Parallel operation of switchmode power supplies

Technical details for passive current-sharing

The aim of operating switchmode power supplies (SMPS) in parallel is to increase output power by increasing the output current. How this can best be achieved by using the passive current-sharing method is described in the following article.

By Martin Rosenbaum

There are two methods of realising parallel operations that conform with today´s state-of-the-art technology. Firstly, using active current-sharing (controlled load-sharing) and secondly, using passive current-sharing.

Active current-sharing measures the output current of each power supply and adjusts the output voltage of each individual SMPS to produce uniform current distribution. This method has the advantage of ensuring very exact current-sharing and constant loading of the SMPSs operated in parallel. The disadvantages are the need for additional components and higher costs.

By comparison, in the case of passive current-sharing, the current is distributed as uniformly as possible via a "soft output characteristic" (Fig.1) for each SMPS. This approach has the advantages of needing less switching technology and allowing for parallel use of an almost unlimited number of SMPSs. The somewhat more inaccurate current distribution must be seen as a disadvantage.

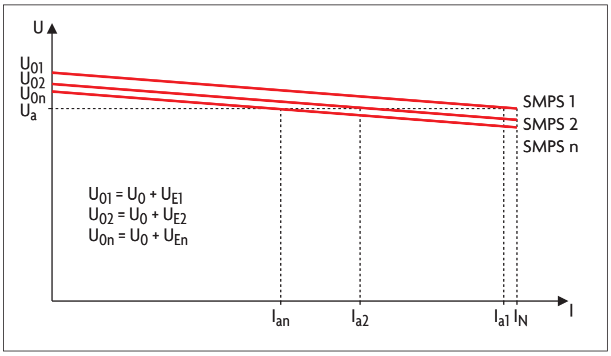

Fig. 1. Characteristic lines („soft characteristics“) of n switchmode power supplies operated in parallel.

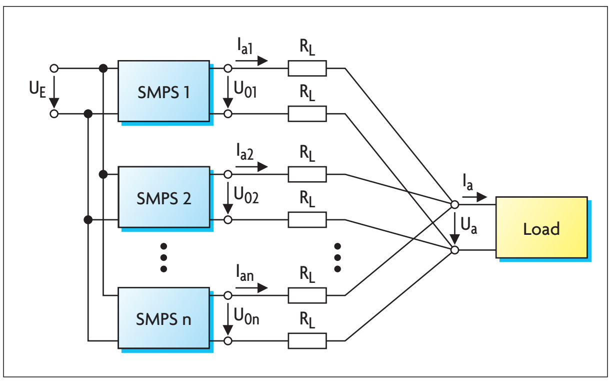

Fig. 2. Symmetric cabling is a basic requirement for using switchmode power supplies in parallel.

Passive current distribution -the basics

Some important details on passive current-sharing follow, based on the assumption that the following requirements have been met.

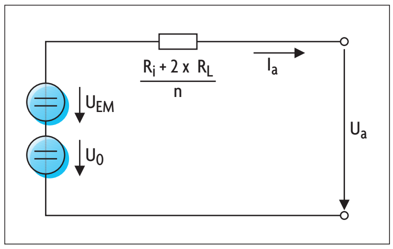

Fig. 3. Equivalent circuit diagram for parallel use of n switchmode power supplies.

- n identical switchmode power supplies are used in parallel.
- Each switchmode power supply is symmetrically cabled to the load (Fig. 2)

The following n equations for the n switchmode power supplies form the basis for calculating parallel operation.

1. $U_{a1} = U_0 + U_{E1} - (R_i + 2R_L)\ I_{a1}$
2. $U_{a2} = U_0 + U_{E2} - (R_i + 2R_L)\ I_{a2}$
3. $U_{a3} = U_0 + U_{E3} - (R_i + 2R_L)\ I_{a3}$

....

n. $U_{an} = U_0 + U_{En} - (R_i + 2R_L)\ I_{an}$

Requirements for parallel operation of n switchmode power supplies:

$$U_{a1} = U_{a2} = U_{a3} = ... = U_{an}$$

and

$$I_a = I_{a1} + I_{a2} + I_{a3} + ... + I_{an}$$

This gives rise to the following equation system for the n SMPSs operated in parallel.

