A Novel Method for Parallel Switching Power with Different Capacity

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Abstract

A novel method of parallel switching power with different capacity in a controllable current sharing method is presented in this paper. It achieves proportional current sharing and stable output DC voltage by using controllable current sharing modes which output assignable feedback signals to the paralleling buck DC-DC converters. The validity and effectiveness are verified through comprehensive experiments. Output voltage is at range of 8.0±0.4V with energy transform efficiency of 80%. Moreover, controllable current sharing is established in a short time interval and it automatically recovers after removing the over current faults.

Keywords: *Buck DC-DC converter, Controllable current sharing, Overflow protection*

1. Introduction

Parallel power systems have been widely used due to their benefits in efficiency and modularity. Typically, compared with the traditional centralized power supply, this distributed power systems are designed so that the stresses among the parallel dc–dc converters are balanced. Therefore they can meet different power requirements by multiple parallel modules. Further, every module handles lower power level with high power density and rapidly responding .However, parallel DC-DC converters require an explicit current-sharing method to ensure balanced stresses among the converters. Without a current-sharing method, even small imbalances in modules' output voltages can cause the output currents to be significantly different. Generally, the current sharing (CS) can be implemented using two approaches. The first one, known as a "droop" method [1-2], relies on the high output impedance of each converter. It is simple to implement, and it doesn't require any communication between the modules. The major deficiency of the droop approach is poor load regulation, and not suitable for high-performance applications. The second approach, known as active current sharing schemes [3-14], overcomes the disadvantages of the droop method. Active current sharing ensures near-perfect current distribution without disadvantages of the droop method such as degraded output voltage regulation and/or requiring that voltage references be trimmed. Active current sharing schemes fall into two major categories: (a) peak and average current-mode control schemes where the current sharing is achieved by providing the same reference for internal current loop of each module [3]; (b) voltage loop error-signal modification. In [15], a new master-slave current sharing design using the inner current source of

CMC (Current Mode Controlled) converters was proposed. Both the benefits and limitations of master-slave methods are recognized in this paper. In[16] , analytically and illustrate with examples how the stability of a paralleled converter system with identical modules depends separately on stability of the current sharing loop (differential-mode stability) and on stability properties that are independent of current sharing were showed, but dependent on output load impedances and the number of converters in parallel (common-mode stability). How to design a stable system of paralleled converters concentrating on the current sharing loop was presented in [17-21]. In addition, [21] presents a new current sharing method which requires no additional interconnections among cells and which does not rely on output droop characteristics. It can thus achieve the reliability advantages of the droop approach, without its performance limitations.

In this paper, a new design of parallel switching power with different capacity in a controllable current sharing method is proposed. By using controllable current sharing modes which output assignable feedback signals to the paralleling Buck DC-DC converters, the design achieves proportional current sharing and stable output DC voltage. Its effectiveness is validated by experiments.

2. IMPLEMENTATION DESCRIPTION

2.1 Outer Loop Combined with Democratic Current Sharing Method

There are two main kinds of current sharing method—Droop method and Active current sharing method. Droop method just suits for low power system since it can't satisfy both load regulation and current sharing performance requirements. However, Active current sharing schemes achieve current sharing stably through adjusting amplitude of power source. Based on the current sharing principle, eighteen kinds of possible current sharing methods were discussed in [11]. In this paper, outer loop combined with democratic current sharing method is proposed according to medium power integrated system. As shown in Figure1, the correction between every power unit's current and CSB's current is achieved through current controller and voltage amplifier, therefore the system obtains current sharing. Because of diode's unidirectional conductivity, only the current controller with maximum current can connect to CSB, and it is in master status. But its master identity is not constant and the system adjusts every parallel power's current according to the current in CSB. Therefore, this method provides quickly reflection and good anti-interference.

