Power Quality Vista Looks Good Thanks to IGBTs

Newly applied technology could ultimately result in downsizing of input conductors, switchgear, transformers and generators in UPS/generator applications

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Perhaps you've seen advertisements praising the value of insulated-gate bipolar transistors (IGBTs) in power applications. Automobile electronics system manufacturer, Delphi, for instance, uses IGBTs in the systems it supplies to General Motors. Hospitals and medical facilities are also employing the technology (see sidebar). It is also being used in motor, power and lighting applications. But what exactly is an IGBT and how does it translate into value for designers and users of power equipment?

Discovered in 1982 by RCA, the IGBT is about the size of a postage stamp. It can be combined with other IGBTs to switch up to 1,000 amps of electric current at voltages of up to several thousand volts. It is a hybrid of two transistors, the bipolar transistor and the metal-oxide-semiconductor field-effect transistor (MOSFET).

The key advantage of the technology is that it provides a higher operating current density than either of its components' individual capacities. Also, when switched on, the IGBT has very low electrical resistance between the collector and the emitter.

In practical terms, these attributes allow IBGTs to be smaller, more efficient and less expensive to produce compared to alternative controllable switches in their voltage range. The smoother sine wave keeps equipment, such as motors, from generating excessive harmonics. Low harmonics mean less heat and wasted energy and quieter operation.

As a result, IGBTs find their way even into washing machines and refrigerators, as they improve efficiency and reduce hum as their frequency range is above human hearing.

Design Considerations

With a breadth of available components, engineers searching for a device that combines the power gain of a silicon-control rectifier (SCR) with the switching characteristics of the solid-state transistor, may find it in the IGBT. In fact, one IGBT manufacturer has gone beyond the simple supply of the basic device, offering standard, fast speed and high-speed IGBTs, coupled with ultra-fast diodes and short-circuit protection.

Here are some IGBT advantages as stated by a manufacturer of variable-speed drives (VFDs):

- Low gate power requirements (requiring less support hardware).
- Simple, more reliable firing.
- Faster switching (higher performance).
- Less costly to manufacture than a Darlington transistor.
- Low forward voltage drop.

According to an application engineer associated with the VFD manufacturer,

Photo: Courtesy of Caterpillar

IGBTs are being used in electronic systems installed in automobiles, in medical facilities for sensitive blood-testing and x-ray equipment—technology greatly affected by power-quality problems—and in motor, power and some lighting applications.

the problem–trying to combine solid-state transistor switching characteristics with SCR power gain in combination with a VFD–is that high-power circuits need SCRs or power transistors for variable-voltage control.

Regarding SCRs themselves, the devices cannot be shut off once gated, unless forced to go to zero current. Power transistors do not have this problem, but once the base signal or gate is removed, the transistor shuts off. Additionally, a transistor's power gain is limited causing very high failure rates. The advent of the IGBT addresses these problems in a solution that is less expensive in a form physically smaller than its predecessors.

Giving further credence to the technology is computer modeling conducted by the National Institute of Standards and Technology (NIST), Acquisition and Assistance Division, Gaithersburg, Md. NIST has made mathematical models available to device and application manufacturers that can be incorporated into commercial simulation modeling software. Users have stated that without this assistance, the modeling software would have been delayed and less accurate.

Power Control

Power control is a broad category. It includes power conditioning, power-factor correction, and uninterruptible power supply systems (UPS). IGBTs are used in power-factor-correction equipment to switch banks of capacitors on- and off-line to maintain high power factor. These units offer high-speed switching capabilities, increasing the equipment's efficiency–and reducing capacitor and resistor component costs.

Use of IGBTs in UPS units follows the same pattern as that for other rectifiers. When switched on, the IGBT has very low resistance between the collector and the

Critical Medical Insurance: IGBTs

One of the best uses of insulated-gate-bipolar transistors (IGBTs) is in the hospital environment. The IGBT's incorporation into the input stage of uninterruptible power supply systems (UPS) has not only served to cut costs in medical facilities by reducing generator size and the cost of installation hardware, but has also reduced damage from harmonics and less-than-perfect output waveforms.

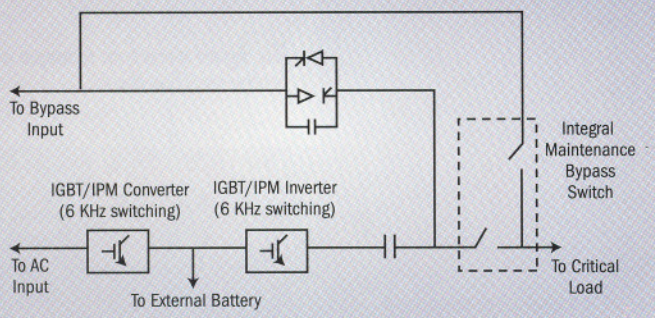
There was a time when operating rooms and diagnostics areas of hospitals could function with a blink of the lights. Now that flicker could potentially kill a patient during a critical operation or destroy important test data. For example, a pathologist in Ft. Wayne, Ind., reports that an entirely new sample is required if the operation of his sophisticated blood-testing equipment is marred by even the slightest power interruption.

