

The working principle of the constant current source circuit is: when the input control signal increases, the in-phase input voltage of A2 amplifier is higher than

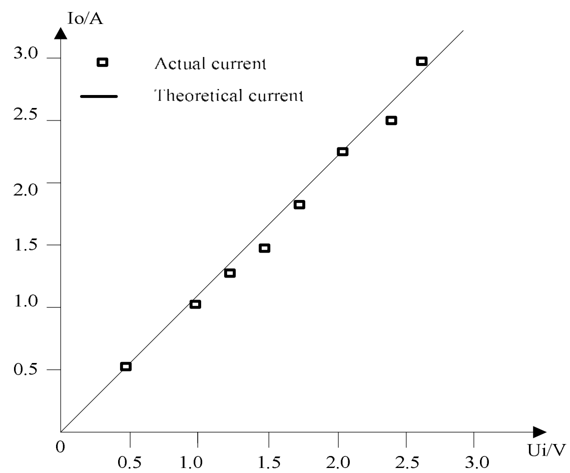

Fig. 4: The relationship between the output current and the input voltage

its inverting input voltage, leading to the rise of A2's output voltage. The output current increases through the composite tube amplifier composed of transistor 9013 and 13005. Then the voltage drop across the sampling resistor increases, so is the inverting input voltage of A2 amplifier, leading to the reduction of the output current. The output voltage becomes stable until the in-phase input voltage of A2 amplifier is equal to its inverting input voltage. The working principle is the same when the input control signal reduces.

Therefore, when the constant current source circuit works stably, it has:

$$4V_{in} = 39\Delta U = 39I_o R6 \tag{3}$$

That is:

$$I_o = \frac{4V_{in}}{39R6} = 1.02V_{in} \tag{4}$$

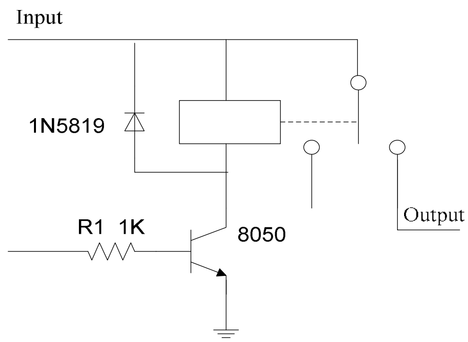

Fig. 5: Over-current protection circuit

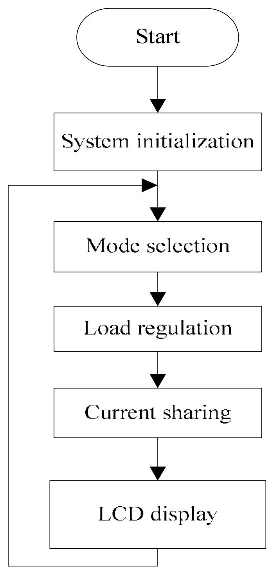

Fig. 6: Main flowchart of software

According to the value of each element in the scheme, when the input voltage changes from 0 to 3V, the changes of theoretical calculation and actual measurement of output current are shown in Fig. 4. There exists a linear proportional relationship between the output current and the input voltage. So the voltage-controlled constant current source is realized.

Over-current protection circuit: In order to prevent the excessive load current from disrupting the system's normal operation, an over-current protection circuit is designed. The circuit uses a 28V/10A relay to constitute a relay switching circuit. When the load current exceeds the threshold current, the switch isn't connected and the system stops work. The system automatically works normally again when the load current is below the threshold current. The scheme is shown in Fig. 5.

