BASICS of Design

HIGH-VOLTAGE DC-DC CONVERSION

Gene Heftman, Contributing Editor

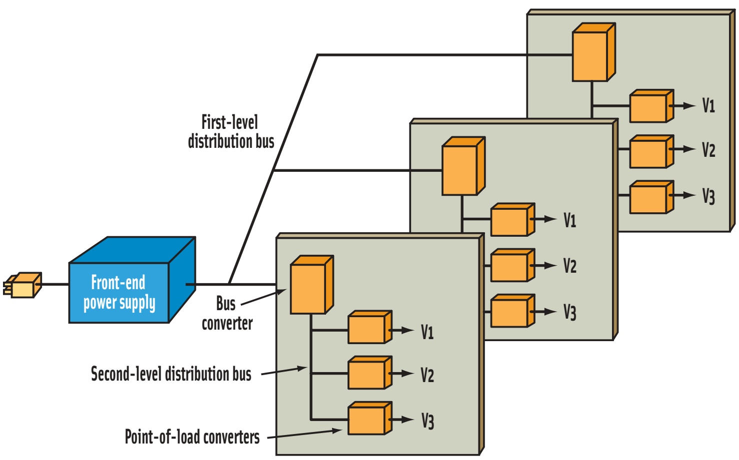
Powering *the* Communications Infrastructure

The delivery of dc voltages and currents to ICs in modern communications systems is turning traditional power-supply design into a new art form, driven by the need for greater bandwidth, faster data rates, tighter security, upgradability, larger numbers of customers, and a broad spectrum of user features. Next-generation power systems based on dc-dc converters must operate over wide input voltage ranges, sometimes from 30 to 100 V. Simultaneously, they're generating a number of low-level dc output voltages to supply high-performance communication system ASICs, DSPs, and microprocessors designed in deep-submicron CMOS processes.

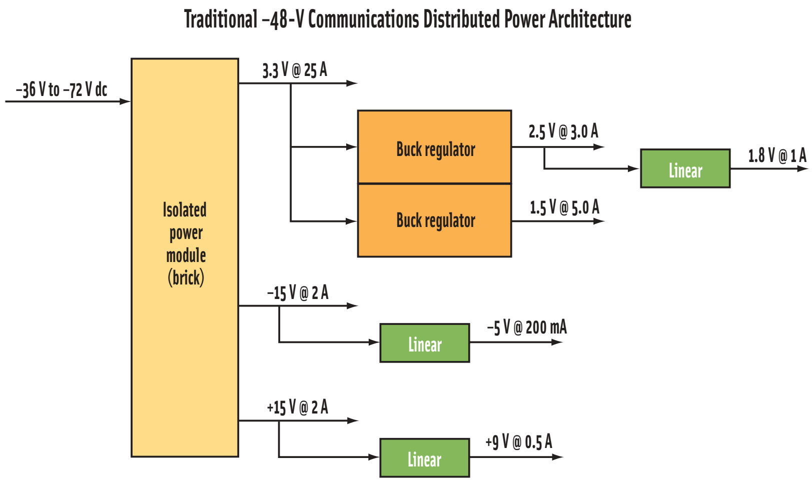
Distributed Power: A Top-Level View

In a distributed power architecture, a front-end power supply converts ac power to dc and distributes a dc voltage via first-level buses (usually –48 V in communication systems) to dc-dc intermediate bus converters (IBCs). The IBC's purpose is to first provide isolation, as well as reduce the ac-dc front-end distributed dc voltage to a lower voltage level. This should occur before sending it to a final set of non-isolated dc-dc (buck) converters via second-level distribution buses. These so-called dc-dc point-of-load (POL) converters deliver the required voltages and currents to the system.

Communications Power Systems 12-V Intermediate Bus Architecture



Distributed Power: A Closer Look



This block diagram shows how the dc-dc isolated power module (brick) and POL converters are configured in a typical distributed power system that provides multiple output voltages and currents. DC voltage (-36 to -72 V) from the front-end ac-dc power supply is fed to an isolated power module or brick, which represents a bus converter. A brick is a completely isolated dc-dc converter in various formats (full brick, half brick, quarter brick, etc.), with a standardized footprint, pinouts, and heatsinking capability. The POL converters can be a combination of switching regulators (buck or boost regulators) and linear regulators, or just linear regulators, depending on the requirements of the circuits to be supplied. Sensitive circuits may require low-noise linear regulators, while high-efficiency switching regulators are the choice in power-supply systems where power loss must be minimized.