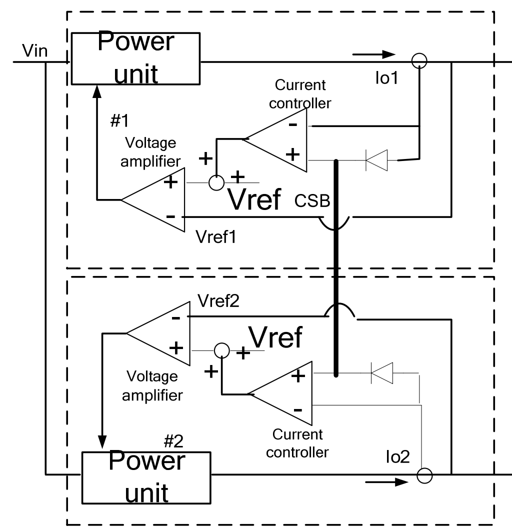


Figure1. Outer Loop Combined with Democratic Current Sharing Method

2.2 Controllable Current Sharing Scheme

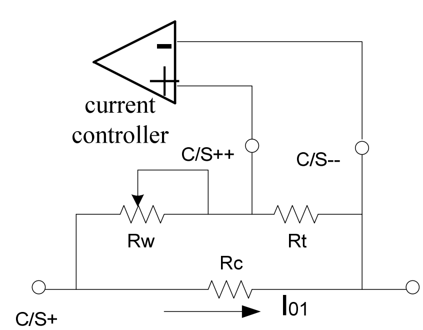


Figure2 Controllable Current Sharing Circuit

In practical applications, it is common to parallel several switching power with different capacity to meet variable demands. This scheme achieves controllable current sharing proportion by regulating the sampling feedback voltage on the condition of stable output voltage. As shown in Figure2, parallel sampling resistance R_C, potentiometer R_W and resistor R_t are connected to make a voltage divider. Voltage of R_t sensed by C/S++ and C/S-- change with changing of R_W. These test values are all sent to CSB after amplification. The highest one is viewed as the master module and the reference, while others, the slave modules try to keep their sensing voltage as same as the master's. Therefore the current through R_t rise, and the controllable current sharing is achieving. The resistance of R_C is far less than R_W and R_t to ensure low power loss.

3. ANALYSIS AND DESIGN

In this paper, a new proposed current sharing scheme is presented to achieve controllable current sharing. The implementation of the method is shown in Figure 3. The model consists of Buck DC-DC converters, current sharing module, and controllable CS circuit and over current protection circuit. It operates on 24V DC power and provides 8V DC power for load by paralleling switching power (LM2596). Current sharing module (UC3907) and controllable CS circuit make current sharing in proportion, and can also maintain steady output voltage through feedback signal to LM2596. Overflow current protection is performed by control circuit and over current protection circuit. Compared with other current sharing schemes using SCM(Single Chip Microcomputer) or DSP(Digital signal Processor), this scheme has fast current sharing response speed with simple structure, and it is more efficient and reliable.

