Advel Application Note – AAN2013.1

Current Sharing: passive vs active

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1. Introduction

When some power supplies are put in parallel, it's recommended to calibrate these at the same output voltage. The calibration must be made in a no-load condition at a precise voltage, before putting them in parallel.
However in reality every power supply output voltage vary slightly in time, also vary with temperature, and even the wiring between a power supply and the other in parallel is cause of asymmetries that determines a different current sharing between power supplies in parallel. All of these issues have already been treated in the **AAN 2009.1**.

To avoid this problems, it would be great that the power supplies in parallel can automatically equally share the load current.
Now will be considered the characteristics of the two types of **CS** (current-sharing) feature of the power supplies present in the market: PASSIVE and ACTIVE current-sharing.

2. Power supply without CS

In Figure1 is showed the block scheme of a typical stabilized switching power supply.

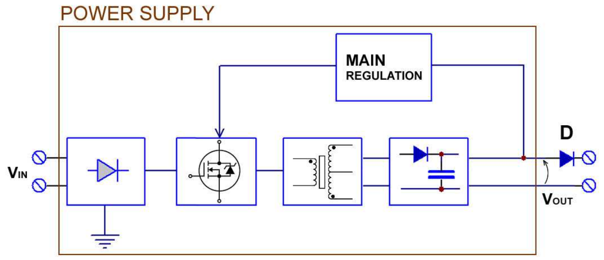

Figure1 *– Block scheme of a stabilized switching power supply.*

The presence of diode **D**, the so called 'decoupling diode' or 'parallel diode' is necessary to put in parallel the power supply (see **AAN2009.1**). This diode can be placed externally, or inside the power supply (as for power supplies manufactured by Advel).

The output voltage, before the diode D, is stabilized by the MAIN-REGULATION block at the rated voltage.

The I/V characteristic of the power supply is represented in Figure 2: the output voltage of the power supply is maintained at the rated voltage output (V_{RATED}) until the load current reaches the value I_{MAX}, over which the voltage begins to drop sharply.

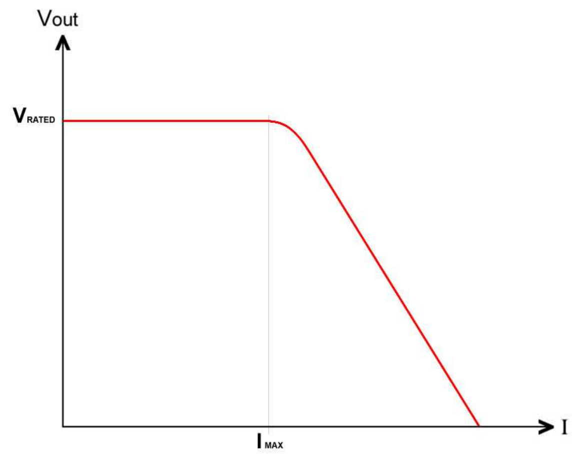

Figure2 *– Typical characteristic of the regulated power supply, without a current-sharing feature.*

Example: two power supplies are in parallel with identical 24.0V output voltage as in Figure3. The load is 20A total.

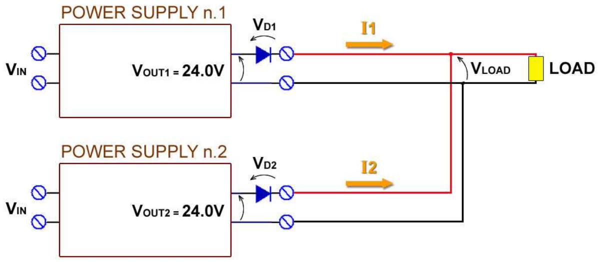

Figure3 *– Two power supplies calibrated at 24,0V put in parallel, with ideal wire ($R_{wire} = 0\Omega$).*

Assuming the wiring cables are ideal ($R_{wire} = 0\Omega$), the currents of the two diodes are identical (then $V_{D1} = V_{D2} = V_D$), and the load is subjected to this voltage:

$V_{LOAD} = 24{,}0V - V_D$

and $I_1 = I_2 = 10A$.

But unfortunately indeed the cables are real, then we must consider the length of the connection cables to determine the corresponding voltage drop (not always negligible).