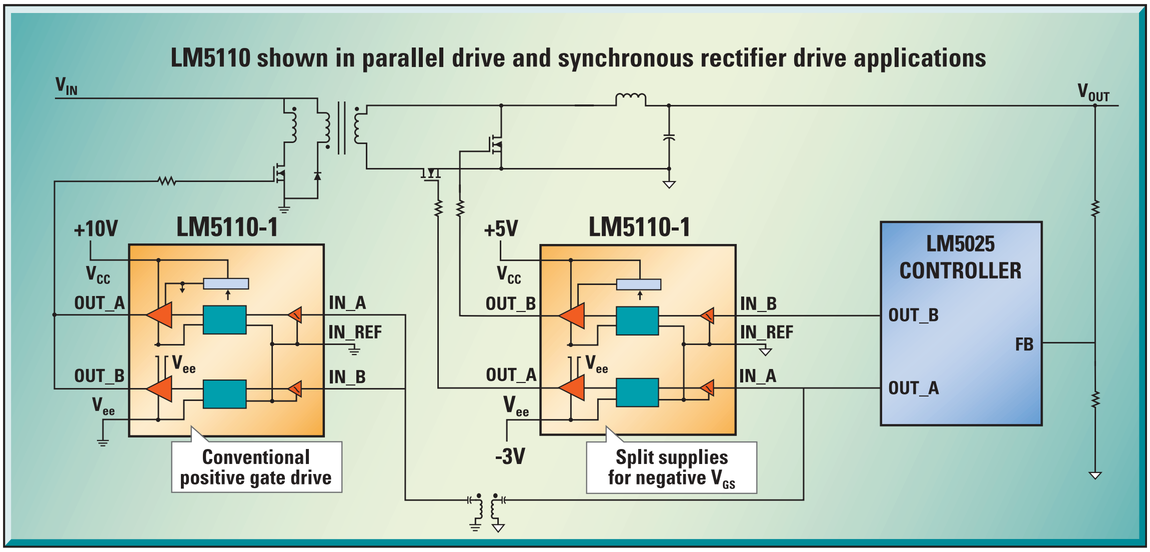
In communications and network server applications, this means converting a 48-V input voltage into not only legacy 5- and 3.3-V supply rails, but also into new lower voltages that range from below 1 to 2.5 V at load currents of 10 to 35 A. Moreover, the power systems must hold tight tolerances and generate minimum noise to preserve signal integrity. These increased demands take place in an environment where space constraints and thermal management are major considerations.

To meet these multiple demands, power-system architectures are moving from earlier centralized delivery of lower voltages and currents to the present distributed approach. Instead of a single supply to produce all of the necessary voltage levels, power is distributed along a network of secondary and tertiary buses to dc-dc converters that step down the voltage levels to suit the requirements of individual circuits or subsystems.

At each level, you can design or buy a dc-dc converter that delivers the necessary voltages and currents to supply a number of ICs, ASICs, mixed-signal devices, or complete pc boards. Each dc-dc converter will have a specific topology that depends on many factors of the circuitry it powers and the system in which it operates, such as efficiency, noise levels, physical factors (height, weight, size), number of output voltages required, power consumption, and heat removal. This tutorial will discuss specific tradeoffs and suggest topologies best suited to meet these various system power design objectives.

Industry's first dual 5A MOSFET gate driver with negative V_{GS} capability

LM5110 reduces switching losses and eliminates spurious turn-on of low-threshold MOSFETs



- **Replaces industry standard gate drivers when Input/Output ground pins are connected to common**
- **Turns off MOSFET with negative V_{GS} when Input/Output ground pins are separated and Output ground pin is connected to a negative bias supply**
- Designed with a compound BiCMOS output stage for highly efficient rail-to-rail output current delivery
- Can be used as a dual gate driver or connected in parallel for a single gate driver with twice the output current
- Each channel can sink/source 5A /3A for very fast rise/fall times (20 ns/10 ns into a 2 nF load)
- Short propagation delay times (25 ns typical)
- Integrated under voltage lockout protection (2.8V typical)
- Shutdown pin disables drivers for low-power standby mode
- Offered in three industry standard configurations: dual non-inverting, dual inverting, and one inverting plus one non-inverting

