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High-Density Power Components Add Flexibility To Distributed-Power Design

Correct load partitioning, thermal management, and filtering help to achieve successful distributed-power solutions.

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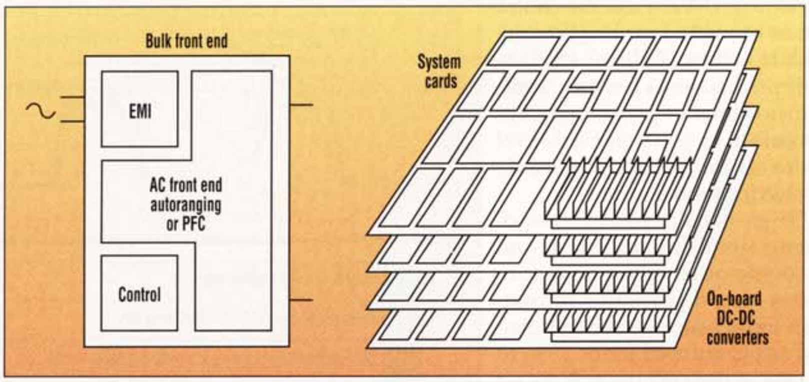
The introduction of high-density power components brought unprecedented flexibility and creativity to power-system development. This provided designers with options to implement power architectures that were never before possible. Furthermore, using high-density power components simplified the design of distributed-power solutions.

The decision to use a centralized power-system design or a distributed-power design, however, often turned on cost considerations. More recently, though, increasing demands for higher reliability, higher performance, and higher system availability have introduced another factor into the cost equation. Respectively, that's the cost of diminished performance or downtime. Additionally, the decreasing cost per watt of high-density component power is making the distributed-power architecture (DPA) attractive for an increasingly broad range of applications. Today, component power can be applied to building distributed-power solutions more easily and at a more competitive cost.

DPAs offer a number of inherent



1. DPAs are characterized by a front-end box that converts ac to an intermediate bus voltage—typically 48 V or 300 V—and distributes it to dc-dc converters located throughout the system.

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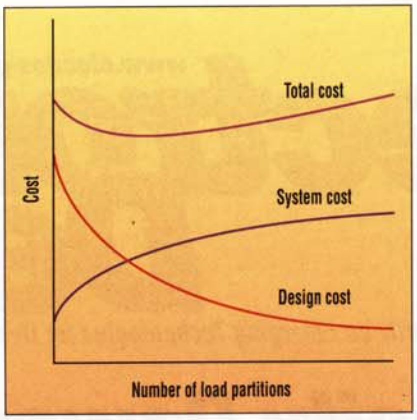
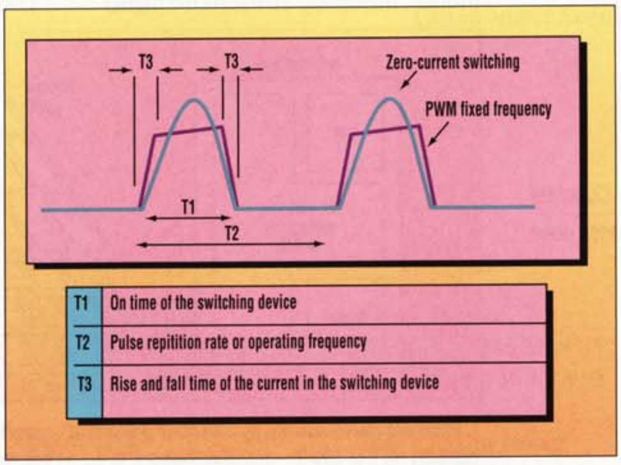
advantages over a centralized system *(Fig. 1)*. In the latter, the accurate voltage regulation that's necessary in some applications often proves difficult and costly to achieve. Inductance may also be an issue where loads are at varying distances from the source and/or they are dynamic. With distributed power, regulation takes place at or near the load. Output lead lengths are minimized, thereby reducing inductance and improving transient response.