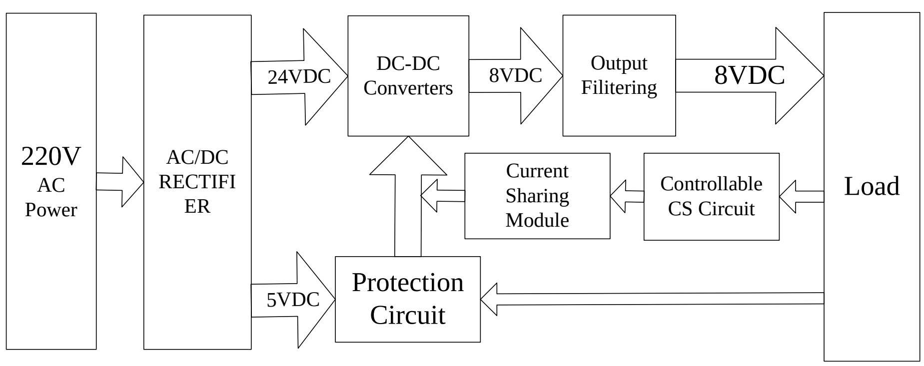


Figure3 System Schematic

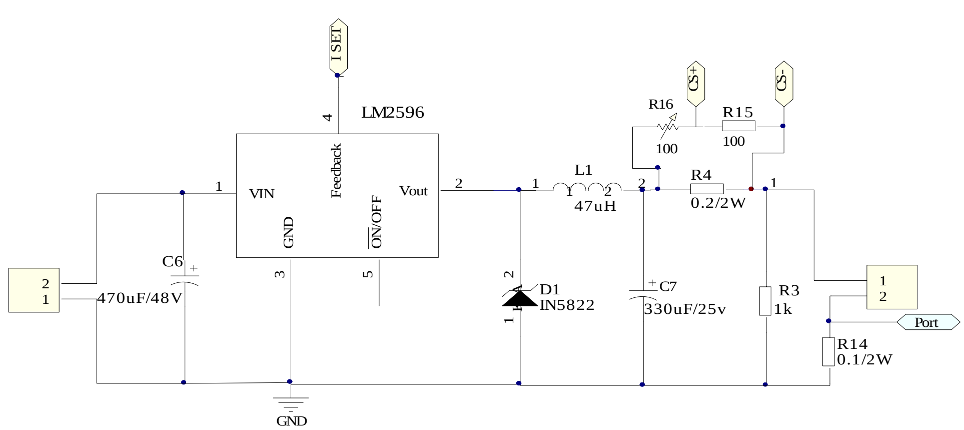


Figure4 Buck DC\DC Converter

3.1 Buck DC¥DC Converter Module

Buck DC\DC converter circuit is based on ASIC LM2596ADJ. It also consists of resistors, inductors and capacitors. These external devices make up filter circuit, sampling circuit and protection circuit. This module achieves 8V DC voltage with self-protection. Its maximum current is 3A. Good linear characteristic make it suitable for variable load. LM2596ADJ changes into sleep mode with only 80uA current supply when the voltage of ON/OFF chip pin is lower than 1.3V. The system can get expected power by paralleling several LM2596ADJ. The circuit diagram of buck DC\DC converter is shown in Figure4.

3.2 Current Sharing Module

Current sharing chip UC3907 can make parallel switching power output assigned current according to the feedback signal while the accuracy is in 2.5%. The current of sampling resistor is sent into comparison point in CSB (Current Sharing Bus) after amplification. Regulation function is base on the comparison result. ISET pin outputs feedback signal to LM2596 to stabilize the output voltage according to the output voltage sensed by SENSE+ and SENSE-.

A controllable current sharing method is presented in this paper, which regulates the output voltage by using the controllable CS circuit as shown in Figure2. Parallel sampling resistance R4, potentiometer R16 and resistor R1 are connected to make a voltage divider. The voltage of R15 in each module flows in voltage sense point and is sent into CSB after amplification. All currents are compared in the CSB; the highest one is viewed as the master module and reference. While others, the slave modules try to match their output currents to the master's. Therefore the design achieves proportional current sharing by modifying the sense current signal from the R15.

If one slave module's sense voltage is closed to master modules, these two modules will become master module alternately. So the current ripple and statue light is not stable during debugging. In order to solve this problem, this design parallels a resistor R7 with C11. It creates a voltage divider circuit, so the changing of voltage can be limited. C13 reduces the influence of noise. The diagram of current sharing module is shown as Figure5.

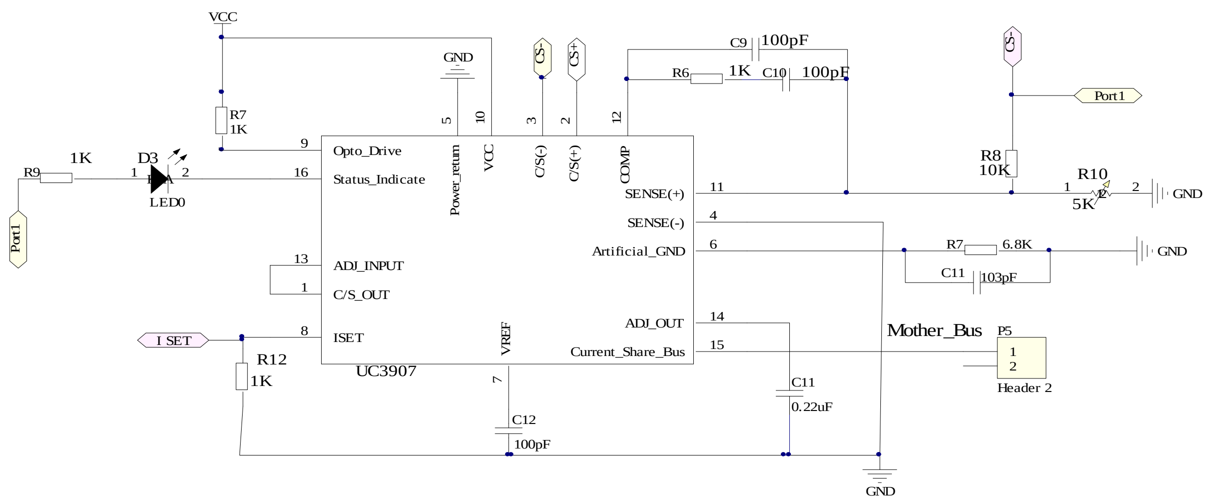


Figure5 Current Sharing Module

3.3 Design of Over Current Protection Circuit

Sampling resistor added in series with load is used to test if the system is in over current condition. The sense value will be compared with reference voltage in voltage comparator. If the sense value is higher, the comparator sends a shut down signal to MCU. LM2596ADJ goes into sleeping mode. Over current protection is achieved in control of MCU. The diagram of current protection circuit is shown in Figure6.