Ideal for use in switch-mode power supplies, DC/DC converters, motor controls, UPS systems, Class D amplifiers, pulse transformer drivers, pulse generators, and line drivers

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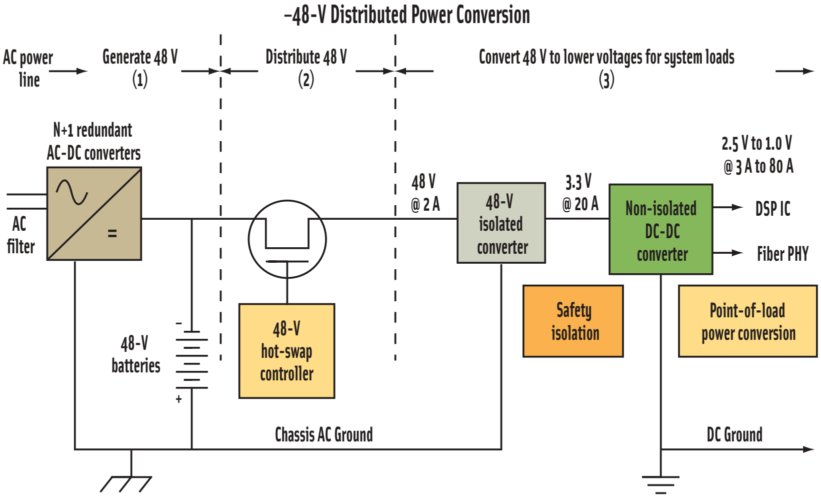
HIGH-VOLTAGE DC-DC CONVERSION

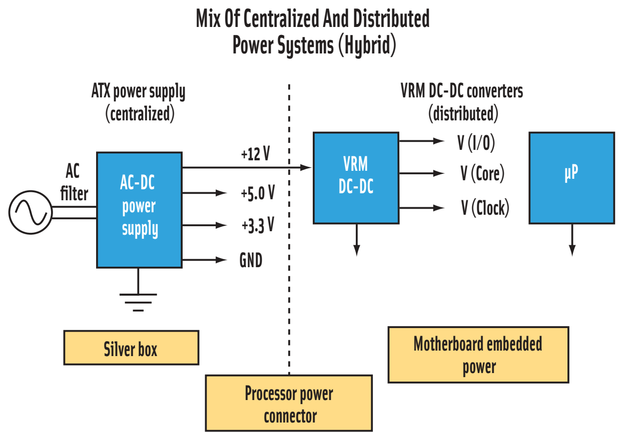
Distributed Power: A –48-V Telecom Power System



A -48-V distributed power system typical for a telecom application illustrates the flow of power from the input ac line to the low-voltage dc-dc POL converters. Batteries (48 V) back up the ac-dc converters in case of a power failure. The -48-V hot-swap controller is an IC that provides intelligent control of power-supply connections during insertion or removal of circuit boards that are under power. It includes inrush current control, short-circuit protection, and other safety functions to protect the power system. The first dc-dc conversion stage is an isolated converter. This means the input ac power ground is isolated, usually by a transformer, from the output dc power ground. Isolation is dictated by safety regulations to protect personnel from dangerous voltage levels that may otherwise appear during failure conditions. However, an isolation scheme makes the converter more expensive and impacts efficiency. The POL converters that deliver power to system electronic circuits needn't be isolated because they're protected by the isolated power modules that provide their dc input power.

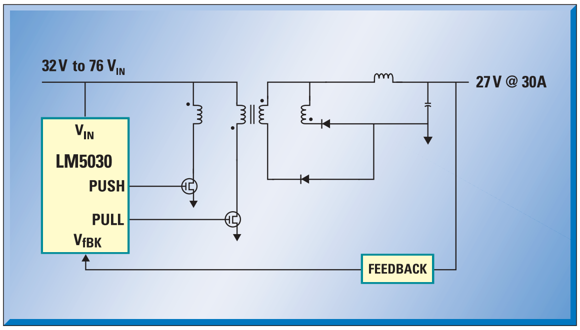
A Mixed System: Typical Desktop Power System

Power systems can be designed with a combination of centralized and distributed elements, as shown in this hybrid system . The centralized supply operating from the ac line generates the 5.0- and 3.3-V logic power, as well as a higher 12-V dc level that's distributed to a voltage-regulator module (VRM). The VRM is used to supply very high current, low voltage core, and I/O voltages for a high-performance processor (P4). This VRM power converter is located near the processor's "point-of-loading" on the motherboard to mitigate pc trace voltage drops that would otherwise be unacceptable for efficient converter operation.



