

BATTERY POWER PRODUCTS & TECHNOLOGY

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Design Issues with High-Density DC-DC Converter Modules

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When component power modules (Figure 1) were introduced several years ago, designers gained unprecedented performance in power density with increased efficiency, lower noise and improved ease of use - and all at reasonable cost. At about the same time, power system designers were under increasing pressure to reduce the cost and time to market and increase the versatility, performance and reliability of their power systems - often with fewer resources. As a result of these complementary occurrences, component-based power systems have become the preferred choice in a wide variety of markets and applications.

Designing with high-density converter modules is generally much simpler and faster than implementing a discrete design. Design issues remain, however. Some of them - such as heat and noise management - are similar to those of traditional designs, while others are unique to modular designs.

Thermal Management: Thermal management can be a challenge in any system, but some strategies can mitigate the problem. A distributed approach (rather than a centralized architecture) spreads the heat throughout the system, minimizing the need for heatsinks or high velocity airflow. With temperature more evenly maintained throughout the system, reliability specifications are easier to meet. Heatsinks, however, are generally needed if airflow is not available in the system or if ambient temperatures are high. Airflow provided by a fan simplifies the power supply design, but cooling fans can add noise (electrical and audio) and reduce reliability unless proper steps are taken.

For a convection-cooled rectifier that must operate at ambient temperatures up to 50°C, straightforward calculations will determine heatsink size. The worst-case power to be dissipated by the heatsink is given by:

$$P_{diss} = \text{Power Output} \times (1 - \eta) / \eta, \text{ where } \eta \text{ is efficiency. (1)}$$

At full power, a 600 W converter operating at 90 percent

efficiency will dissipate 67 W. The heatsink-to-air thermal resistance (Θ_{sa}) can then be calculated:

$$\Theta_{sa} = [(T_{base} - T_{ambient}) / P_{diss}] - \Theta_{bs}, \text{ where (2)}$$

$T_{ambient}$ = worst case ambient air temperature,

Θ_{bs} = surface interface thermal resistance (0.1°C/Watt for a thermal pad or thermal grease),

P_{diss} = worst case power dissipation (from (1) above),

T_{base} = baseplate temperature; assuming a maximum operating baseplate temperature of 100°C, an ambient temperature of 50°C, and

$$\Theta_{sa} = (100 - 50) / 67 - 0.1 = 0.64^\circ\text{C/W.}$$

Heatsink manufacturers provide curves for determining the required heatsink surface area based on thermal resistance. Typically, for a value of 0.64°C/W, a heatsink, say of about 10 0in², might be required.

If this size is impractical, consider attaching the converter to a cold plate such as a chassis wall. Alternatively, forced air cooling allows the designer to use a much smaller heatsink. In the above example, airflow of approximately 1,000 ft/min can reduce the required heatsink area to around 10 in².

EMI Management: Electromagnetic interference is a major design issue for switching power supplies and for power system designers. All forms of noise - conducted, radiated, common-mode and differential - have to be considered. While this complex topic cannot be covered fully in this article, some major areas can be addressed. Any design, for example, requires good electrical and mechanical design and layout: adequate trace widths, minimized trace lengths and decoupling to reduce noise.

Common-mode noise can be the most significant system noise problem to solve. In DC-DC converters, common-mode noise is the current that circulates between the primary and secondary. It is a function of the voltage transients across the main switching device and the input-output coupling capacitance. By using Zero-Current and Zero-Voltage switching architectures, main switch current transients are greatly

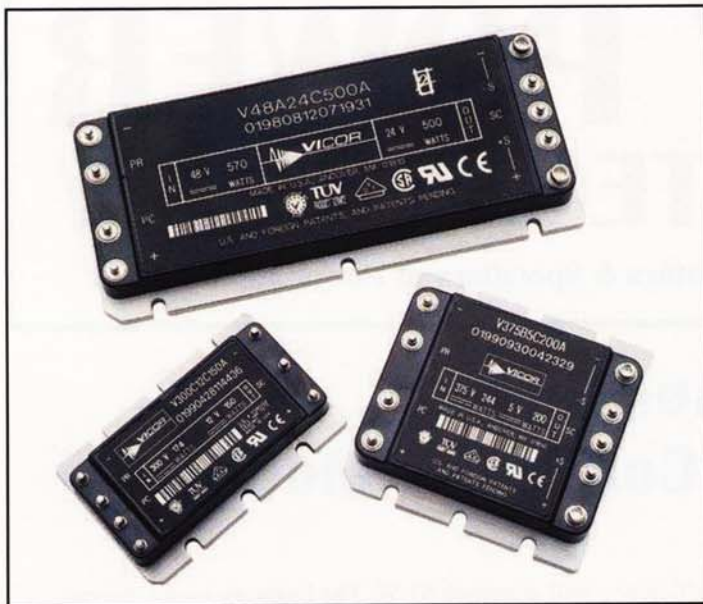


Figure 1. High-density DC-DC converters come in thousands of combinations of input voltage, output voltage, and power levels. The smallest module shown here measures 2.28 by 1.45 by 0.5 inches and has a rated output power of 150 Watts.

reduced. New magnetics in second generation units use a plated cavity core that couples widely-separated primary and secondary windings, resulting in very low input-output parasitic capacitance. Very low common-mode noise is the result.

