By David Marsh, Contributing Technical Editor

Inverters rev up small-motor drives

VARIABLE-SPEED DRIVES GREATLY IMPROVE EFFICIENCY IN DOMESTIC-APPLIANCE AND SMALL-MOTOR APPLICATIONS. POWER-DEVICE DESIGNERS IMPROVE PROCESSES TO REDUCE THE LOSSES THAT ACCOMPANY OFFLINE-SWITCHING-INVERTER OPERATION. OFF-THE-SHELF INTELLIGENT POWER MODULES EMERGE TO CHALLENGE IN-HOUSE INVERTER DESIGNS.

Photo courtesy International Rectifier

It’s sobering to realize that, amid today’s frenzy for ever-increasing efficiency, as much as 53% of the industrial nations’ electricity production still feeds electric motors. If you think that the futuristic-looking domestic appliances at your local store embody the latest in design and construction techniques, you’re probably wrong. As much as 90% of appliances that employ fractional-horsepower electric motors conceal brush-commutated universal motors that operate at about 30 to 40% efficiency, compared with as much as 95% efficiency for a modern three-phase permanent-magnet motor. Reasons to stay with the old technology include low initial cost—maybe one-third the cost of a $50, three-phase motor with speed-control electronics—and the smallest available size for a given-power output.

But there are signs that this situation is changing, and variable-speed drives are fast gaining popularity for low-power applications in the home and for the light industry. Offsetting hefty purchase-price premiums, advanced washers achieve annual savings in electricity- and water-consumption costs of as much as $200 and thus appeal to energy-conscious consumers. Other domestic-environment factors include quiet operation; civic authorities in some areas outlaw late-night chores that exceed prescribed acoustical limits. Although speed control in a traditional appliance relies on clunky belts, pulleys, and clutches to vary the output of a fixed-speed motor, electronically controlled motors can smoothly and far more quietly ramp up speed. With less abrupt torque changes, such operation also results in lower stress on mechanical components and the loads they drive—providing benefits in load handling from clothing to conveyor belts.

Designing a complete motor-control system from scratch isn't a job for the faint-hearted. Designers must handle control and power-delivery issues and ensure safe operation, and their designs must meet EMC-emission limits. The new generation of low-power designs relies on ac-induction, brushless-dc (BLDC), and even switched-reluctance motors. The dominant control method for these motors relies on pulse-width-modulation (PWM) techniques to switch an inverter bridge that delivers the electrical output power. Motor-control designers already have multiple choices for speed-control schemes and associated ICs, and more options are now emerging for inverter-system design (**Reference 1**). Reference-design kits can help you rationalize discrete-inverter designs with gate-driver ICs and integrated three-phase bridge modules. Alternatively, you can consider an off-the-shelf intelligent power module (IPM) that does the hard work for you.

AT A GLANCE

▷ Three-phase variable-speed motors vastly improve domestic-appliance efficiency.

▷ Motor construction presumes control strategy and influences inverter design.

▷ IGBTs and MOSFETs obsolete bipolar devices in low-power inverters.

▷ Power-device process-technology improvements widen your design options.

▷ Off-the-shelf intelligent power modules challenge in-house inverter systems.

▷ Custom services find new, high-volume markets.