In addition, a DPA system typically distributes higher voltages with significantly lower current levels through the system than does a centralized system. This architecture reduces power losses during distribution, which results in smaller and lower-cost power conductors. Thermal issues are managed better as well. By spreading power conversion around the system, heat is dispersed and hot spots are removed. Often, this reduces the need for heatsinking or fans.

Furthermore, with a DPA, the converters can be either on the pc boards they are powering, or close by, powering a group of boards. This provides a level of flexibility that's not available in centralized or scalable systems. Each board may be powered by its own converter, providing another level of flexibility. When power components are in use and a higher power rating is needed, it can usually be achieved by simply swapping one converter for another, assuming that the same pinout is used and the bus voltage and related external components are suitably rated. Extra filtering and other features can be easily added as they impact only one load, not the whole supply.



2. Thermal management, hot-swapping, and mechanical design become simpler as the number of load partitions increases. Power-system cost, however, tends to increase with the number of partitions.



3. The current waveforms (not drawn to scale) produced by zero-current-switching and pulse-width modulation converters are shown. The PWM pulse train's sharp edges create much more harmonic noise than the sinusoidal waveform. Pulse-width modulation converters operate at a lower frequency than zero-current-switching converters.

Several design issues need to be addressed concerning dc-dc converters in DPAs. First, the choice must be made regarding how the loads will be partitioned. Distributed systems have an unrestricted level of partitioning. It's possible to go from card-level conversion to a single module powering several cards.

High-density power components simplify partitioning and provide other advantages too. Most second-generation converters, for instance, can be trimmed or programmed from 10% to 110% of their output-voltage set point by using fixed resistors, potentiometers, or digital-to-analog converters (DACs). With such a wide range of output voltage, it's conceivable that not only to all of the converters in a distributed system have the same footprint and pinout, but also that they have the same nominal output voltage.

Generally, certain tasks—like thermal management, hot-swapping, and mechanical design—become simpler as the number of load partitions increases. Plus, if the load is partitioned to the card level, power-system assembly is easier, and the dc supply-bus design is simplified.

Power-system cost, on the other hand, tends to increase with the number of partitions *(Fig. 2)*. One 200-W converter to power four 50-W circuit cards, for example, is less expensive than four 50-W converters. Additionally, overall aggregate power requirements may be higher because each card will need a converter that's able to supply the maximum power required for its function. This is true even though the system specification doesn't call for each card to function at maximum power. Each card, for instance, could have an average power consumption of 40 W and a peak of 60 W, with only two cards operating at peak at a given time. A single converter of 200 W could supply the needs of the system, but 240 W of total capacity would be needed if four converters were used.

Still, the designer should be cautioned not to consider the price of components in isolation. The short- and long-term savings resulting from more partitions—such as from easier thermal management, greater system flexibility, easier hot-swapping, and improved mechanical design—should also be remembered. Furthermore, power-system assembly is simplified with card-level partitioning. These usually have a significant offsetting influence on system cost.

Next, selecting the intermediate distribution (bus) voltage requires the consideration of several factors. The higher the bus voltage is, the lower the I^2R losses and the smaller the conductor-size requirements are, particularly when the application includes a number of relays, switches, and connectors. In such high-power applications as high-end data processing, the savings from lower power losses and smaller conductors can be substantial. From rectification and filtering of the ac line, 150 or 300 V can be obtained too. Again, this can be done at substantial cost savings. Universal (85- to 264-V ac) input or power-factor-correcting front ends also produce a 300-V output. In fact, 300 V is one of the de facto "standards" for intermediate voltages.

Safety standard requirements, though, typically conflict with the selection of a higher intermediate voltage. The Safety Extra Low Voltage (SELV) directive—a requirement in most countries—restricts the voltage level that personnel may be exposed to. The maximum SELV is usually 60 V. Because of the telecommunications industry's historic use of 48 V, this has become a "standard" for power distribution as many power components are available for this voltage.

