Fixed or Variable Frequency?

DC/DC converters employ many different topologies, none of which is superior to all others in every respect. With thousands of DC-DC converters and multiple manufacturers to choose from, selecting the right module can be challenging. What's more, each supplier is, of course, seeking a competitive edge. As a result, one provides the highest efficiency, another the smallest footprint, another a new high for power density, and every other one something else. Each achievement likely comes with trade-offs made somewhere else in the specifications. **Robert Marchetti, Brick Product Marketing Manager, Vicor, Andover, Massachusetts, USA**

Some applications have requirements that are best satisfied by a specific topology. Although full consideration of the large number of topologies available could be a daunting task, it is helpful to consider the advantages and disadvantages of the two main topological classes: fixed frequency and variable frequency. A specific comparison is made between DC/DC converters using fixed-frequency pulse width modulation (PWM) and variable-frequency quasi-resonant zero current switching (ZCS).

Fixed versus variable frequency

Of the two, PWM can be somewhat simpler in design, but it inherently trades off efficiency against operating frequency. High-frequency operation has long been recognised as one of the main keys to achieving high-power density i.e. smaller magnetics, filters, and capacitors in switchmode converters. With fixed-frequency switchmode converters, however, switching losses increase directly with operating frequency, resulting in a 'frequency barrier' that limits achievable power density. Variable-frequency converters overcome the frequency barrier by having each turn-on and turn-off of the switch occur at zero current. Such converters operate at frequencies in excess of 1MHz and can achieve power densities considerably greater than low-frequency converters.

A second major difference between fixed-frequency and variable-frequency DC/DC converters is the noise generated by the switch. Many designers intuitively assume that it is easier to design a filter for a fixed frequency converter than for a variable frequency converter. In actuality, the opposite is true! The perception is, in all likelihood, attributable to the term 'fixed frequency', which is actually a misnomer. Both types of topologies, in fact, have frequency elements that are more or less fixed and frequency elements that vary as a function of operating conditions.

Figure 1 compares the waveforms of the current flowing through the main switch of a DC/DC converter. In a module using a quasi-resonant topology, the pulse width (T1) is fixed, while the repetition rate (T2) is variable. In a module using PWM, the opposite is true; the repetition rate is fixed and the pulse width is variable. Each topology generates characteristic noise spectra.

In the variable-frequency design, however, there are no high-frequency components associated with the leading and falling edges of the current waveform (T3), because it is essentially a half-wave rectified sine wave. The spectral content of the variable frequency waveform is lower in amplitude and contained in a narrower band.

In PWM converters, most of the energy is at the fixed frequency and odd multiples (harmonics) of it. A 100kHz PWM converter will have most of its conducted noise at 100kHz and some at 300 and 500kHz. They also have significant harmonics at or above 10 to 30MHz due to the shape of the current waveform, i.e., high di/dt values that excite parasitic elements within the converter. The input conducted filter has to be sized to handle maximum power at 100kHz. In the fixed-frequency waveform, the spectral content is

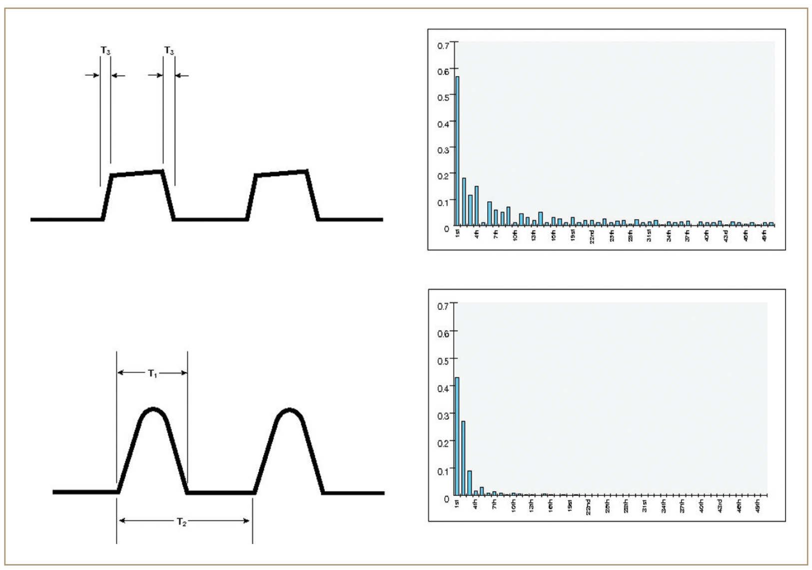


Figure 1: Current waveforms and spectral content for PWM (top) and ZCS (note that waveforms not drawn to scale)