We need to use some realistic parameters:

ℓ_1 = 1mt (distance between SPS n.1 and the parallel-points of the power supplies)

ℓ_2 = 2mt (distance between SPS n.2 and the parallel-points of the power supplies)

For example, using a 2.5mm^2 wiring cable, the corresponding resistors are:

$$R_1 = \frac{0{,}018 \times 2\ell_1}{S_1} \cong 15m\Omega$$

$$R_2 = \frac{0{,}018 \times 2\ell_2}{S_2} \cong 30m\Omega$$

(note that for a distance ℓ between power supply and load, you need a 2ℓ lenght cable, cause of the positive and the negative cable. In addition the result is rounded up, to take in account the contact resistance cable-terminals).

It's also decided to use the classic Schottky diodes: D1 = D2 = **MBR6045**.
The system is shown in Figure4.

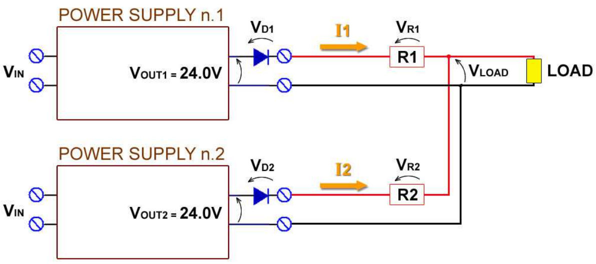

Figure4 *– Two power supplies calibrated at 24,0V (no load) then put in parallel with a 2.5mm^2 wire, the power supplies are 1m and 2m respectively far from the parallel point.*

To determine the currents for each power supply, I_1 and I_2, the following system must be solved:

$$\begin{cases} V_{OUT1} - V_{D1} - I_1 \cdot R_1 = V_{OUT2} - V_{D2} - I_2 \cdot R_2 \\ I_1 + I_2 = 20A \end{cases}$$

Moreover V_{D1} and V_{D2} depend respectively on I_1 and I_2, and are derived from the I/V characteristic of the diode MBR6045, showed in Figure5.

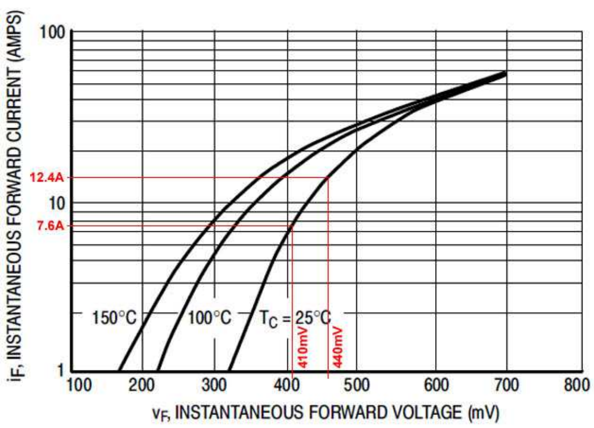

Figure5 *– Direct I/V characteristic of diode MBR6045, taken from On Semiconductor original datasheet.*

As shown in Figure5 V_{D1} and V_{D2} also depend on the diode temperature. We assume the diode temperature equal to 25°C, for simplicity of calculation.
Graphically it's found that the system is solved for:
I_1 = 12.4A and I_2 = 7.6A
while the load is subjected to voltage:
V_{LOAD} = 23.36 V.

The just seen example makes it clear how important is the wiring connection between the power supplies in parallel.

3. Power supply with passive CS
The block diagram of a stabilized switching power supply with passive current-sharing functionality is apparently identical to that of Figure1.
However in this case the I/V characteristic of the power supply, presented as in Figure6, changes: the nominal output voltage (V_{RATED}) tends to decrease linearly with increasing load current. Then, just passed I_{MAX} , the output voltage starts to fall off more abruptly.

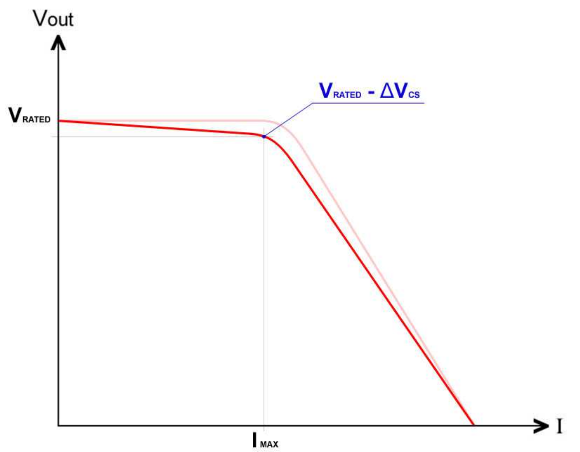

Figure6 *– I/V characteristic of a stabilized switching power supply with passive current-sharing functionality.*

We repeat the example given above to see how the result changes:

load = 20A

ℓ_1 = 1mt → R_1 = 15mΩ

ℓ_2 = 2mt → R_2 = 30mΩ

wire = 2.5mm^2

D1 = D2 = **MBR6045** (On Semiconductor)

diode temperature = 25°C

The passive-CS linearly lowers the voltage V_{out} with increasing of load current, with a typical rate 50mV/A (value that can still vary depending on the manufacturer of power supplies).