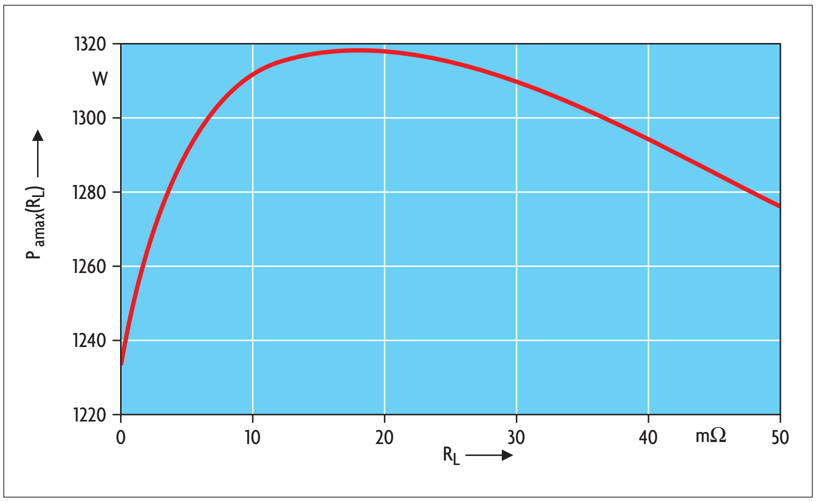

Fig. 4. Maximum load output in relation to wire resistance. (The diagrams shown in Figures 4...8 are available upon request for all switchmode power supplies with passive current-sharing designed for parallel operation purchased for example from the company MGV Stromversorgungen (www.mgv.de).)

$$U_a = U_0 + U_{E1} - (R_i + 2R_L)\, I_{a1}$$
$$U_a = U_0 + U_{E2} - (R_i + 2R_L)\, I_{a2}$$
$$U_a = U_0 + U_{E3} - (R_i + 2R_L)\, I_{a3}$$
$$\dots$$
$$U_a = U_0 + U_{En} - (R_i + 2R_L)\, I_{an}$$

After a number of simplifications, various equations for the n SMPSs operated in parallel can be deduced with the aid of this equation system. But first of all, the definition of the mean value of the setting tolerances:

$$U_{EM} = \frac{1}{n} \cdot \sum_{i=1}^{n} U_{Ei}$$

Voltage at load:

$$U_a = U_0 + U_{EM} - \frac{R_i + 2 \cdot R_L}{n} \cdot I_a \qquad (1)$$

Based on equation (1), the equivalent circuit diagram for the n SMPSs used in parallel can be constructed as shown in Fig. 3.

It is amazing that this results in such a simple equivalent circuit diagram (ECD) for a parallel connection. The ECD consists of only three elements. On the one hand, it is made up of two voltage sources with parameters that are easy to ascertain. Added to these is a resistance, which can also be simply calculated based on the power supply´s internal resistance, the wire resistance (load wire) and the number of switchmode power supplies in parallel connection. By going a step further and adding together the two voltage sources, one arrives at an equivalent circuit diagram for a real equivalent voltage source consisting of an ideal voltage source and internal resistance.

Current at the kth switchmode power supply ($1 \leq k \leq n$):

$$I_{ak} = \frac{U_{Ek} - U_{EM}}{R_i + 2 \cdot R_L} + \frac{1}{n} \cdot I_a \qquad (2)$$

Accuracy of the current-share at the kth power supply ($1 < k < n$):

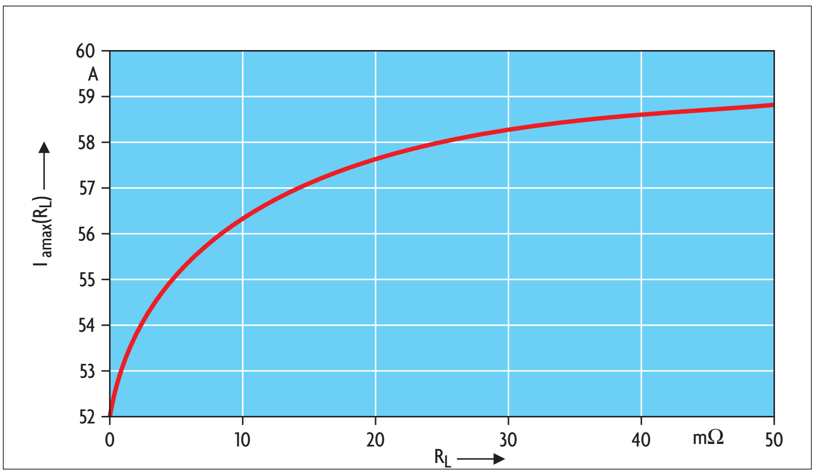

Fig. 5. Maximum available current that can be drawn from the parallel series in relation to wire resistance.