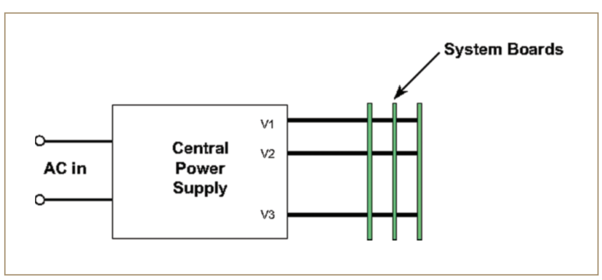


Figure 2: A centralised power supply contains the entire power supply in one housing and buses each voltage to the appropriate load

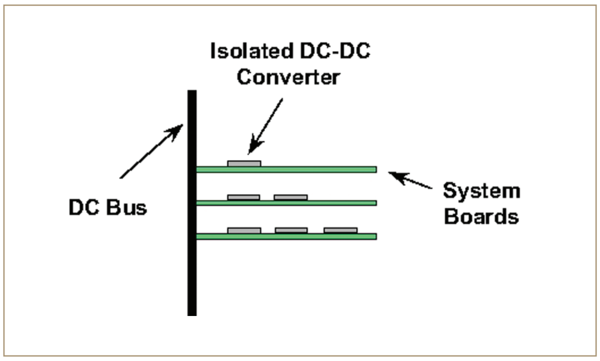


Figure 3: Distributed power is a decentralised power architecture consisting of DC/DC converters located near the load they serve

higher in amplitude and spread over a broader range of harmonics.

DC/DC converter modules are available that deliver a wide range of features and capabilities - efficiency, high power density, small size, a wide variety of input and output voltages, low cost - regardless of topology. Power conversion topology, however, can be an important consideration if low noise, high power density, and constant efficiency are needed.

Having said all that, if fixed versus variable frequency was ever a significant criterion in the selection of a DC/DC converter, it is much less so now. Both topologies continue to introduce improvements that blur their value as differentiating classes. New power architectures available to designers have increased the value of focusing on specific DC/DC converter attributes. As always, the most important design guideline is that, in the end, the application rules.

To take advantage of the potential benefits of these new architectures, topologies, and package designs, a designer must understand his or her application as well as the technology. The mundane selection criteria involved in identifying the right DC/DC converter have not diminished in importance. Designers must still define the performance parameters such as input and output voltages and power, EMI constraints, efficiency, available space needed to satisfy their application. Depending on the application, time to market, product lifecycle, agency approvals, product cost, and cost of ownership, may also play a part. Also, power architectures deserve a more careful look.

Centralised power architecture

The classic centralised power architecture, which is simple and cost effective, continues to be applied wherever appropriate. Starting with communications systems applications, however, centralised power ran into a brick wall because of its inability to effectively deliver lower voltages at higher currents.

A centralised power supply contains the entire power supply in one housing, from the front end through the DC/DC conversion stages (Figure 2). It converts the line voltage to the number of DC voltages needed in the system and buses each voltage to the appropriate load. It is cost effective and does not consume valuable board real estate at the point of load with the power conversion function. It is fairly efficient because it avoids serial power transformations, and it concentrates the thermal and EMI issues into one box. In the past, the centralised system, usually a custom design, was often chosen because it was the least expensive approach. These systems, in general, work well when the power requirements, once defined, are not likely to change and space is not an issue.

In order to minimise I^2R distribution losses, the central supply should be located near the load. For safety and EMI reasons, it should be located as close as possible to the AC entry point. This is often a difficult trade-off.

Distributed power architecture

Distributed power architchture (DPA) is a decentralised power architecture characterised by bussing a 'raw' DC voltage, usually 48 or 300VDC depending on the power source, which is then converted by on-board DC/DC converters located near the loads they serve (Figure 3). On-board isolated DC/DC converters are matched to the load requirement. This helps with dynamic response and eliminates the problems associated with distributing low voltages around the system.

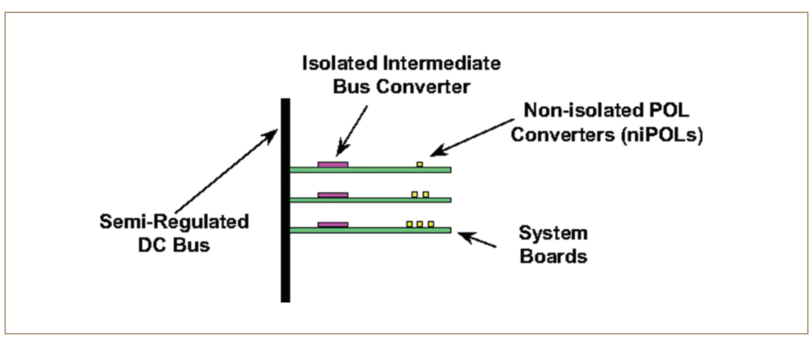
A distributed approach spreads the heat throughout the system, greatly reducing or eliminating the need for heatsinks or high velocity airflow. With temperatures more evenly maintained throughout the system, reliability specifications are easier to meet. Also, since the power is located on the board, configuring system variations and options is much more cost effective than in a centralized architecture, which requires the power supply to be sized for worst-case loading. Redundancy is easy to implement for any critical load by simply paralleling additional DC/DC converters where required. DPA, however, can also be more costly. Since isolation, regulation, transformation, EMI filtering, and input protection are repeated at every load, as the loads proliferate, both the costs and board area for power conversion increase.