THE DESIGN OF SOFTWARE

When the system initialization is completed, the key value is read through the external interrupt and decides

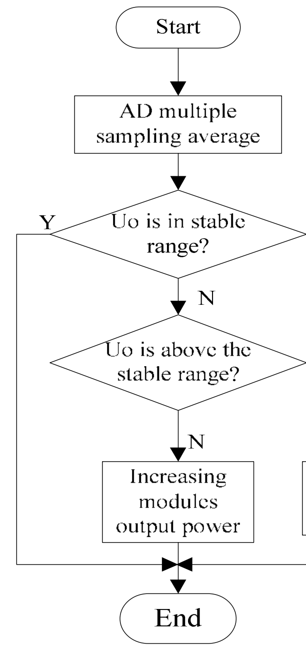

Fig. 7: The load regulation subroutine flowchart

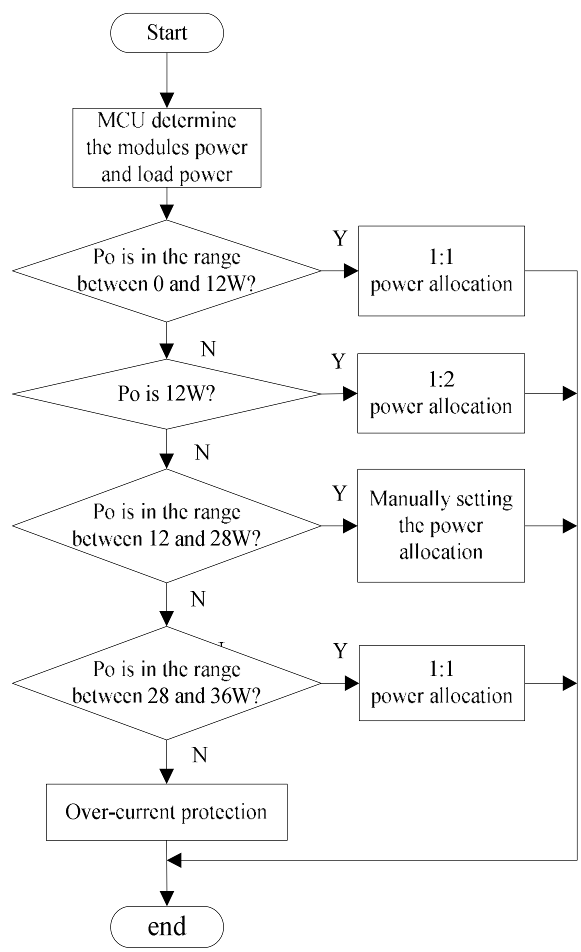

Fig. 8: The current-sharing subroutine flowchart

the operation modes of the system: automatic current-sharing or manual current-sharing. Then the system will detect whether the output voltage reaches the predetermined value. If not, it will be adjusted by changing the output current. The current-sharing of the two DC-DC converters is determined by the operation mode that has been selected. At the same time, the relevant parameters can also be displayed in real time. The flowchart of the software is shown in Fig. 6.

The program design of load regulation: To make sure that the output voltage sampled is more accurate, the multiple sampling averaging method is used. Then the detected value will be compared with the predetermined value. If the detected output voltage is larger than the predetermined value, the power of the DC-DC converters will be reduced. Otherwise, the power of the DC-DC converters will be increased. The load regulation subroutine flowchart is shown in Fig. 7.

The program design of current-sharing: The current sharing subroutine allocates the output power of the two DC-DC converters according to the current operating mode of the system. In different ranges of the output power, the system will perform the function of current-sharing with different current ratios and ways. The flowchart of current-sharing is shown in Fig. 8.

EXPERIMENTAL RESULTS

The system test is divided into three parts: the automatic ratio test, the preset ratio test and over-current protection test. The main testing equipments are LPS-305 NC DC power supply, UT-35 digital multi-meter and GDM-8055 high precision digital multi-meter.

The scheme of the detect way is shown in Fig. 9. The module current I_1 and I_2 is detected respectively with ammeter A1 and A2. The voltmeter V and the ammeter A3 are used to detect the output voltage U_o and the output current I_o.

The automatic ratio test: The automatic ratio test is done when the output voltage is 8.0±0.4 V and the output currents are respectively 1A, 1.5A and 4A. The test results are shown in Table 1.