MOTOR TYPES INFLUENCE INVERTERS

The type of motor you choose determines control and power-switching

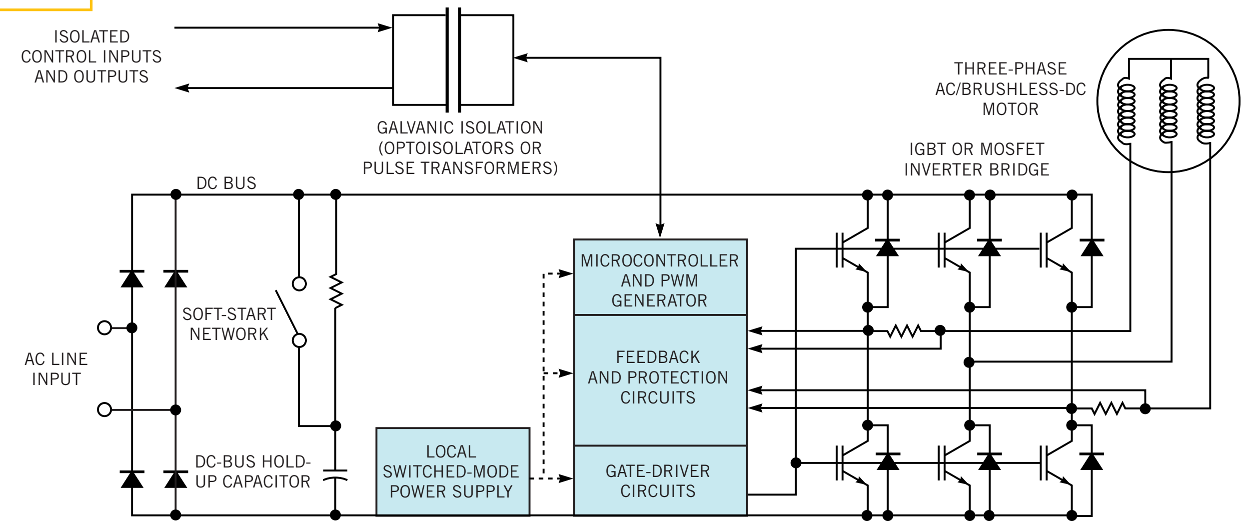
TABLE 1—INVERTERS FOR SMALL AC MOTORS

Vendor	Product	Power rating	Functions
Dynex Semiconductor **Enter No. 330**	AS-series of application-specific power modules	600V-dc breakdown voltage for 0.25- to 2.2-kW motors	Complete inverter module, suits two- and three-phase ac induction motors; 16-kHz PWM supports sine or deadband triplen waveforms; 93 to 96% typical efficiency; internal-voltage-amplitude control with adjustable acceleration and deceleration; instantaneous overcurrent, overvoltage, overtemperature, and undervoltage-lockout protection
Fuji Electric **Enter No. 332**	R-IPM Mini series	600V-dc breakdown-voltage current range 15 to 30A	Three-phase IGBT modules use fourth-generation punch-through IGBTs; integral gate drivers; low- and high-frequency versions; overtemperature protection integrated with IGBT chips; overcurrent and undervoltage-lockout protection; alarm-signal output; direct-bonded copper substrate
	R-IPM series	600 and 1200V breakdown voltage current range 15 to 300A	Three-phase IGBT bridge; 500-nsec IGBT switches; PWM to 15 kHz; gate drivers with input amplifier hysteresis and transient overvoltage protection; output-driver short-circuit, overcurrent, overtemperature, and undervoltage-lockout protection; single-pin alarm signal; brake IGBT option
International Rectifier **Enter No. 335**	PowIRtrain power-module family	180V- to 480V-ac line operation single-/three-phase ac supply for 0.37- to 3.7-kW motors	Three-phase IGBT-inverter-bridge family offers four circuit configurations; fast soft-recovery freewheel diodes; integral single- or three-phase ac line rectifiers; withstands 50% overload for 60 sec; NTC temperature sensor; high- and low-side current shunts; brake IGBT option; gate-driver-IC and IRMDAC reference-design kits available
Leistungsmodule Nürnberg (LN) **Enter No. 337**	PM series	600V-dc breakdown-voltage current range 10 to 15A	Three-phase IGBT bridge with gate driver and protection circuitry; 5- to 30-kHz PWM frequencies; integral soft-switching diodes; high-side driver supply with bootstrap circuit; input logic provides dead time between high- and low-side switching; short-circuit, overcurrent, earth-fault, overtemperature, and undervoltage-lockout protection
Mitsubishi Electric **Enter No. 338**	PS212xx family	220V-ac line operation for 0.2- to 1.5-kW motors	Three-phase IGBT inverter bridge; 5- and 15-kHz PWM versions; provides input-signal conditioning, level shifting, protection and output gate drivers; user-configurable short-circuit protection; undervoltage-lockout protection; withstands 50% overload for 60 sec
	PS1103x family	220V-ac line operation for 0.2- to 2.2-kW motors	Includes three-phase ac-line-rectifier bridge; six-IGBT inverter uses third-generation IGBT and diode technology; 15-kHz PWM; signal conditioning, level shifting, protection and output gate drivers; user-configurable short-circuit protection; supply undervoltage-lockout protection

strategies and thus influences the inverter design. BLDC motors are typically today's choice for new appliance designs (see **sidebar** "BLDC motors spin up volumes"). Power-delivery systems rectify ac line voltage to charge a holdup capacitor, producing a high-voltage dc bus that supplies the inverter. The holdup capacitor is typically the largest, most expensive, and least reliable system component, with a rating of about 1000 μF/kW of motor power. A single-stage conversion architecture minimizes or dispenses with galvanic isolation, dominating low-power, lowest cost designs (**Figure 1**). Although connections such as the "six-by-six" design that drives each end of a phase winding are possible, the most popular inverter configuration is a six-control-input, three-wire power-output connection. Notice that, with this connection arrangement, the voltage across any one winding is the difference between the applied voltage and the voltages across the remaining windings; a six-by-six connection can supply full dc-bus potential, improving speed-control ability in low-voltage applications.