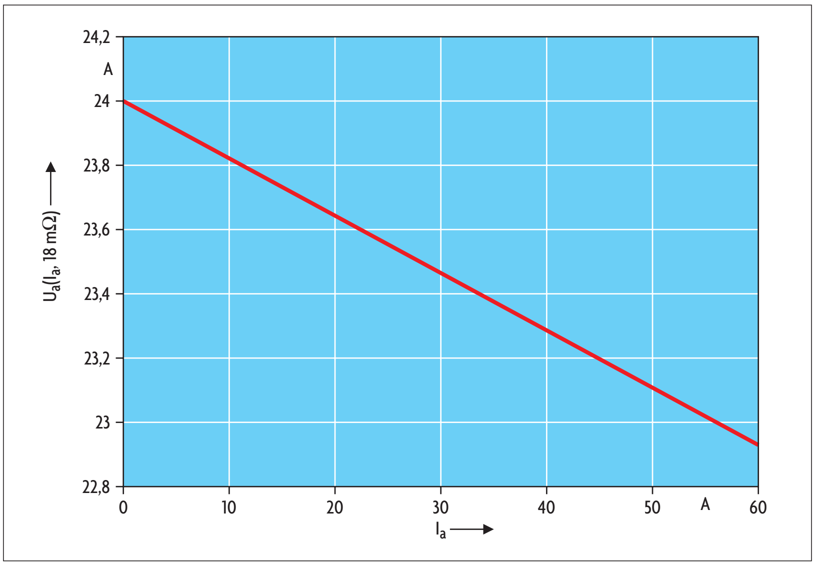

Fig. 6. Load voltage in relation to load current at optimal wire resistance.

$$\Delta I_{ak} = \frac{U_{Ek} - U_{EM}}{\frac{I_a}{n}\cdot(R_i + 2\cdot R_L)} \qquad (3)$$

Analysing equation (2) more closely, it will be noted that the second part of the sum represents the share of current in the case of equal current distribution across the parallel connection. It is therefore logical that the first part of the sum represents the deviation from this uniform current distribution. By calculating the deviation as a proportion of the current produced by an SMPS in the case of uniform current-sharing, one arrives at the deviation in percentage terms (equation (3)). It is interesting to note the factors affecting this percentage deviation. For instance, the current share becomes more exact as the load current (see Fig. 7), internal resistance and wire resistance increase. Furthermore, the accuracy of the current share also increases, the nearer the setting tolerance moves towards the mean value of the tolerance of adjustment.

The maximum current that can be drawn from the parallel connection (assuming $U_{E1} > U_{En}$ and I_{a1} = 1N) is:

$$I_{a\,max} = n\cdot I_N - \frac{n\cdot\left(U_{E1} - U_{EM}\right)}{R_i + 2\cdot R_L} \qquad (4)$$

The maximum current that can be drawn from the parallel series is reached when the switchmode power supply with the highest no-load-operation (in this case, SMPS 1 is assumed to have the highest no-load-operation) draws the rated current. The total output current of all other SMPSs is therefore always lower, or not more than the rated current of one SMPS (Fig. 1). The maximum load output in relation to the wire resistance when drawing the maximum current amounts to:

$$P_{a\,max} = \left[U_0 + U_{E1} - I_N\cdot\left(R_i + 2\cdot R_L\right)\right]\cdot \left[n\cdot I_N - \frac{n\cdot\left(U_{E1} - U_{EM}\right)}{R_i + 2\cdot R_L}\right] \qquad (5)$$

Calculation example demonstrating application of the derivative formulae

The following switchmode power-supply data are assumed for the purpose of this example:

- Nominal voltage: U_0 = 24V
- Rated current of one SMPS: I_N = 20A
- Internal resistance of the SMPS: R_i = 17.5mΩ
- Switchmode power supplies used in parallel: n = 3
- Setting tolerances of the three power supplies:

U_{E1} = 50mV, U_{E2} = -10mV, U_{E3} = - 30mV
Mean value of setting tolerance:
U_{EM} = 1/3 (50mV – 10mV - -30mV)
U_{EM} = 3.33mV

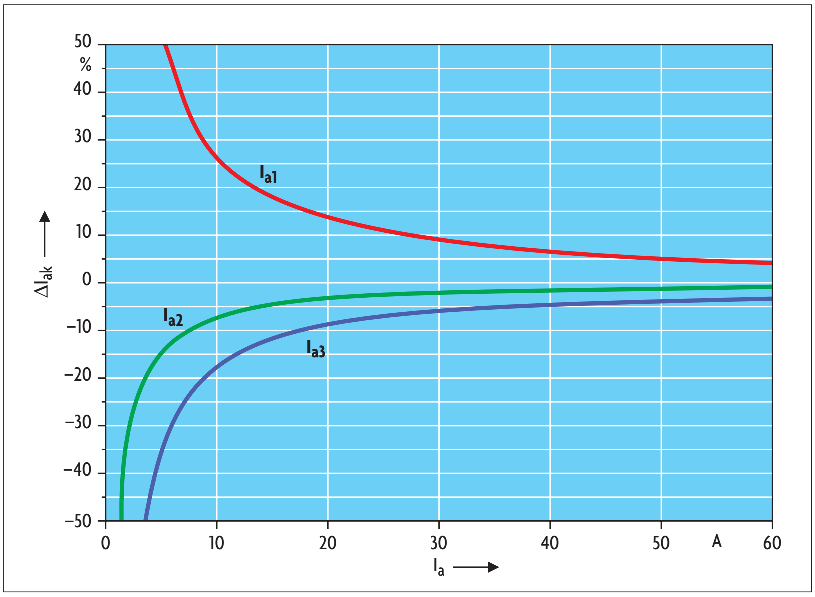

Fig. 7. Percentage current-share in relation to the load current at optimal wire resistance.

Determinating the level of wire resistance based on the maximum available output that can be drawn off by the load, applying concrete values (see also Fig. 4)

$$P_{a\,max} = \left[24.05\text{ V} - 20\text{ A}\cdot\left(17.5\text{ m}\Omega + 2\cdot R_L\right)\right]\cdot \left(60\text{ A} - \frac{140\text{ mV}}{17.5\text{ m}\Omega + 2\cdot R_L}\right) \quad (5a)$$

The optimal wire resistance can be read off on the diagram shown under Fig. 4 at the point where the output reaches its maximum. In the case of this sample calculation, optimal wire resistance is reached at about 18mΩ. All further calculations will be based on this optimal wire resistance.

Maximum current which can be drawn from the parallel connection, applying concrete values:

$$I_{a\,max} = 60\text{ A} - \frac{140\text{ mV}}{17.5\text{ m}\Omega + 2\cdot R_L} \quad (5b)$$

According to Fig. 5, the maximum current that can be drawn from the parallel supplies, taking into account the optimal wire resistance, amounts to about 57.5A. This figure is equivalent to 95.8% of the 60A that are theoretically possible.

The load voltage in relation to the load current at an optimal wire resistance of R_L = 18mΩ (Fig. 6) is calculated as the result of:

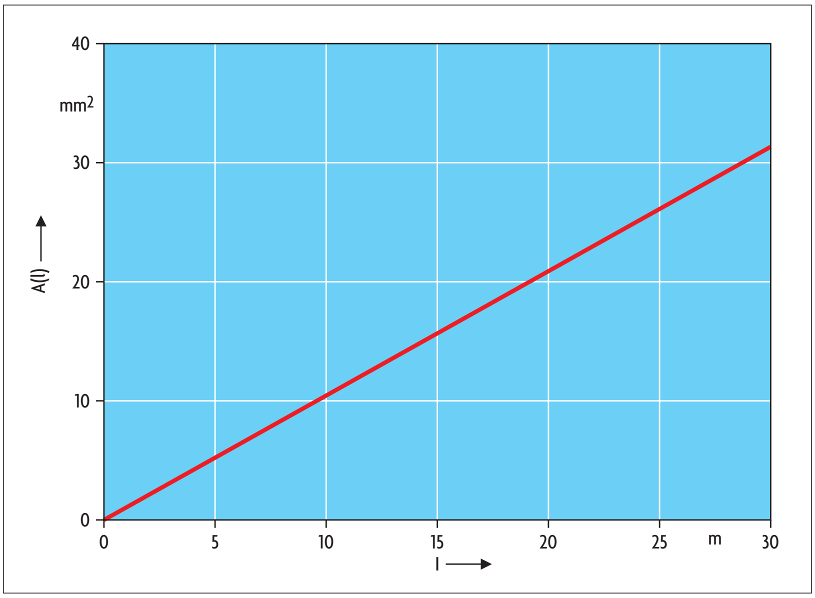

Fig. 8. Cross-section of the wire in relation to its length for optimal wire resistance.

Abbreviations used

A	Wire cross-section	R_i	Internal resistance of the SMPS
ECD	Equivalent circuit diagram	R_L	Load-wire resistance (go-and-return lead)
i	Index number	SMPS	Switchmode power supply
ΔI_{ak}	Percentage deviation of the current share at the kth SMPS	U_a	Output voltage of the SMPSs operated in parallel
I_a	Load current	U_{an}	Output voltage of the nth SMPS
I_{amax}	Maximum available load current	U_E	Input voltage
I_{an}	Output current of the nth SMPS using parallel operation	U_{EM}	Mean value of the setting tolerances
I_N	Rated output current of an SMPS	U_0	Nominal open-circuit voltage
κ	Electrical conductivity	U_{0n}	Actual open-circuit voltage of the nth SMPS
k	Index number	U_{En}	Setting tolerance of the output voltage for the nth SMPS (calculated as the open-circuit voltage minus rated voltage)
l	Wire length		
n	Number of SMPSs operated in parallel		
P_{amax}	Maximum load output		

$$U_a = 24.0033V - 17.83m\Omega \cdot I_a$$

Percentage current-share (based on Ia/n) of the three power supplies in parallel series in relation to the load current at optimal wire resistance:

$$\Delta I_{a1} = 2.617A/Ia$$
$$\Delta I_{a2} = 0.748A/Ia$$
$$\Delta I_{a3} = 1.869A/Ia$$

Fig. 7 illustrates clearly the interrelation between the current share and the load current. The zero-per-cent line on the vertical axis of the diagram corresponds with a uniform current share, meaning that each switchmode power supply is providing the same current. Very small load currents lead to extremely unfavourable current distribution. As a rule, this does not however present a problem, as in such case the individual SMPSs are operated far below their rated output. From a load current of about 25A upwards, the divergence in the current shares is under 10% and at the maximum level of available current, even lower than 5%.

As far as the user is concerned, it is not so much the optimal wire resistance that is of interest as the cross-section measurement of the wire that should be used in relation to its length in order to realise an optimal wire resistance. This can be calculated using the well-known formula for wire resistance:

$$R_L = \frac{1}{\kappa \cdot A} \qquad (6)$$

Preparing a diagram based on this equation can help to determine relatively quickly and simply the required cross-section of the wire at a given length, based on the assumption of maximum available output.

The diagram shown in Fig. 8 must be qualified by pointing out that the cross-section of the wire is subject to a minimum value (current carrying capacity of cables in accordance with the relevant regulations).

In view of the minimal cross-section measurements, it will not be possible to realise optimal wire resistance in the case of every application. However, care should by all means be taken to ensure symmetrical cabling of the individual switchmode power supplies.

Martin Rosenbaum
Qualified engineer

was born in Coburg. After training as a power-plant electronics engineer and gaining two years´ skilled experience in this field, he studied electrical engineering at Coburg Polytechnic, specialising in Electrical Power-Technology. After completing his studies, he supervised a research project at Coburg Polytechnic on the subject of "Inverter-fed asynchronons machine". Since October 1997, he has been active for the company MGV Stromversorgungen, both developing standard switchmode power supplies and realising customised solutions.
E-mail: martin.rosenbaum@mgv.de