Connecting power supplies in parallel

Application note AN18-001

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Ioan Calapod, Eng.
Sr TSM, GE Power
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Foreword

It is important to highlight that this application note applies to paralleling of power supplies in general. It does not apply strictly to the CLP family of PSU’s. The CLP0412, within this family, was chosen just as an example because of the high maximum value of the current in secondary, with the goal of clarity and conciseness in exposing the advantages and disadvantages of different current sharing and ORing topologies.

Introduction – current sharing versus redundancy

Connecting power supplies in parallel is commonly used to increase the available output power or to provide system redundancy in the event of a power supply failure. The correct and reliable way to connect two or more power supplies in parallel is to have them equally share the load current. There are two main (analog) techniques for getting power supplies to share the load “active” and “droop” mode.

Current sharing allows for increased power output but if one of the PS’s fails the other one won’t be able to support the full load and will shut down and therefore no power will be supplied to the load (power system failure – no redundancy)

Let’s consider PS 1 and PS 2 (see Figure 1), both able to provide 35A. If using current sharing, they will be able to provide 70A. In the case of one of them failing, the other one won’t be able to sustain 70A and will go into current limit (usually set at 10-15% over the maximum current level – let’s say 38A) and then shut down.

In conclusion, the current sharing (for extra power) has the advantage of providing more power but cannot provide redundancy. Sometimes current sharing is used in order not necessarily to have more power but rather to increase MTBF for the system by having
the paralleled power supplies working at a percentage of their maximum power (50% when two power supplies are used.)
If the same two power supplies are connected through an ORing mechanism and the maximum current provided to the load is in fact the maximum current provided by each of them (PS1 or PS2 – 35A as per the previous example) then in case of one of the power supplies failing, let’s say PS 1, the second power supply, PS 2, will be able to support the load by itself, hence providing redundancy. The given system will continue being supplied!
While the two power supplies are in parallel they do share the current! (if the current required by the load is 35A then each power supply will provide 17.5A)

**Active current sharing**

Active current share uses a signal wire (called public bus) interlinking two or more power supplies.
In simple terms, the voltage on the wire is proportional to the total current supplied to the load.
That voltage is used to “inform” a unit that it is not contributing enough current, thus raising its output voltage to produce more current.
In most of the telecom and Datacom systems, the power supplies are usually rack mounted and plugged in to a PCB backplane. The current share connection is therefore identical from installation to installation. In industrial applications wires of different length are used for the public bus, sometimes they are too long and therefore exposed to EMC interference.
There are two types of active current sharing: auto average and auto maximum.

**Active Current Sharing – auto average**

Auto average current sharing connects current amplifier output of all parallel power modules to public bus through resistor R, which is called current-sharing bus. Its block diagram is shown in Figure 2. As can be seen, this topology is not too complex but with acceptable accuracy.
Caveat: however, if current-sharing bus is short or any module connected with this bus fails, the average voltage of bus to the other modules is reduced.
Therefore, if using this method for parallel power systems, an auto-withdrawal mechanism when a power module failed, is needed.
Active Current Sharing – auto maximum
Auto maximum current sharing is a dynamic method which determines master module automatically according to maximum output current. The differences between master module and slave modules are controlled respectively to regulate the current distribution, so it’s called “auto master/slave control method”. Its block diagram is shown in Figure 3. The parallel power sources are not isolated but connected through a current-sharing bus. It provides a current reference to every module and regulates output current according to the reference so that accurate current-sharing is achieved among parallel modules. This topology is avoiding system performance degradation due to one single module fault. However, master/slave modules are switching all the time, and it will result in low frequency oscillation at output current; besides, power modules regulate the output according to “maximum current”, it means all power modules except the master will increase output current. With constant load, current increments among slave modules are greater than current reduction of master module, which results in
output voltage being higher than rated voltage (known as “overvoltage”). “Overvoltage” may have some bad influence on safety, reliability and stability of power system and it will reduce the system dynamic response.

![Diagram of Switching Controller and Output](image)

**Figure 3: Active Current Sharing - auto maximum.**

**Active current sharing for the CLP family**
The CLP0412 PS offers the active sharing current, auto average method. Paralleling of up to four power units is supported. Current sharing of multiple units is implemented by connecting the Parallel pins together and connecting identical output voltage and remote sense polarity pins of the modules together at the load (see Figure 4). At load current levels above 20%, the output currents of multiple power supplies are within ±5% of the full load value. When not using this feature, paralleling pins should be left unconnected.
Droop sharing
One solution that does not need any current share connection (public bus) is droop mode.  
Droop mode is a very simple way of paralleling power supplies.  
The output voltage drops as in Figure 5 (droops intentionally) in proportion to the current drawn from the power supply. (droop variation of voltage at the output against the load current for 5 PSU’s is illustrated)  
If one power supply is supplying more current than the others, the output voltage will fall and then load balancing will occur.  
Certain electronic loads can be sensitive to variations in the supplied voltage (3.3V or 5V for logic ICs for example), but typically 12V, 24V or 48V outputs drive relays, DC/DC converters or motors and are more tolerant to droop mode current share.
For drooping paralleling to work well the power supplies to work in parallel need to be calibrated so that they have similar droop behavior. Droop sharing works better if the slope of the droop function is steeper. That exposes its limitations as a paralleling method as broader droop means poor load regulation!
Redundancy and active ORing

The uninterrupted availability of server, communications and telecom equipment is frequently critical to its client applications, so this equipment typically uses two or more power sources in a redundant power architecture.