Supply-line voltage, motor current, PWM carrier frequency, and overload tolerance make up key power-device-selection criteria. Components with 600V-dc breakdown voltages suit 230V-ac line operation; 1200V dc suits operation from 415 or 575V-ac, three-phase supplies. Unlike their fragile bipolar predecessors, today's MOS-controlled power devices

Figure 1



A single-stage, common-ground architecture dominates today's low-power, lowest cost motor-drive applications.

Packaging	Guide price/availability
Preassembled and tested module, typically measures 100×80×60 mm (includes fixings and dc-bus link capacitors)	AS-series, 100 euros (sample quanities) available in fourth quarter of 2000
21-pin insulated flat-base package, measures 64×46.5×16.5 mm (including terminals)	6MBP15RY060 (15A/600V), 20 euros (100,000); available now
21-pin flat-base insulated package, measures 70×46.5×16.5 mm (including terminals)	6MBP15RH060 (15A/600V): 16 euros (100,000); available now
Two insulated flat-base package sizes, measure 66×45×16.5 mm (including terminals) and 98×53×16.5 mm (including terminals)	IRPT1058A (12A/600V), 45 euros (100); IRPT2056A (30A/600V), 80 euros (100); both available now
14-pin flat-base insulated package, measures 98×56×18 mm (including terminals)	PMC15 U060, 19 euros (10,000); PMC20 U060, 22 euros (10,000); available now
26-pin insulated Transfer Mold DIP package, measures71×39×12.8 mm (including pc-board terminals); newly available mini-DIP version, measures 49×31×5 mm, plus pc-board terminals	PS21204 (15A/600V), 20 euros (sample quantities); available now
30-pin flat-base insulated package, measures 74×63×16.5 (including terminals)	PS11033 (15A/600V), 20 euros (sample quantities); available now

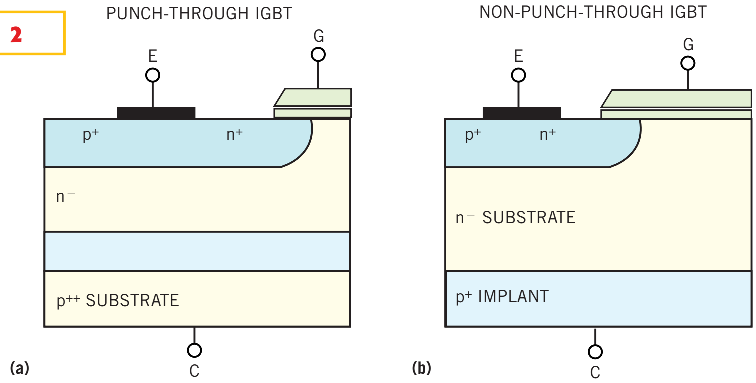
withstand repeated transient-voltage overloads, converting excess energy into heat during submicrosecond periods of avalanche operation. You should anticipate supply peaks and overvoltage transients that arise from other loads switching further down the local supply line. Transient overvoltage protection and surge-current limiting are essential, as is a noise filter to attenuate harmonic emissions that couple back into the supply line (**Reference 2**). One highly effective way to condition the supply line adds a preboost converter to control the dc-bus potential, providing power-factor correction and quashing harmonic current emissions (**Reference 3**). Another active technique, especially suiting high-power drives, replaces the ac-line rectifiers with silicon-controlled rectifiers (SCRs) and an adaptive control circuit to provide soft-start capabilities.

Power-device characteristics determine MOSFETs and insulated-gate bipolar transistors (IGBTs) for motor-drive applications that reach several kilowatts. For applications reaching 200W with 600V breakdown ratings, motor-drive designers often prefer MOSFETs. IGBT conduction losses remain similar across load-current changes, but MOSFETs have almost constant on-resistance across the conduction region; ohmic losses linearly decrease with decreasing load current. At breakdown ratings beyond 600V or for applications that demand more than about 500W, MOSFETs give way to IGBTs at frequencies of 30 kHz or less. Semiconductor vendors informally classify motor-control applications as low-speed (1 to 5 kHz) and high-speed, in which the carrier may be 15 kHz or greater. To reduce audible motor noise, motor-drive designers favor frequencies that lie in the ultrasonic region (16 kHz or greater). To reduce high-speed operational losses, check for interwinding capacitances in the motor that you choose.