Further, if it's required, battery backup becomes easier to implement with a 48-V distribution bus because it's a multiple of lead-acid battery voltage. Using 48 V, however, adds cost and complexity if the system is powered from an ac line. In that case, either intermediate dc-dc converters must be used to convert the rectified line to 48 V, or a transformer is needed to reduce the line voltage to the appropriate level.

The use of intermediate dc-dc converters increases cost and reduces overall system efficiency, while a 60-Hz transformer adds cost, considerable weight, and occupies more space. Of course, too, the dc-distribution bus for 48 V needs to be larger than such a bus for 300 V. Many times, industrial systems use 24 V, which reduces the cost of battery backup. But, it increases power losses and the cost of distribution.

Whether distributing final output voltages from a central supply or providing local, on-board conversion, dc distribution must satisfy three requirements. It must provide regulated and isolated dc voltages. It has to meet dynamic load-current demands. Finally, it needs to minimize noise susceptibility and emissions. These complex issues are much easier to accomplish with a distributed system than with a centralized system.

What can pose a challenge in a centralized architecture is thermal management. To keep the relatively small area of the power supply from becoming overheated, massive heatsinks and gale-force airflow might be necessary. These system "hot spots" can be a source of reduced system reliability.

Cooling Is Important

Cooling the front end, for example, is critical, whether the system is centralized or distributed. Airflow provided by a fan can help, but it can add electrical and audible noise and reduce reliability, unless the proper steps are taken. In fact, the two most unreliable parts of a power system are fans and electrolytic storage capacitors. Unlike high-density dc-dc converters that have typical operating temperature ratings of 85°C to 105°C, both fans and capacitors are greatly affected by heat.

A distributed approach spreads the heat throughout the system, greatly reducing, or even eliminating, the need for heatsinks or high-velocity airflow. With temperature more evenly maintained throughout the system, reliability specifications are easier to meet. Second-generation dc-dc converters have significantly fewer parts than first-generation units, thus granting them higher reliability.

Another issue yet to be addressed is filtering. Conducted and radiated noise levels are influenced by many system design variables. Noise generation from converter modules isn't a simple subject. Although component power modules usually incorporate some input and output filtering, additional filtering is often needed to meet either system requirements or agency specifications. Examples include the FCC and VDE, which specify the allowable levels of power-supply noise that may be conducted back into the ac line. Meeting these levels with some dc-dc converters can require substantial input filtering, which reduces power density and the mean time between failure (MTBF). If EMI is a major design issue, be sure to acquire noise plots for the converters under evaluation.

Available are several proprietary dc-dc converter topologies—such as those in which switching is performed at the zero-current or zero-voltage crossing—that produce less harmonic noise than other designs. These "zero-switching" converters have sinusoidal waveforms rather than square waveforms. The lack of sharp edges and lower harmonic content produces much less excitation of the parasitic elements, resulting in far less noise *(Fig. 3)*.

Another issue that needs ample attention is fault tolerance. When reliability and/or system availability were important requirements for an application, DPAs have always been favored over centralized designs. As suggested in the beginning of this article, this favoritism is happening with greater frequency today.

Fault-tolerant power systems usually incorporate some level of redundant front ends and dc-dc converters. Incidentally, redundant current-sharing converters not only share the load, but they also share the heat for better thermal management. Redundancy at the front end can be provided in a number of ways, including by independent front ends. Alternatively, it can be provided by a separate dc input from a battery plus an ac-mains connection with appropriate switching in case the ac mains are lost.

Redundancy can also be built in at the converter level. So, if a failure occurs, there's always one extra dc-dc converter to power the system. The designer must further decide if the system must be shut down for replacement, or if it should be capable of replacement online, in other words, be hot-swappable.

This decision rests largely on the level of availability and reliability that's required. If the unit must have 100% availability, hot-swap is a necessity. If MTBF is the only issue, then the module doesn't have to be replaced online. The MTBF of the power system is significantly increased by providing a redundant module.

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