The system is summarized in Figure 7.

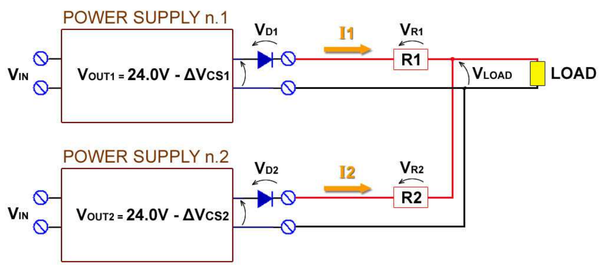

Figure7 *– Two power supplies (with passive current-sharing feature) calibrated at 24,0V (at no load) then paralleled with 2.5mm² wiring cable, the power supplies are 1m and 2m respectively far from the parallel point.*

The system to be solved is:

$$\begin{cases} V_{OUT1} - V_{D1} - I_1 \cdot R_1 = V_{OUT2} - V_{D2} - I_2 \cdot R_2 \\ I_1 + I_2 = 20A \end{cases}$$

with:

$$V_{out1} = 24.0V - \Delta V_{CS1}$$

and $V_{out2} = 24.0V - \Delta V_{CS2}$

and as seen previously V_{D1} and V_{D2} depend respectively on I_1 and I_2.

It is not easy to solve exactly the system, but intuitively it is clear that the decrease in V_{out} (resulting on the increasing load current), improves the equitable current sharing of the current.

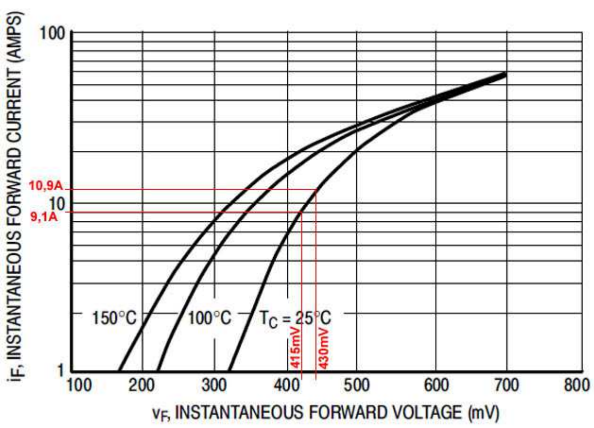

Figure8 *– Direct I/V characteristic of diode MBR6045, taken from On Semiconductor original datasheet.*

From Figure 8, and considering
V_{out} = 24,0V – (50mV x I)
the system is solved for:

I_1 = 10,9A and I_2 = 9,1A
while the load is subjected to voltage:
V_{LOAD} = 22,85V.

As you can see, the passive current-sharing has just a little improved the current sharing, compared to the previous case.
In contrast, however, V_{LOAD} is decreased, especially for the operation of the passive current-sharing behaviour.

Note that the temperature, which in this discussion we considered constant and equal to 25°C, in reality tends to worsen the current sharing: every diode heats up as a function of the flowing current, consequently lowering its V_d, and therefore this (physical) behavior is opposed to an equal current sharing.

4. Power supply with active CS

In a power supply with active current-sharing feature, the control stage is composed of two blocks:
the block called MAIN-REGULATION tries to keep the output voltage V_{out} stabilized at the rated value,
a second block CS-REGULATION instead tries to raise V_{out} if I_{out} is lower then the output current of the other power supplies in parallel.
The communication with the other power supplies is realized with an interconnecting cable between the power supplies.
In Figure9 is represented the block diagram of a switching power supply with active current-sharing feature.