PROCESS IMPROVEMENTS WIDEN OPTIONS

Device structures, such as Infineon's CoolMOS process, reduce ohmic losses and widen high-voltage MOSFET applications. As a MOSFET's breakdown voltage increases, device engineers increase the thickness of the epitaxial layer and decrease its doping level. Conductivity thus decreases disproportionately quickly with increasing breakdown voltage. In MOSFETs with a 600V breakdown rating, 96.5% of the power-sapping drain-source resistance, $R_{DS\ (ON)}$, lies in the epitaxial layer. Inserting vertical p-strips into the epitaxial layer forms a folded 3-D structure that resists voltage breakdown in the vertical and horizontal planes, allowing higher doping levels and a thinner epitaxial layer. The CoolMOS process reduces $R_{DS(ON)}$ by as much as a factor of five. A conventional 600V MOSFET has a best-case $R_{DS(ON)}$ of about 800 mΩ, and an equivalent CoolMOS device has about 190 mΩ. Critically, the CoolMOS process suits further integration, allowing device designers to construct "smart" power devices that include on-chip control and protection circuitry.

Figure 2



Punch-through IGBTs have low saturation voltages but wide switching-speed characteristics: non-punch-through IGBTs' simpler construction tightens switching speed but lowers conductivity.

IGBTs combine the MOSFET's low drive-current requirements with a saturation voltage (VCE_{SAT}) of around 2V across the operating-current range. IGBTs are extremely rugged, with rectangular reverse-breakdown safe areas of operation (RB_{SOA}) that typically withstand short circuits for 10 μsec or more—long enough for simple protection circuits to activate. Like MOSFETs, IGBTs have positive-temperature-coefficient characteristics, decreasing the likelihood of thermal runaway and making it easy to parallel devices to increase output-power ratings. Today's process technologies also assure freedom from device latch-up by controlling the parasitic gate-drain thyristor that can latch the power switch on under severe reverse-bias conditions. You can choose punch-through (PT) or non-punch-through (NPT) IGBT technologies. With typically 10% lower saturation voltages, PT IGBTs dominate at 600V-dc breakdown ratings levels; NPT derivatives suit 1200 to 3500V-dc operation.

PT IGBTs comprise a control-side cell structure that's similar to a MOSFET, coupled with an epitaxial-layer structure that's built on a p-doped substrate wafer (**Figure 2a**). A highly doped n^+ buffer layer constrains the space-charge region when the device is off; the thickness of the adjacent n^- layer principally determines device conductivity. Despite heavy metal diffusion or irradiation to adjust carrier lifetime and switching speed, it's

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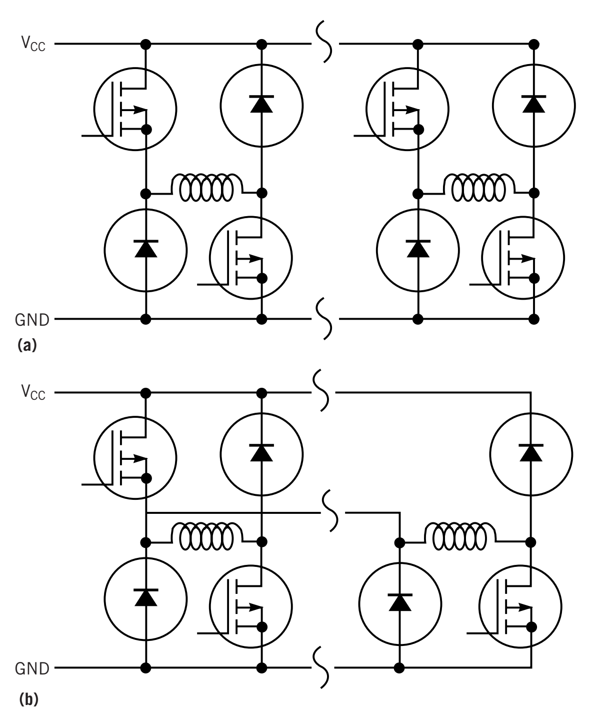
difficult to control the doping levels of the n^+ buffer and n^- layers, resulting in relatively widespread device parameters. The characteristic current "tail" that slowly decays as IGBTs stop conducting can exhibit large variations in PT types. Check the worst-case switching parameters over temperature to allow adequate "deadband" time, ensuring that each device fully turns off before its partner starts to conduct. NPT IGBTs use a single, slightly doped n^- layer on a p-layer that's implanted after the wafer is ground to the required thickness (**Figure 2b**). At the 600V level, this thickness is around 100 μm, which is difficult to machine and traditionally restricts NPTs to minimum 175-μm wafer thicknesses. But the