It can be drawn from the table that the system can automatically control the current of the two DC-DC converters with the ratio of 1:1 when I_o = 1A or 4A and 1:2 when I_o = 1.5A. The absolute value of every single module's relative current error is less than 2%. The maximum relative error of actual current ratio is 4%.

The preset ratio test: The preset ratio test is divided into two aspects:

- In the premise that the output voltage is stabile, maintain the output current to a fixed value and arbitrarily preset the current ratio of the two DC-DC converters's then analysis the relative error of every DC-DC converter's current.

  When the output voltage is 8.0±0.4 V and the output current is 3.0A, the ratio between I_1 and I_2 can be arbitrarily preset. The test results are shown in Table 2.
- In the premise that the output voltage is stabile, maintain the current ratio of the two DC-DC converters to a fixed value and adjust the output current I_o of the system, then analysis the relative error of every DC-DC converter's current.

  When the output voltage is 8.0±0.4 V, the current ratio of the two modules is preset at 3:2 and then adjusts the output current I_o. The tested current of the modules is shown in Table 3.

Table 1: The results of the automatic ratio test

U_o/V	I_o/A	Automatic ratio	I_1/A	I_2/A	Actual ratio
8.12	1.00	1:1	0.49	0.51	1:1.04
8.02	1.50	1:2	0.49	1.01	1:2.06
8.04	4.00	1:1	1.99	2.01	1:1.01

Table 2: The results of the preset ratio test when the output current is fixed

U_o/V	Preset ratio	I_1/A	I_2/A	Actual ratio
7.98	1:2	1.00	2.01	1:2.01
8.06	1:1	1.50	1.51	1:1.01
8.02	3:2	1.79	1.21	3:2.03
8.03	2:1	2.00	1.00	2:1.00

Table 3: The results of the preset ratio test when the current ratio is fixed

U_o/V	I_o/A	I_1/A	I_2/A	Actual ratio
8.03	1.50	0.90	0.60	3:2.00
8.10	2.00	1.21	0.79	3:1.96
8.02	2.60	1.53	1.07	3:2.10
8.03	3.20	1.92	1.28	3:2.00

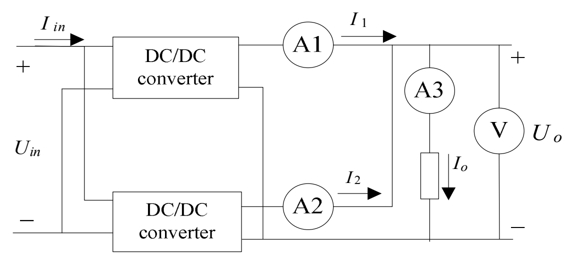

Fig. 9: The scheme of the detect way

From the experimental results shown in Table 3, we can observe that the current ratio of the two DC-DC converters can be arbitrarily preset. The absolute value of every single module's relative current error is less than 2%. This indicates that the design method proposed by this study can achieve current-sharing better and has a high precision.

Over-current protection test: The load resistance is adjusted so that the system output current can be changed in the range between 1~4.5 A and observe the state of the system. When the output current reaches 4.45 A, the input DC voltage is disconnected and the system stops working. The system automatically reworks normally when the output current is reduced to 4.45 A below. The test results show that the system has a function of over-current protection and automatic recovery and the threshold current is 4.45 A.

CONCLUSION

The current sharing technology is the key to the parallel switching power supply system. This study introduces a parallel switching power supply system which is controlled by C8051F020 MCU and uses voltage-controlled constant current source as the main circuit. The system selects the operation mode based on the set of the MCU and regulates the current of the two switching power supply modules according to the current ratio in the operation mode so that the current ratio can be arbitrarily set. The test results show that the output voltage is stable and the system can control the current ratio of the two modules in the way of automatic proportion and preset proportion. The absolute value of every single module's relative error is less than 2%. The system has a function of over-current protection and automatic recovery and the threshold current is 4.45 A. Furthermore, the parallel switching power supply system has lots of advantages, such as the circuit structure is simple, the performance of the system is steady and it is easy to control. This design has a certain practical value.

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