Additional filtering will probably be needed to meet agency specifications for conducted noise such as FCC Rules and Regulations, Part 15 (domestically) and EN55022 (internationally). Using units with inherently low noise makes this a relatively simple task. Using a simple filter with common-mode and differential chokes and Y capacitors, second generation converters can easily meet these specifications.

Radiated EMI is another source of system noise. Conventional switch mode power supplies are quite prone to generating this type of noise, due to the large currents that are switched on and off with very short rise times. Metal shielding around the noise source is the usual solution. Modules with six-sided internal shielding further minimize radiated noise.

Paralleling for Higher Power or Fault Tolerance:

Power architects often employ multiple power supplies or power converters to increase output power or to provide fault tolerance. Fault tolerant systems should use ORing diodes to isolate modules in the event of an output fault. Current sharing is generally preferred when paralleling supplies for increased power and/or N+1 redundancy.

A reliable and cost-effective way to achieve high power levels is to use identical independent supplies operating in parallel. For example, using five 600 W supplies for a 2.4 kW load (N+1 redundancy) allows the power needs of the system

to be met if one of the five supplies fails. The parallel (PR) pin of a Vicor Second Generation converter, for example, offers several approaches to solving some of the technical challenges of parallel operation, including accurate power sharing and true fault tolerance.

The simplest approach to current sharing is to interconnect all of the PR pins. Current sharing accuracy will typically be within ± 2 percent. This method is not truly fault tolerant, however, in that a fault to ground on the common bus may bring the entire array down. Since the signal on the PR pin of the Vicor converter is actually a pulse, each converter can be isolated from the common bus via a capacitor or transformer, eliminating this failure mode.

To reduce input and output filtering requirements of multi-module arrays, converters can be connected through a Phased Array Controller (PAC) interface. The PAC integrated circuit not only supports accurate current sharing through an isolated bus, it automatically adjusts the relative phase angle of each module in the array to $360/N$ degrees, where N is the number of active modules and is ≤ 12 . By interleaving the switching of each converter, the effective switching frequency of the array is increased by a factor of N, significantly reducing the size of any required filtering elements.

Hot Swapping for High Availability: Most applications that require fault tolerance or redundancy also require hot-swap capability to ensure continuous system operation. Telecommunications applications, for example, typically require uninterrupted operation, which means that a failed power supply card must be replaced while the system is still powered up.

Hot-swap cards must be designed to keep any primary referenced potentials (or secondary-side circuitry capable of delivering large amounts of energy) from coming into contact with the user. It is also essential that when a module fails, the failure is detected and identified by an alarm or notice to provide service.

The design must also protect the input voltage and output voltage buses from transients during swap-out. Typically, in the event of a short-circuit fault on the input bus caused by a faulty unit, large capacitors provide the necessary hold-up time until the fuse on the faulty unit has blown. However, these large capacitors can cause the input bus to sag when the replacement card is inserted. This capacitance can be decoupled with a series resistor and a shunt switch (a FET or relay). To minimize efficiency loss, the shunt switch is open on initial plug-in and then closes to short out the series resistor.

Output considerations during hot-swap are similar. ORing diodes help to isolate the capacitance on the hot-swap card to avoid discharging the same capacitors on the redundant cards already in the system. If ORing diodes are not used on the output, the output capacitance on the hot-swap card will have to be isolated in a similar manner to that used for the input bus.

Safety: A modular design can simplify the agency approval process because most modules have already earned safety agency approvals such as UL, VDE, CSA and TÜV. Prequalified safety agency approvals can shave significant development time and cost from a project.

Isolation, the electrical separation between the input and the output of a power supply, is a basic safety issue in the selection process. For AC input or high-voltage DC input systems, isolation is required to protect the end user from dangerous voltages and currents. Isolated DC-DC converters have internal transformers and simplify a design by providing the necessary isolation. Non-isolated converters need an external transformer to reduce the input voltage to a safe level and provide protection from the AC line voltage.

A given bus voltage requires the consideration of several factors. The higher the voltage, the lower the power loss and the smaller the conductor size. However, safety standards typically conflict with the selection of a higher bus voltage. SELV - Safety Extra Low Voltage, the highest voltage that can be contacted by a person and not cause injury - is a requirement of most countries and restricts the voltage to which personnel may be exposed.

Packaging: The modular form factor of DC-DC converter modules helps a designer shape the power supply to fit the available space. A supply can be designed to almost any physical configuration rather than just a rectangular box.

The "industry standard" full-size module package is 2.4 by 4.6 by 0.5 inches; half-size and quarter-size packages are also available.

DC-DC converter modules are available in a very wide range of standard input voltage, output voltage and output power combinations, and virtually any special combination. Some modules are available in different power levels in the same physical package with identical pinouts. If a specification change requires more power - e.g., the output now requires 150 Watts instead of 100 Watts - a higher power module can easily be used with a minimum of design changes.

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