BLDC MOTORS SPIN UP VOLUMES

Asynchronous ac induction motors are still the cheapest, most rugged electrical motors, and three-phase motors readily suit electronic speed control. Control schemes for this motor typically compare a variable-frequency-reference sine wave with a fixed-frequency carrier to generate a PWM waveform, driving the inverter. The inverter sequentially switches current through each stator phase to generate a rotating field that induces current flow in the short-circuited rotor windings. Magnetic-field currents acting on the air gap between the rotor and the stator generate torque, causing the rotor to turn at speeds that approach the stator field frequency. Simultaneously varying frequency and excitation voltage maintains near-constant torque across the speed range (volts-per-hertz control). Modified sine-reference waveforms that include third harmonics, such as "triplen" and "deadbanded triplen" shapes, improve on the basic 65 to 70% operating efficiency by as much as 16 to 33% (**Reference A**).

Many appliance designers favor brushless-dc (BLDC) motors, which are permanent-magnet, synchronous ac motors. A three-phase BLDC motor comprises a stator that carries the phase windings, which surround a permanent magnet rotor that's built from a high flux-density material such as neodymium-iron-boron alloy. To generate the rotating field, the control system switches current to two stator phases with the third phase inactive ("two-phase on" operation); magnetic attraction causes the rotor's pole pairs to chase the field and generate torque. The control system manages the lead angle between the rotor and the stator field to smooth torque delivery, so the control loop requires rotor-position feedback. (Some sensorless control schemes measure the back-electromotive force from the inactive winding to replace Hall-effect and other rotor-position sensors.) Because there's no need for rotor magnetising current, the BLDC motor delivers 90 to 95% operating efficiency. Other attributes include maintenance-free operation, a power factor that remains close to unity across the speed range, and flexible packaging options–such as the "pancake" motor, which is wide and thin to suit direct-drive arrangements in applications such as washers and dryers.

Switched-reluctance (SR) motors match BLDCs' greater-than-90% operating efficiency, replacing brittle and expensive magnet rotors with steel laminations that form rotor teeth. This robust design saves 20 to 30% on material cost and accommodates greater-than-25,000-rpm operation, compared with competitive motors that typically operate at 3000 rpm or less. A three-phase SR motor comprises six stator windings and eight rotor teeth that never fully align. The inverter's switching action generates a rotating field that forces the rotor to move to its next position of "least reluctance," creating torque. Torque ripple–the motor's inability to smoothly deliver torque across the operating range–is a major problem and can generate unacceptable audible noise; four-phase designs ease torque-delivery characteristics. SR motors are difficult to control and typically employ DSP-based proportional-integral-differential (PID) control loops. Torque-control and current-control schemes dominate; a wide-speed-range SR motor may use both schemes to smooth its torque delivery. The torque-control strategy adapts the inverter's switching points at low speeds to match the motor's torque profile; the current-control strategy actively measures phase currents at high speeds to derive control-loop corrections. To provide full control over a range of motor speeds, the inverter connects to both ends of each phase winding (**Figure Aa**). A simpler but less flexible scheme uses a Miller inverter to reduce a three-phase motor's power-device count from six devices to four (**Figure Ab**).