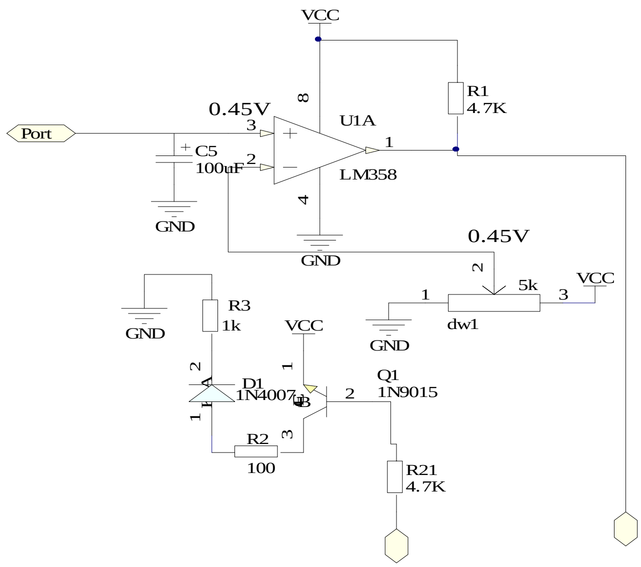


Figure6 Current Protection Circuit

4. SELECTION OF KEY COMPONENTS

The parameters of key components of peripheral circuit not only are very important for the system to achieve expected result but also affect the accuracy and reliability of the result. The selection rules will be illustrated in the following part.

4.1 Selection of Inductor

Inductor L_1 is magnetic ring in closed-loop magnetic flux or E type ferrite magnetic core. Magnetic core must be in unsaturated state to prevent rapid increase of switching current doing harm to the chip.

- Calculation of Inductance:

$$E \cdot T = (V_{IN} - V_{OUT} - V_{SAT}) \cdot (V_{OUT} + V_D) / (V_{IN} - V_{SAT} + V_D) \cdot 1000 \ / 150 \ KHz$$

$E \cdot T$: Calculate the inductor Volt • microsecond constant;

V_{IN} : Input voltage; V_{OUT} : Output voltage;

V_{SAT} : Saturation voltage of LM2596.

V_D: Diode forward voltage drop.

With the parameters, the result is

$$E \cdot T = 35.9V \cdot \mu S$$

L1's value is 47 μH refer to chip manual of LM2596.

- Calculation of Wire Diameter:

Wire diameter (d) depends on the formula

$$J * \pi (d/2)^2 = I_L$$

The maximum current (I_L) of L1 is 3A and the current density (J) is $4A/mm^2$. Calculation result is 0.893mm. The operating frequency is 150 KHz, so skin effect must be considered. In the production, multi-line twining type is selected to prevent over current and skin effect.

4.2 Selection of Capacitor

Output capacitor C7 is output filter capacitor, which has ability to promote voltage-stabilizing circuit. Therefore, C7 is aluminum electrolytic capacitor or tantalum capacitor with low ESR. The selecting rule is in the manual.

$$C \geq 13300(V_{IN}/(V_{OUT} * L))$$

In the formula, V_{IN} =24V, $V_{OUT}=8V$, L=47uH. So the value of C7 is selected 330uF.

Feed-forward capacitor C6 should be aluminum electrolytic capacitor or tantalum capacitor with low ESR and the connection wire should be as short as possible. Feed-forward capacitor has two functions. One is to suppress transient voltage, the other is to deliver required current when switch open. According to chip manual, feed-forward capacitor must be greater than 300uF if output voltage is in high level. The maximum pressure endurance of C6 is greater than 110% of output voltage in consideration of surge voltage occurring in switching on and off. So the value of C6 is selected 470uF/50V.

4.3 Selection of Absorb Diode (D1)

Diode D1 is used to provide fly-wheel loop for inductance current. Therefore D1 is schottky diode with quickly switching character and low forward voltage drop. The maximum current that D1 can bear is 1.3 times greater than maximum output current at least. If the power source is designed to withstand continuous short circuit output, the maximum current of D1 is equivalent to maximum output current of LM2596. The worst situation for D1 is overload or short circuited output, so the reverse voltage is 1.25 times greater than maximum input voltage. In consideration of discussions above, D1 is selected IN5822.

5. EXPERIMENT RESULTS

The feasibility and practical features of the proposed controllable current sharing method have been evaluated. Two switching power modules are paralleled as shown in Figure7. In this section, current sharing in proportion of each module is demonstrated experimentally with stable output DC voltage at 8V.