Simplify telecom power conversion: New LM5030 100V PWM controller with LM5642 dual buck regulator

3G Basestations: 850W push-pull DC/DC converter up to 90% efficiency



Embedded telecom brick solutions

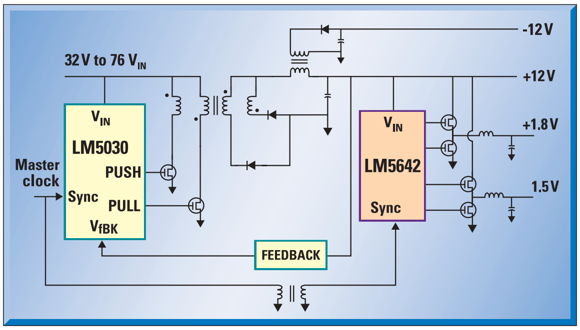
The LM5030 can be used as chipset with the new 100V LM5100 half-bridge drivers and LM5642 dual synchronous buck controller

Configurations	Controller	Driver	Benefit/application
Push-Pull	LM5030	Not required	High efficiency/medium power
Half-bridge	LM5030	(1) LM5100	High efficiency/medium-high power
Full-bridge	LM5030	(2) LM5100	High efficiency/high power
Multi-output converter	LM5030, LM5642	Optional	High efficiency/multi-output power

LM5030

- Fully integrated LM5030 includes high bandwidth error amp, precision reference, programmable softstart, and dual-mode current sense
- Internal high-voltage (100V) start-up regulator
- Single resistor oscillator setting
- Synchronizable to external clock
- 1.5A drivers
- Thermal shutdown

DSL Line Card: –48V multi-output isolated power supply



Primary controller: LM5030 100V current-mode push-pull
Secondary controller: LM5642 dual synchronous buck

- 48 V_{IN}, multiple outputs ±12V, 1.8V, and 1.5 V_{OUT}
- High efficiency >90%
- Tight regulation <2%
- Oscillators synchronized to a master clock
- User-programmable softstart and power on/off sequencing
- Available separately or together:
  - LM5030 (MSOP-10)
  - LM5642 (TSSOP-28)

Ideal for use in telecom power systems, automotive power systems, -48V distributed power systems, and industrial power supplies, as well as push-pull, half-bridge, and full-bridge converters

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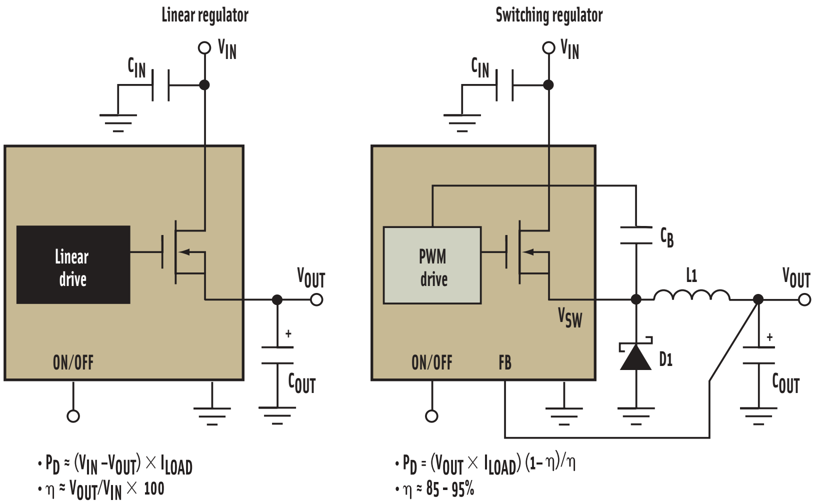
Basic DC-DC Converter Topologies

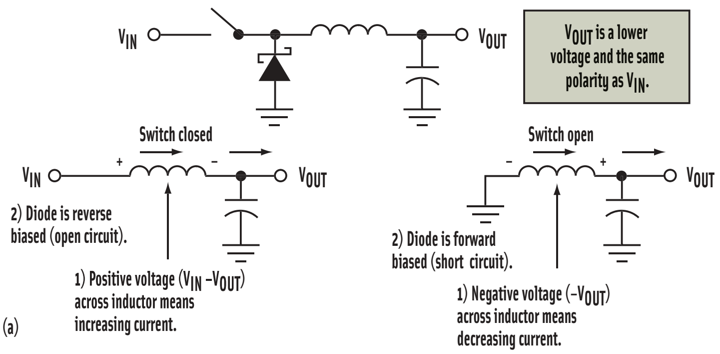
Voltage Regulators Come In Two Basic Flavors