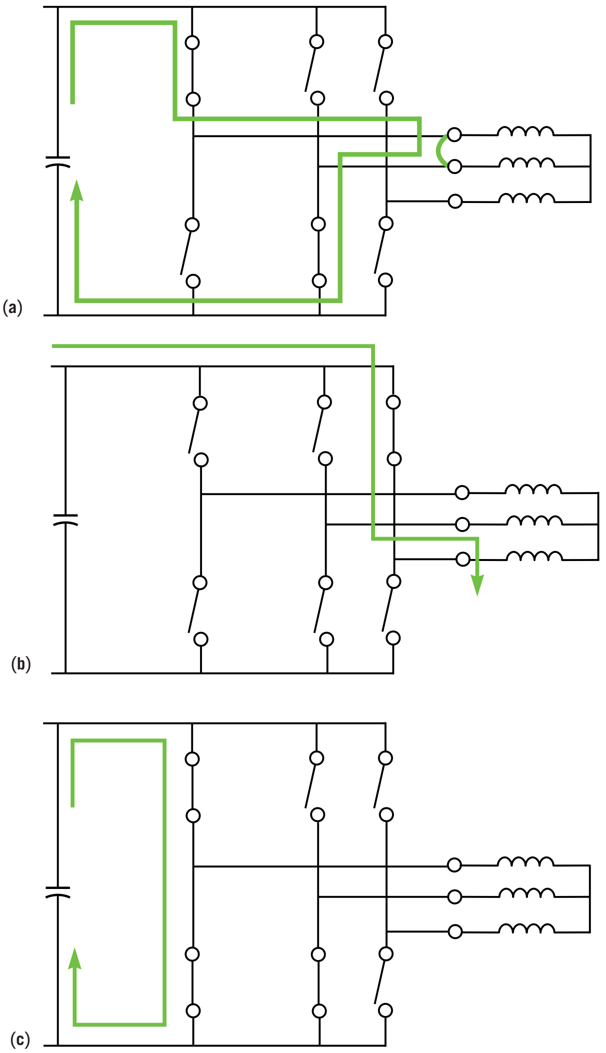
Six switches provide wide-speed-range control in a three-phase inverter for switched-reluctance motors (a). Single high-side devices save cost in low-end switched-reluctance motor-drive inverters (b).

REFERENCE

A. Mallinson, N, and P Masheder, "High efficiency SA808 PWM controller with serial microprocessor interface for low cost induction motor drives," Dynex Semiconductor, Lincoln, UK, www.dynexsemi.com.

NPT's structure is more reproducible than that of the PT device, resulting in better controlled switching characteristics; new devices from vendors such as Infineon extend these improvements to the 600V level at currents of 2 to 100A.

Figure 3



Consider motor-stall overloads, and design your product to handle inverter short circuits and prevent shoot-through.

Replacing the flywheel "snubber" diode that protects the power devices from reverse-bias transients with a fast-recovery diode (FRED) limits flywheel-diode losses. FREDs minimize EMI generation during switching with fast turn-on/slow turn-off characteristics. To work effectively, the FRED's silicon area is similar to that of the power device it protects. Device engineers balance the FRED's conflicting switching speed and conductivity trade-offs to arrive at forward voltages typically less than 2V. Some MOSFETs substitute FREDs for the intrinsic source-drain diode, giving rise to devices that vendors generically label FREDFETs. Substituting a fast-recovery diode for the intrinsic body diode involves injecting additional impurity into the n^- region, which reduces the MOSFET's drain-source voltage-blocking capability and requires a thicker, less conductive layer. But if you compare losses per watt across a refrigerator compressor's pressure-operation cycle, FREDFETs are more efficient than IGBTs.

The first step in rationalizing discrete-inverter design is to integrate the inverters' power devices and their flywheel diodes—or at least, combine them in one package as a power module. Improved packaging provides better thermal management and guaranteed characterization, reduced EMC due to less wiring interconnects, reduced inventory requirements, and lower overall cost. Semiconductor vendors offer an array of products built in their proprietary processes that suit low-power, offline motor control applications (see **sidebar** "For more information). Options such as integral current shunts and thermistor temperature sensors provide tighter integration. Modules such as Semikron's Mini SKiiP series offer further design flexibility with a variety of circuit configurations, including the six-by-six connection that suits switched-reluctance motors.

GATE DRIVERS PROTECT DEVICES

Power-device gate-driver and protection issues are the hardest aspects of inverter design. Design from the outset to accommodate motor- or wiring-failure scenarios, such as motor stalls, ground faults, and line-to-line short circuits. Qualify the gate-driver logic under worst-case conditions to guarantee freedom from "shoot-through" that occurs when both upper and lower devices simultaneously conduct (**Figure 3**). Causes of shoot-through include system noise falsely triggering the power devices and insufficient "deadband" time between switching the high- and low-side devices. But excessive deadband time creates nonlinearities in the power circuit's transfer function that can be hard for the control loop to compensate. Accordingly, you match the deadband period to power-device switching characteristics and consider temperature-related propagation delay changes within the entire inverter system. Three-phase control ICs, such as the Ixys IXPD630, let you vary deadband time by altering the reference-oscillator frequency; for this IC, deadband time is eight clock cycles.

To turn on the high-side device, you must provide a gate-drive signal that exceeds the dc-bus rail potential by around 15V. Designers typically achieve this requirement with a bootstrap supply that requires several pulses at start-up to charge the holding capacitor. And, although MOSFETs and IGBTs are off when there's zero gate-drain/gate-emitter voltage, designers often reverse-bias this node to ensure that the device stays off under the high dV/dT conditions that arise during switching. When the low-side switch is off and the high-side switch turns on, the supply potential appears at the low-side device's drain/collector and couples into its gate. Without active control, this Miller coupling capacitance is sufficient to instantaneously raise the gate voltage by several volts and into the device's conduction region.