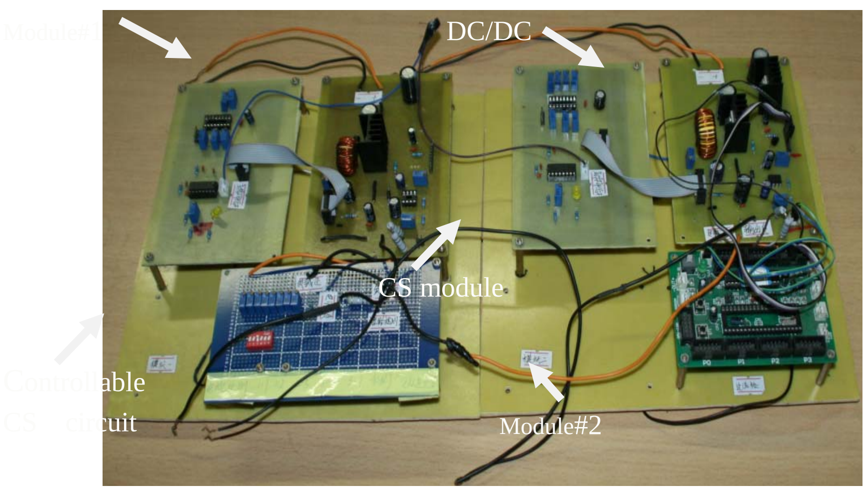


Figure7 Experiment Test-bed

A. The rated power and efficiency of each module is shown in Table. 1

B. Adjusting load resistance to change load current from 1.5A to 3.5A. The output voltage stabilize at 8.0±0.4V. This experimental model achieves proportional current sharing within a certain proportion (1.0~3.0). The relative error of output current is lower than 3%. The current sharing in proportion experiment results are shown in Table .2 and Figure8

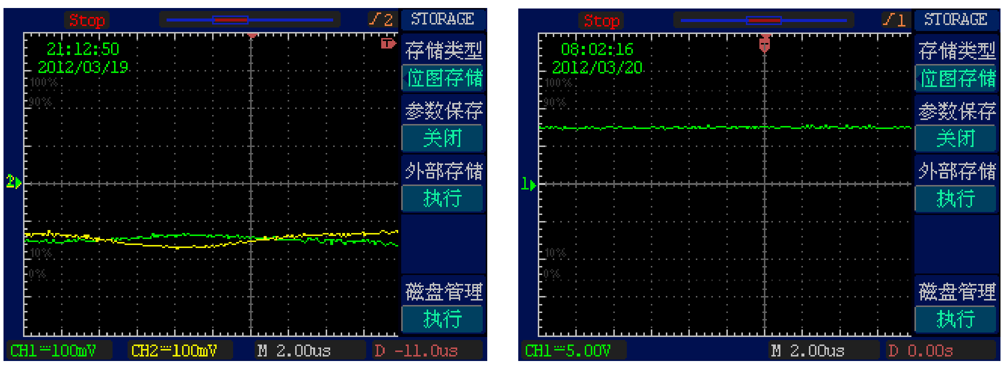
Table 1 Rate Power and Efficiency

	Uin	Iin	Pin	Uo	Io	Po	Efficiency
Power Module 1	25.4V	0.818A	20.97W	8.08V	1.954A	15.788W	75.28%
Power Module 2	23.23V	0.876A	20.35W	8.07V	1.903A	15.357W	75.47%

U_{in}：the input voltage of DC-DC converter；I_{in}：the input current of DC-DC converter；Pin：the power input of DC-DC converter；Uo：the output voltage of DC-DC converter；Io：the output current of DC-DC converter；Po：the power output of DC-DC converter；

Table 2 Current Sharing in Proportion

Proportion	Presetting current	Actual current	I1	I2	I1 relative error	I2 relative error
1:1	1.610A	1.609A	0.814A	0.795.A	1.10%	1.24%
1:2	2.20A	2.192A	0.713A	1.479A	2.32%	1.21%
1:3	3.50A	3.495A	0.866A	2.629A	1.02%	0.15%



(a) (b)

Figure8. Experiment Results for Current Sharing in Proportion (a) proportion at 1:1 (b) output voltage

6. CONCLUSION

This paper proposed a controllable current sharing method for paralleling switching power with different capacity. A summary of the work and some conclusions are as follows:

- This design achieves proportional (1.0~0.3) current sharing. Controllable current sharing module regulates the proportion and stabilizes output voltage through feedback signal.
- Experimental results show that the proposed method achieves good system performance. Each module's efficiency is higher than 75% and the relative error of each module's output voltage is less than 2%.
- Controllable current sharing can be done in a short time interval and automatically recovering is feasible after removing the overflow faults.

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