All dc-dc converters can be classified as either nonswitching-linear or switching regulators. Linears have the advantage when it comes to simplicity, lower output ripple voltage and noise, and better line and load regulation. Switchers offer much higher efficiency, as high as 95% compared to about 50% or less for linears, and greater power density (the power-to-volume ratio measured in W/in.[3]). A switching converter is more efficient than a linear for wide input-to-output voltage ratios because it takes advantage of the output filtering componentry.

Non-Isolated Buck Topology

The buck converter is the basic topology that underlies most switching-converter architectures. It's the most commonly used topology, and it will find homes in distributed power systems that must convert a high dc voltage (48 V) to a lower voltage with low power losses. The switch is a power transistor (usually a MOSFET) whose gate is driven by an IC that performs pulse-width modulation (PWM) to control the duty cycle (switching times of the transistor), hence the magnitude of the output voltage.



(a)

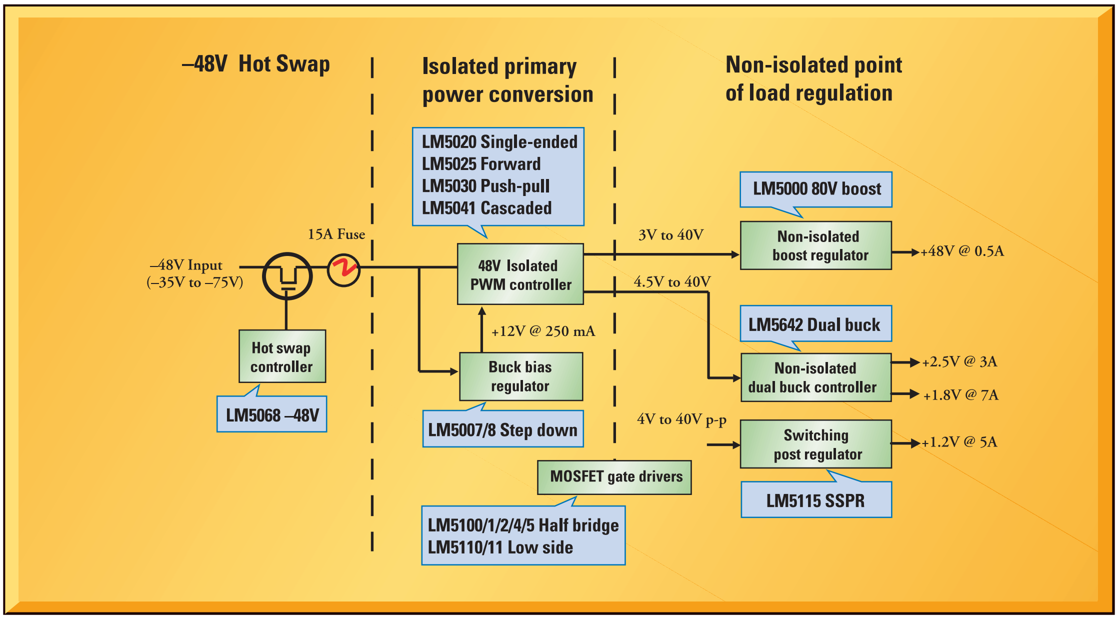
Buck Converter Characteristics

- Non-isolated ground
- Voltage step-down only
- Single-output only
- Very high efficiency
- Low-output ripple current
- High-input ripple current
- High-side gate drive required
- Large duty-cycle range
- Wide regulation range (due to above)

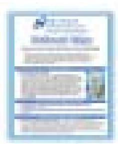
(b)

High-power, high-voltage ICs for power distribution and DC/DC conversion

New LM5000 family of power products



- Comprehensive family of 100V controllers and drivers covering a wide range of power levels and applications
- Highly integrated, using minimal external components
- Up to 90% efficient at full loads
- Available in tiny (3 mm x 3 mm x 0.75 mm) LLP™ package with thermal resistance down to -40° C/W
- Ideal for a wide variety of topologies including traditional buck, boost, forward and flyback regulators, as well as high-performance current-fed push-pull, half-bridge and full-bridge