Gate-driver ICs from vendors such as Hitachi, International Rectifier, and Ixys simplify the interface between control logic and the power devices. Gate-driver ICs accommodate the low-to-high voltage-level shift between control logic and the power devices with separate control inputs that suit control-switching strategies for all three-phase motors. Gate-driver ICs generate power-device drive currents of ±100 to ±500 mA with transient capabilities as great as 2A, sufficient to charge capacitive gate connections at speeds greater than 30 kHz. Gate-driver ICs, such as the Ixys 4410 family, reject common-mode transients reaching ±50V/nsec and 1200V peak to guarantee freedom from false triggering. The Ixys chip sets comprise low-and high-side drivers that share common grounds; pulse transformers couple control signals between the low-side driver and its high-voltage floating counterpart. A fault-current input provides controlled power device shutdown with 20 μsec of fault detection. You can detect fault currents using a resistor in series with the load, but this approach is intrinsically lossy. Sensing the power device's saturation voltage during its on-time detects the motor desaturation that occurs under overload conditions, eliminating resistive losses and accounting for the device's full-power on-resistance rating (**Figure 4**).

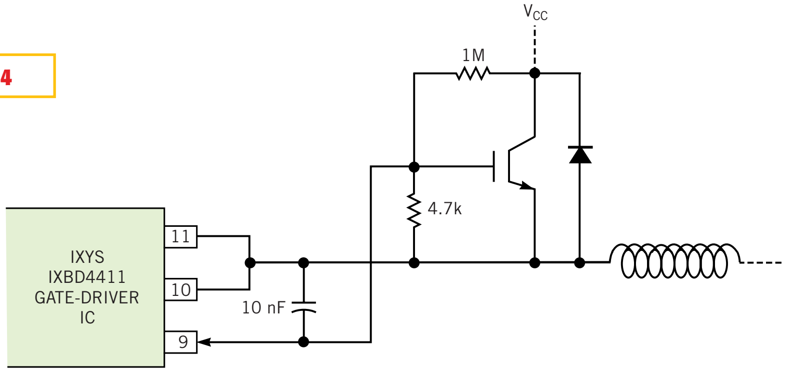
International Rectifier uses a proprietary high-voltage-IC process to monolithically combine the low- and high-side drivers, such as in the company's IR2132 three-phase bridge driver. This IC provides a fixed 800-nsec dead-time switching period with matched propagation delays across the three channels. Undervoltage-lockout and overcurrent detection logic turns off all six drivers. The 600V-rated IR2137 includes protection mechanisms that detect high-side motor desaturation and provide a synchronous slow shutdown under fault conditions. Available for sampling now, this third-generation IC will be in production by June. The company's IRMDAC family of reference designs allows you to evaluate gate-driver ICs and power modules that suit 750W to 2.2-kW motors. Features include inrush current limiting and surge suppression, integral supplies, device-temperature sensing, and dc-bus voltage and current feedback. The 2.2-kW versions include a brake switch to support a regenerative-motor-braking option.

IPMs THREATEN POWER MODULES

You can largely sidestep output-stage design issues by using an intelligent power module (IPM). Originally an Asian phenomenon, vendors such as Fuji, Mitsubishi, and Toshiba offer a range of high-power (50 to 300A) IPMs that account for more than 30% of the Japanese market for industrial motor-drive inverters. Several vendors now target inverter systems for low-power, lowest cost applications (**Table 1**). European interest comes from Alcatel subsidiary Leistungsmodule Nürnberg (LN) with a range that spans 10 to 15A at PWM-carrier frequencies reaching 20 kHz. But with industry estimates of a $750 million inverter market by 2003 just for domestic appliances and air conditioners, expect additional interest from companies such as Infineon and its power-specialist subsidiary, Eupec.

IPMs make the apparently obvious step of combining the power components with dedicated gate-driver and protection circuitry, providing the simplest microcontroller-to-motor interface. A typical construction method encapsulates gate-driver and protection circuitry together with IGBT power devices and fast-recovery diodes within an insulated, flat-base module. Suiting power levels of 0.2 to1.5 kW, Mitsubishi's PS212xx family employs a 26-pin, dual-in-line plastic package that solders like an IC to a conventional through-hole-plate pc board; a newly available mini-DIP version shrinks package size to 49×31×5 mm. Higher power IPMs typically solder silicon chips to a copper slug that's epoxy-glued to an aluminium substrate. Fuji's Mini R-IPM design employs a direct-bonded-copper (DBC) substrate with a ceramic insulator that reduces earth-leakage currents by more than 50% (**Figure 5**). Earth-leakage-current flow occurs during power-device switching with a magnitude that's proportional to switching-speed and chip-to-substrate capacitive coupling.