Active ORing using Schottky diodes

Figure 6 shows a simple solution to providing redundancy using diodes. Schottky diodes are used as their forward voltage drop is smaller than for regular diodes.

Each diode allows current to flow in a forward direction only, while preventing either supply from drawing short-circuit current. Therefore, the system can continue to function if one supply fails this way providing redundancy.

In figure 7 a simple ORing circuit using Schottky diodes from Infineon, 15CGQ100 – 35A @ 100V, is shown. (Two CLP0412 outputs are OR’ed at maximum current loading of ~33A each, or ~66A in the RLoad)

Power lost on each diode in the OR’ing circuit is 38.3W! The Schottky diode used in this simulation example has a VF of 1.2 V @ 33A; it is possible to find better Schottky diodes that have VF only 0.6V @33A but even then, the power dissipated in one diode is ~20W!

If the values of the currents to be shared are smaller, the ORing with diodes can be a valid option. Care must be taken to terminate the remote sensing circuits for the power supplies just before entering the ORing (Anode of the diodes - physically on the PCB)
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Figure 7: OR'ing circuit using Schottky diodes.

Although simple and fast, this arrangement has a drawback due to the diodes' high forward voltage in their normal state of forward conduction. This creates high power and heat dissipation and an unwelcome need for thermal management and extra board space. As systems have increased in power and component density, these drawbacks have become unacceptable.
Active ORing using MOSFET’s and ORing controllers (”ideal” diodes)

Active ORing offers a better alternative; it comprises a power MOSFET and controller IC that together play the role of an “ideal” diode. The MOSFET has an on-state resistance RDS(ON) which, multiplied by the square of the current through the device, creates an internal power loss. However, this loss can be substantially lower than that of a Schottky diode for the same current; a ten times efficiency improvement is typically achieved. For example, for a 33 A application, a Schottky diode with a 0.6 V forward voltage drop would dissipate ~20 Watts of power, while a MOSFET (BSG0811NDQ2 from Infineon) with a 1 mOhm RDSon would dissipate only ~1W. Impressive reduction in power loss.

(see Figure 8 and 9)

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Figure 8: OR'ing using ideal diodes; controller from LT.
When it comes to power dissipation it is obvious that using MOSFET’s plus ORing controllers (“ideal” diodes) has a huge advantage, yet an active ORing solution requires care in its design and set-up. A MOSFET passes current in either direction when turned on, allowing the possibility of a large reverse current if one of the power sources has a short-circuit failure. This will bring down the system if it persists for too long. Therefore, the active ORing solution must be very accurate, and able to detect reverse current fault conditions extremely fast. When a fault is detected, the controller must turn the MOSFET off as fast as possible, isolating the input fault from the rest of the system.

The controller IC senses information across the MOSFET to determine the magnitude and polarity of current flowing through it. Transgression of its reverse current threshold indicates a power source failure; therefore, sensing in this case must be tightly accurate to provide the consistent, fast fault detection required. Speed of response is also critical, as this determines the magnitude and duration of reverse currents. Higher peak reverse currents increase reliability concerns, leading to larger MOSFETs, higher costs and more demand for real estate. These issues can be exacerbated by some of today’s low-impedance power architectures. Conversely, tight, fast control can mean the difference between a damaged system and a safe disconnect of a failed power supply.

Figure 9: Power dissipation in the MOSFET’s used in the ideal diodes is only 1W. Compare with 20W.
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In Conclusion, we can say that the best Active ORing solutions comprise an ORing controller that is fast and accurate in detection and fast in response, together with a MOSFET offering the lowest possible RDS(ON). These attributes allow minimized losses and dependence on thermal management, with smaller size and greater ease of use.

Example of ORing circuit for CLP0412
In the specific case of CLP0412, one suggested solution to use, is the TPS2412 ideal diode controller from TI designed specifically for ORing applications. TI has available an evaluation board, the TPS2412EVM. The MOSFET’s on the evaluation board will need to be replaced to handle the maximum current capability of the CLP0412; replace the original Si7336ADP from Vishay, 30A @ 30V, with CSD16570Q5B from TI, 100A @ 25V. Schematic and more information is provided in the TPS2412EVM user’s guide. Care must be taken to terminate the remote sensing circuits from the CLP0412’s just before entering the ORing (physically on the PCB).
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References
1) A Novel Parallel Current-sharing Control Method of Switch Power Supply by Chao Wu, Bingjuan Lu and Yuwang Ge.
2) ORing Controllers Facilitate Redundant Power Supply Design by Ashok Bindra
3) Paralleling power supplies using the droop method by Robert Kollman
4) TPS2412 N+1 and ORing Power Rail Controller evaluation board
5) TPS2412 N+1 and ORing Power Rail Controller datasheet
6) LTC4359 – ideal diode controller
7) CLP0412 – Compact Low Power AC/DC
8) BSG0811NDQ2- Power MOSFET
9) Si7336ADP – Power MOSFET
10) CSD16570Q5B
11) 15CGQ100