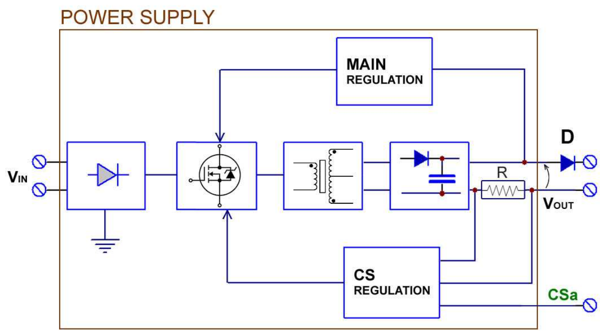

Figura9 *– Block scheme of a stabilized switching power supply with attive current-sharing functionality*

Here we don't care the details of the operation of CS-REGULATION control block.
Instead we repeat the example made in the previous two cases and see how the result changes:

load = 20A

ℓ_1 = 1mt → R_1 = 15mΩ

ℓ_2 = 2mt → R_2 = 30mΩ

wire = 2.5mm²

D1 = D2 = **MBR6045** (On Semiconductor)

diode temperature = 25°C

active-CS through CSa cable

The test was performed using two power supplies **SPS501DZ1_230A-24-20** manufactured by Advel, and containing internal decoupling diodes MBR6045 (Figure 10).
These power supplies, that have the active current sharing functionality, have been calibrated at 24.0V (no load) then placed in parallel, as per the procedure recommended in the data sheet of the product.

Figure10 *– Power supplies SPS501DZ1 used in the test.*

Results:

$V_{o'}$ = 23,6V(*) and I_1 = 10,2A
$V_{o''}$ = 23,75V(*) and I_2 = 9,8A
while the voltage is subjected to voltage:
V_{LOAD} = 23,45V.

(*) $V_{o'}$ e $V_{o''}$ readings after the decoupling diode, that are internal.

To make a comparison with precious cases, assuming $V_{d1} \sim V_{d2}$ = 0,425V @25°C, we have:
V_{out1} = 23,6V + 0,425V = 24,025V
V_{out2} = 23,75V + 0,425V = 24,175V

The system is summarized in Figure 11.

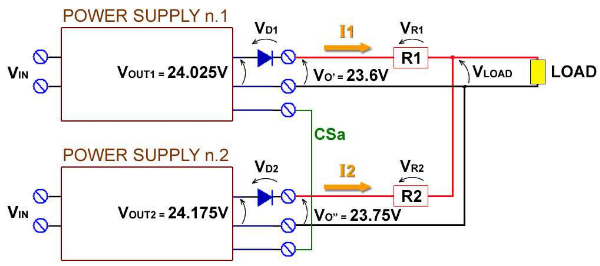

Figure11 *– Two power supplies (with active current-sharing feature) calibrated at 24,0V (no load) then paralleled with 2.5mm² wiring cable, the power supplies are 1m and 2m respectively far from the point of parallel. The CSa cable is wired, to enable active current sharing.*

Note that the active current-sharing makes the second power supply raise its output voltage to compensate the voltage drop on the connecting cables and thus allows a more equitable distribution of load.

5. Comparison of the systems, using calibrated power supplies

The comparison of the three just seen systems (no-CS, passive-CS, active-CS) is shown in Table1 and graphically in Figure12. The conditions of the systems are the following: power supplies calibrated at 24.0V (at no-load), then placed in parallel with 2.5mm² connection cables, power supplies are 1m and 2m respectively far from the load, total load 20A.

	SPS1	SPS2	
Vout (rated at no-load)	**24,0V**	**24,0V**	**dev.**
Iout (no-CS)	12,4	7,6	24,00%
Iout (passive-CS)	10,9	9,1	9,00%
Iout (active-CS)	10,2	9,8	2,00%

Table1 *– Results of the 3 systems just seen, calibrated at 24,0V (no load) then put in parallel.*

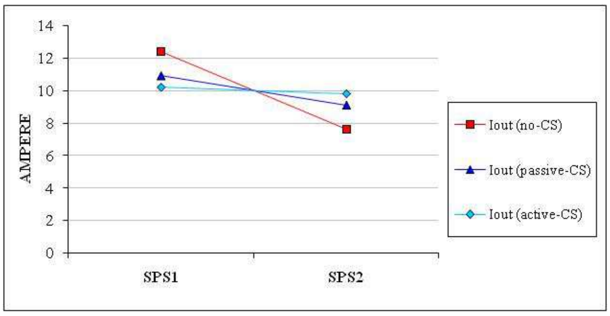

Figure 12 *– Graphical representation of Table1 results.*

It must be said that the results of CS-passive system are theoretical, and to simplify the calculations were not taken into account the diode temperature, which increases with the current, and in reality would tend to worsen the current sharing.
This reinforces even more the excellent results obtained with the active-CS system, tested with the SPS501DZ1 manufactureb by Advel:
the average deviation was only 2% using active-CS, compared to 9% with passive-CS and 24% without CS.

