Most paralleled power components — transistors, rectifiers, power conversion modules, offline power supplies — will not inherently share the load. In the case of power converters, one or more of the converters will try to assume a disproportionate or excessive fraction of the load unless forced current share control is designed into the system. One converter — typically the one with the highest output voltage — may deliver current up to its current limit setting, which is beyond its rated maximum. Then the voltage will drop to the point where another converter in the array — the one with the next highest voltage — will begin to deliver current. All of the converters in an array may deliver some current, but the load will be shared unequally. Built-in current limiting may cause all or most converters to deliver current, but the loading will remain unbalanced.

If one module in a two-module array is providing all of the load and it fails, the load on the second module must go from no load to full load, during which time the output voltage is likely to droop temporarily. This could result in system problems, including shutdown or reset. If both modules were sharing the load and one failed, however, the surviving module would experience a much less severe transient (one half to full load), and the output voltage would be likely to experience no more than a slight momentary droop. In a current-sharing system, all of the converters or supplies run at a lower temperature than some modules would in a system without current sharing. As a result, all of the modules age equally.

Current sharing, then, is important because it improves system performance: it minimizes transient / dynamic response and thermal problems and improves reliability. It is an essential ingredient in most systems that use multiple power supplies or converters for higher output power or for fault tolerance.

One of the common methods of forcing load sharing in an array of parallel converters is to sense the output current of each converter and compare it to the average current. Then, the output of a given converter is adjusted so that its contribution is equal to the average. This is usually accomplished by current-sense resistors in series with the load, a sensing amplifier for each converter module, and a summing amplifier. Load sharing is accomplished by actively trimming the output voltage using trim or sense pins.

The resistor values typically range from a few milliohms up to about 100 milliohms, depending on the power level or current range of operation. Selecting the right value requires a tradeoff between power dissipation and sensitivity (signal-to-noise ratio or noise immunity). The larger the resistor value, the better the noise immunity, but, of course, the greater the power dissipation. Determining the size of the resistor needed to generate a signal above the noise can be a bit tricky — a potential pitfall. Another potential pitfall with this (or, for that matter, any other) approach is the need for good electrical and mechanical design and layout — adequate trace widths, minimized trace lengths, and decoupling to reduce noise. An experienced designer should have no difficulty with this, but it is an area rich with opportunities for error.

The droop-share method, shown in Figure 1, artificially increases the output impedance to force the currents to be equal. It is accomplished by an error signal which is interjected into the control loop of the converter causing the output voltage to operate as a function of load current. As load current increases, output voltage decreases. All of the modules will have approximately the same amount of current because they are all being summed into one node. If one supply is delivering more current than another supply, its output voltage will be forced down a little so that it will be delivering equal current for an equal voltage out of that summing node. Figure 1 illustrates a simple implementation of this scheme where the voltage dropped across the auctioneering diode, being proportional to current, is used to adjust the output voltage of the associated converter.
Droop share has advantages and disadvantages. One of the advantages is that it can work with any topology. It is also fairly simple and inexpensive to implement. A major drawback, though, is that it requires that the current be sensed. A current-sensing device is needed in each of the converters or power supplies. In addition, a small penalty is paid in load regulation, although in many applications this is not an issue.

Most converters can employ the driver / booster (or master / slave) array for increased power (see Figure 2). Driver / booster arrays usually contain one intelligent module or driver, and one or more power-train-only modules or boosters. The driver is used to set and control output voltage, while booster modules, as slaves to the master, are used to extend output power to meet system requirements.

![Figure 2 – Current sharing driver / booster array for output power expansion](image)

It is important to remember that when using boosters, the input voltage, output voltage, and output power of the boosters must be the same as the driver.

The advantages of driver / booster arrays are that they have only a single control loop so there are no loop-within-a-loop stability issues, and they have excellent transient response. However, this arrangement is not fault tolerant. If the driver module fails, the array will fail to maintain its output voltage.

Analog current-share control involves paralleling two or more identical modules, each containing intelligence. The circuit actively adjusts the output voltage of each supply so that the multiple supplies deliver equal currents. This method, however, has a number of disadvantages. Each converter in the array has its own voltage regulation loop, and each requires a current sensing device and current control loop.

Analog current-share control supports a level of redundancy, but it is susceptible to single-point failures within the current share bus that can, at best, defeat current sharing, and, at worst, destroy every module in the array. The major reason for this is the single-wire galvanic connection between modules.

Current sharing is an essential element in fault-tolerant arrays, and regardless of the approach, there is an inherent additional cost incurred by the addition of at least one redundant converter or supply.

A power supply failure can cripple an entire system, so a redundant converter or supply can be added to ensure that, in the event of a failure, the system will continue to operate. Adding an extra module (N+1) to a group of paralleled modules will significantly increase reliability with only a modest increase in cost.

Synchronous current sharing (see Figure 3) is available with variable frequency converters — converters that use the zero-current-switching topology. Each module has the capability to assume control of the array, that is, they constitute a democratic array. The module that assumes command transmits a pulse on the parallel bus to which all other modules on the bus synchronize.
The converter modules use this pulse as a current-sharing signal for power expansion and fault-tolerant applications. The pulsed signal on the parallel bus simplifies current-sharing control by synchronizing the high-frequency switching of each converter. The parallel pin is a bi-directional port on each module used to transmit and receive information between modules. If the lead module relinquishes control, a new module will transparently take command with no perturbation of the output bus.

A pulsed signal also gives designers the option to add capacitors or transformers between parallel pins, providing DC-blocked coupling. Such coupling prevents certain failure modes internal to a single module from affecting the other modules in the array, thus providing an increased level of fault tolerance.

Use of a current-share bus transformer (see Figure 4) allows arrays of variable-frequency converter modules to current share when they are widely separated or operated from independent sources. Because the current-share signal is a pulsed signal, it can be transformer coupled. Transformer coupling this pulsed signal provides a high level of common noise immunity while maintaining SELV isolation from the primary source. This is especially useful when board-to-board load sharing is required in redundant applications.

Synchronous current sharing eliminates the need for current-sensing or current-measuring devices on each module, and load regulation is not compromised. Additional advantages of the synchronous current sharing architecture includes excellent transient response, no loop-within-a loop control problems, and, as stated earlier, a high degree of immunity from system noise.

The availability of synchronous current sharing in democratically-controlled arrays offers power architects new opportunities to achieve simple, non-dissipative current-share control. It provides options that simplify current sharing and eliminates the tradeoffs — such as the need to sense the current from each individual module and adjust each control voltage — as is the case with other current-sharing methods.

The synchronous current sharing method described above applies to quasi-resonant, variable frequency converters with the necessary intelligence only, such as the Vicor Maxi, Mini or Micro of high-density DC-DC converters, where the energy per pulse is fixed.

Most current-sharing schemes employed with power converters involve either artificially increasing the output impedance of the converter module or actually sensing each output current, forcing all of the currents to be equal by feedback control. In a synchronous current-sharing scheme, however, there is no need for having a current-sensing or current-measuring device on each module, nor is there a need to artificially increase the output impedance which compromises load regulation.

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