Intermediate bus architecture

To deal with the multiplicity of low voltages more cost effectively, the intermediate bus architecture (IBA) relies on non-isolated point of load regulators (niPOLs), reducing the POL function to regulation and transformation. The niPOLs operate from an intermediate bus voltage provided by upstream isolated converters. IBA can be a more cost-effective solution because niPOLs, being non-isolated, are less expensive than complete DC/DC converters. But typical niPOL buck converters are in constant conflict between efficient power distribution and efficient power conversion duty cycle.

The intermediate bus architecture differs from the distributed power architecture in that it converts the raw DC voltage (48 or 300VDC) to an intermediate voltage, typically 9.6 or 12VDC, to feed non-isolated and relatively inexpensive POL converters (Figure 4). The niPOLs are also likely to be smaller and lighter than DC/DC converters,

Figure 4: The intermediate bus architecture uses an isolated intermediate bus converter to provide an unregulated voltage to power non-isolated and relatively inexpensive POL converters



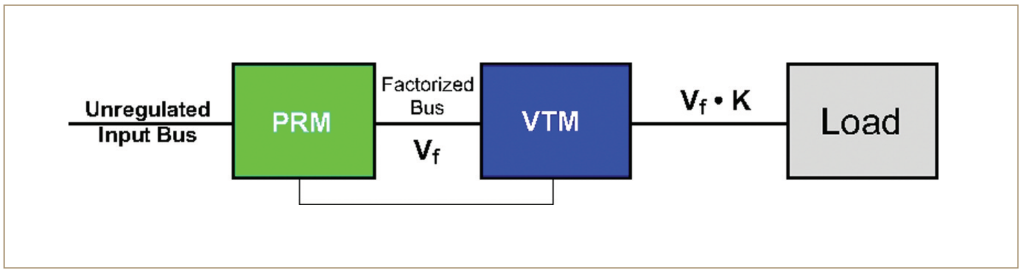


Figure 5: Basic FPA block diagram

providing the benefits of a small footprint and consuming correspondingly less board real estate. Non-isolated POL converters within the IBA forego isolation and high voltage transformation ratios to improve cost-effectiveness.

The niPOLs of IBA depend upon a bus converter to provide isolation and voltage step-down from the raw DC bus. This is accomplished by the intermediate bus converter, which is usually either a complete DC/DC converter operating from a wide range DC source, or an unregulated IBC operating from a narrow range input. The conversion to the intermediate bus voltage intrinsically reduces efficiency of the system. Also, the intermediate bus converter really does need to be located close to the load, because, even with a 12V intermediate bus, four times the current needs to be moved around the board as compared to a 48V distributed power system, so larger traces or shorter runs are needed.

The 12V intermediate bus is also too high for efficient conversion to low voltage outputs (<2VDC) as the transformation ratio becomes too high, and the switch duty cycle becomes too low. Lowering the bus voltage to overcome this limitation simply increases the problems associated with the previous issue.

Factorised Power Architecture

Vicor's Factorised Power Architecture (FPA) reorganises the basic power conversion functions (voltage transformation, isolation, and regulation) and implements them in IC-style packages. A buck/boost pre-regulator module (PRM) provides a stable voltage from an unregulated DC bus, and a voltage transformation module (VTM) steps the voltage up or down and provides isolation at the point of load. High-frequency FPA V•I chips using zero-current/zero-voltage soft switching topologies, offer a number of advantages such as small size, high efficiency, low noise and fast transient response combined with high power density (>1,000W/in^3 at the point of load).

Figure 5 shows the FPA modules in a basic arrangement, but the PRM and VTM can be operated alone, together, open loop, local loop, adaptive loop, remote loop, co-located, separated, paralleled, or combined with conventional power conversion devices (DC/DC converters, point-of-load converters, charge pumps) to achieve the desired power solution.

The VTM is enabled by a new class of power conversion topologies called Sine Amplitude Converter (SAC).