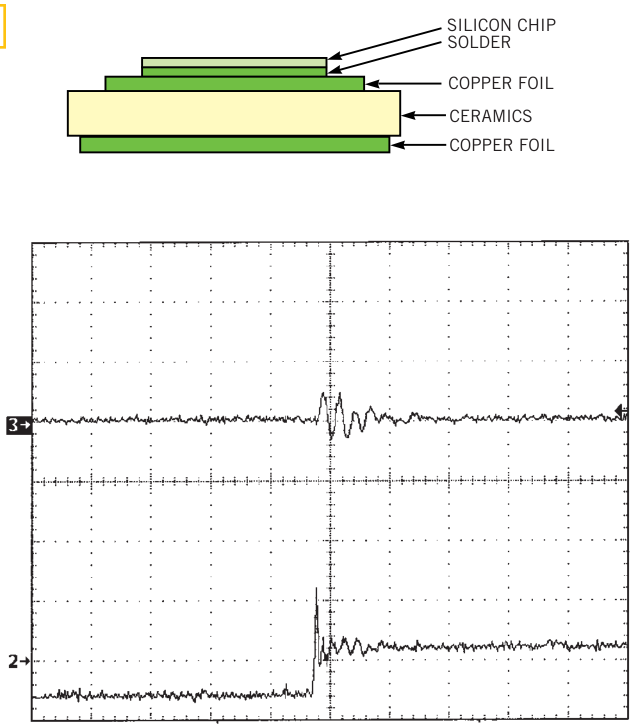
Figure 4



Sensing on-state power-device saturation voltage detects motor desaturation and eliminates losses in current-sense power resistors.

IPM-packaging techniques promise optimum power-device protection with features such as undervoltage-lockout protection and short-circuit current limiting. Most IGBT power modules that include temperature sensors use positive- or negative-temperature coefficient (PTC/NTC) thermistors, and this practice carries over to many IPM designs. Such modules typically withstand current overloads to 150% of rated current for 1 minute to accommodate fault conditions, such as a temporary motor stall. Depending on the protection-circuit de-

Figure 5



NOTES:
LEAKAGE CURRENT=0.5A/DIV.
COLLECTOR CURRENT=5A/DIV
TIME=1 μSEC/DIV

Fuji's direct-bonded-copper substrates employ ceramic insulation to reduce earth-leakage current amplitude by more than 50% compared with aluminium-based structures.

sign, this time may be insufficient to prevent power-device burnout under worst-case conditions. Modules such as Fuji's Mini R-IPM series integrate a diode sensor on each IGBT chip, reducing thermal shutdown times from 60 sec or more to a few hundred milliseconds. But fault-protection considerations remain an issue, and you must ensure that the IPM you select accommodates European-region requirements, such as earth-fault protection—with or without additional circuitry.

CUSTOM SERVICES WIN FAVOR

Looking at **Table 1**, you might wonder why there are so few off-the-shelf items. One reason is that the low-power market is only just emerging, but it's difficult to see why European market acceptance of the IPM concept trails Japanese acceptance. IPM vendors argue that inverter designers' key task is to implement motor-control algorithms, semiconductor manufacturers know how best to drive and protect their power devices, and IPMs reduce design cost and improve motor-system quality. Antagonists argue that IPMs are inflexible compared with custom designs and motor-drive designers wish to retain complete control of their systems.

Compellingly, motor-drive applications frequently require custom work, if only to fit restrictive enclosures. This requirement provides a business opportunity for companies such as Danfoss Silicon Power and Dynex Semiconductor. Nick Mallinson, PhD, business-development manager for low-power systems at Dynex, notes that many customers come to the company to add speed control to an ac-induction-motor application. Most customers' drive requirements are simple, but cost considerations exclude commercial inverter systems with controls and displays. Dynex's custom capability accommodates inverter modules that exactly fit the application.

"Of course, power level is important," Mallinson says, "but that's normally a matter of appropriately sizing the IGBTs and the dc-bus-reservoir capacitor; form factor is far more significant." Dynex is also developing an off-the-shelf range of application-specific modules that will be available this year.□

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