6. Comparison of the systems, using uncalibrated power supplies

It's useful to repeat the test using uncalibrated power supplies, in fact, as said, after years of operation, the power supplies can become uncalibrated each other, because of the inevitable aging of the internal components.
So for example we calibrate the power supplies at 24.1V and 24.0V respectively (calibration at no load, as in Figure 13).

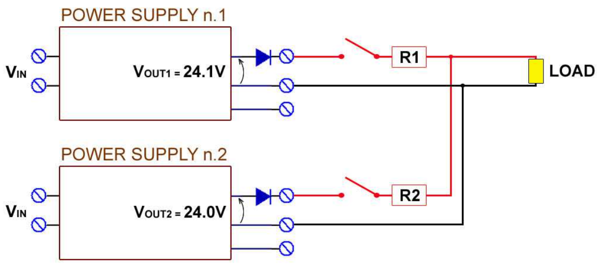

Figure13 *– New test: two power supplies calibrated (no load) at 24,1V and 24,0V respectively. Then the power supplies will be put in direct parallel with a 2.5mm² wire, respectively 1mt and 2mt far from the parallel point, in the systems: no-CS, passive-CS and active-CS.*

no-CS:
as done previously, we assume T = 25°C for the decoupling diodes, and repeating the calculations made above, we get:
V_{out1} = 24,1V and I_1 = 15.2A
V_{out2} = 24, 0V and I_2 = 4.8A
V_{LOAD} = 23,41V

passive-CS:
as done previously, we assume T = 25°C for the decoupling diodes, and repeating the calculations made above, we detected:
V_{out1} = 23,48V and I_1 = 11.6A
V_{out2} = 23,56V and I_2 = 8.4A
V_{LOAD} = 22,91V

active-CS:
on a real system realized with two **SPS501DZ1** manufactured by Advel, we detected:
V_{out1} = 24,1V and I_1 = 10.3A
V_{out2} = 24,19V and I_2 = 9.7A
V_{LOAD} = 23,47V

The comparison of the three systems just seen (no-CS, passive-CS and active-CS) with power supplies specially calibrated with a 100mV error, is shown in Table2 and graphically in Figure 14.

	SPS1	SPS2	
Vout (rated at no-load)	**24,1V**	**24,0V**	**dev.**
Iout (no-CS)	15,2	4,8	52,00%
Iout (passive-CS)	11,6	8,4	16,00%
Iout (active-CS)	10,3	9,7	3,00%

Table2 *– Results of the 3 systems just seen, calibrated at 24,1V and 24,0V respectively (no load) then put in parallel.*

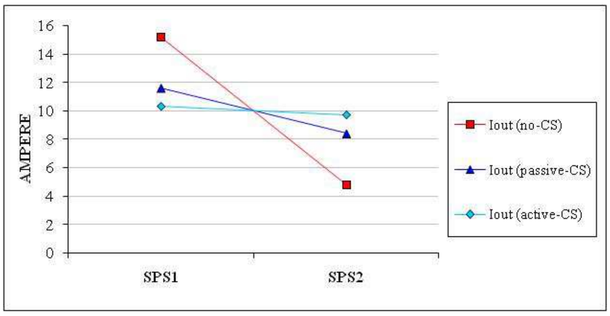

Figura 14 *– Graphical representation of Table2 results.*

Even in this case the active-CS ensures an imbalance not exceeding 3%, quite acceptable. Note that the control block CS-REGULATION raise the output voltage of the power supply that delivers less current (n.2) up to 200mV, compensating for both the voltage drop of the cable, and the calibration error.

6. Conclusions

Have been compared three systems consisting of two power supplies in parallel, specially wired with different lengths cables, and not well calibrated. The system with power supplies SPS501DZ1, manufactured by Advel, having **CSa** (active current sharing feature) have allowed a distribution of current more than acceptable between the power supplies in parallel. On the other hand the system with **CSp** (passive current sharing) gave unsatisfactory results, and just slightly better than the system without the CS functionality. Moreover, the same voltage drop on the connecting cables realizes a CSp.

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