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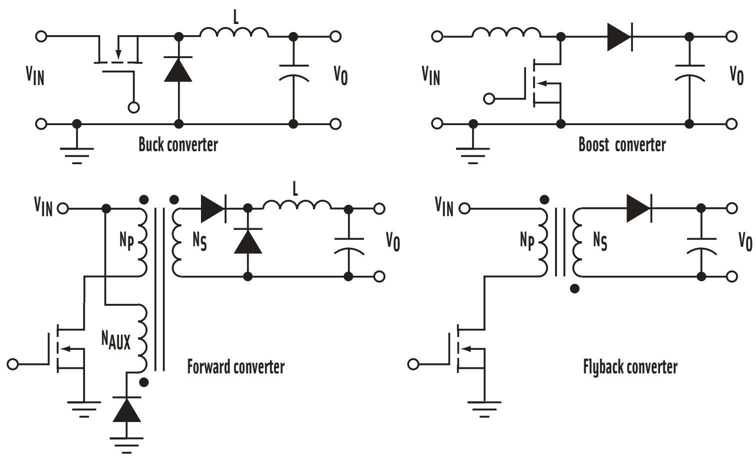
Low-Power Topologies

Single-transistor topologies, such as the buck, boost, forward, and flyback, are dc-dc converters intended to supply relatively low-power loads in distributed systems (up to about 100 W). The buck and boost circuits are non-isolated, while the forward and flyback converters provide transformer isolation.

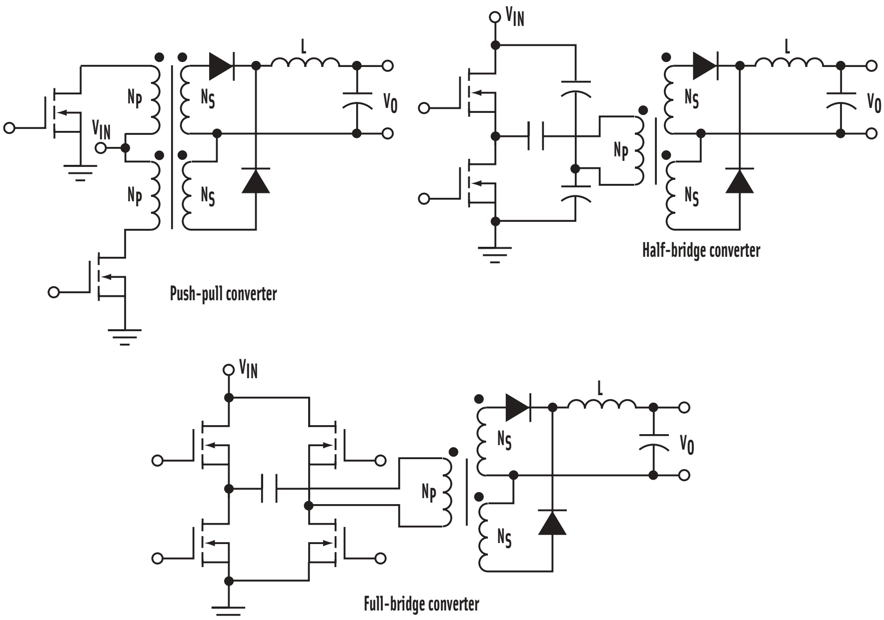
Common Single-Transistor Switching DC-DC Topologies



High-Power Topologies

Push-pull, half-bridge, and full-bridge dc-dc converters are isolated switching topologies that provide greater power output than the single-transistor types. An advantage of two-transistor topologies is that they can deliver twice the power of a single-transistor type using the same size transformer. Transistors in the bridge topologies see only one-half or less the voltage stress of a forward or push-pull configuration. So, transistor voltage ratings can be a fraction of what is required in other topologies. Half-bridge and full-bridge converters are used often in offline applications, operating with a very high 400-V-dc input voltage that's derived from a rectified and power-factor-corrected ac input line voltage.

Two-Transistor Switching DC-DC Power Topologies



Forward and flyback converters are also used in offline applications at lower power (less than 100 W). Unlike forward and flyback converters, bridge converters will provide high efficiencies in high-power dc-dc applications up to 1500 W. The push-pull converter is particularly effective at low input voltages. It can generate multiple output voltages, some of which can be of opposite polarity.