With these problems in mind, the Evansville, Ind., engineering firm of Biagi, Chance, Cummins, London, Titzer, Inc., wrote a specification for a hospital incorporating an IGBT in the output stage with a UPS to eliminate harmonics downstream and to provide a clean, nearly perfect sine wave.

The same piece of equipment has a pulse-width modulator (PWM)-controlled IGBT on the front end. This reduces harmonics 3 percent to 7 percent–even at half load–without a filter. Filters have a tendency to weaken with age and become a maintenance issue. Since they are tuned to a specific frequency and load characteristics, they cannot provide stable reduction in harmonics at the range of loads from 25 percent to 90 percent that may be seen by a single UPS.

With the IGBT controlled by the electronics of the PWM, the filter is not required. The IGBT-based system outright eliminates the upstream harmonics that could interface with the "tools" of a brain surgeon, the rhythm of a heart or delicate eye-correction lasers.

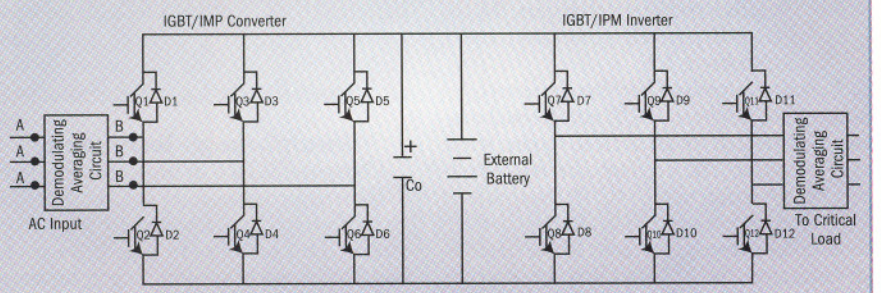
FIGURE 1. IGBT/IPM SINGLE-LINE DIAGRAM



LEFT: An on-line double-conversion system configuration for an IGBT/IPM, including a transistorized converter and inverter.

BELOW: Shows IGBT/IPM three-phase boost-converter topology for active reduction of reflected-input current harmonic distortion without the use of a passive-resonant LC filter. Inverter also uses IGBT/IPM technology.

FIGURE 2. IGBT/IPM THREE-PHASE BOOST-CONVERTER TOPOLOGY



emitter. As so many electrons flow through the bipolar base region, the base's conductivity increases 1,000 times. The improved conductivity keeps power loss at a minimum. The IGBT has a higher operating current density than its bipolar transistor and MOSFET components. The MOSFET current and the current of the bipolar transistor's emitter collector combine to produce an operating current density twice that of their individual capabilities.

IGBTs eliminate the majority of harmonic problems associated with SCRs

It should be noted that to create an IGBT, bipolar transistors are joined so that the channel current flowing to the substrate is also the current flowing to the base of the bipolar transistor. The IGBT's MOSFET can usually control 10 volts, but the whole unit can control 1,500 volts and 100 amperes. This can amount to a high power gain. The high power gain allows the unit to be controlled by delicate integrated circuits.

Practical Application: UPS

For 20-plus years, consulting engineers have listened to arguments debating the virtues and vices of six-pulse vs. 12-pulse rectifiers on UPS equipment. The IGBT is taking that discussion to a new level, as a result of its high-speed switching capabilities and its capability to eliminate a majority of the harmonics problems associated with SCRs, which are still used by several UPS manufacturers in their older designs. The SCR's most significant drawback is its inherently high-reflected harmonics, which may be as high as 12 percent to 34 percent. UPS manufacturers have attempted to get around this problem with resonant input LC filters. This filter is tuned to a specific harmonic frequency (typically 11th or 5th). Since the filters are tuned for full load, the device obviously will not be tuned for the 50-percent load where many UPS systems operate. They also may resonate with other power-factor-correction devices in the building or with generators.

One company is using an IGBT in both the converter and inverter sections of one of its UPS'. Specifically, the manufacturer has taken the device and combined it with an intelligent power module (IPM) to create a hybrid IGBT/IPM semiconductor device that is suitable for power conversion applications. The combined unit incorporates the IGBT, gate-drive circuitry, short-circuit sensing, protection circuitry and over-temperature sensing all in one package.

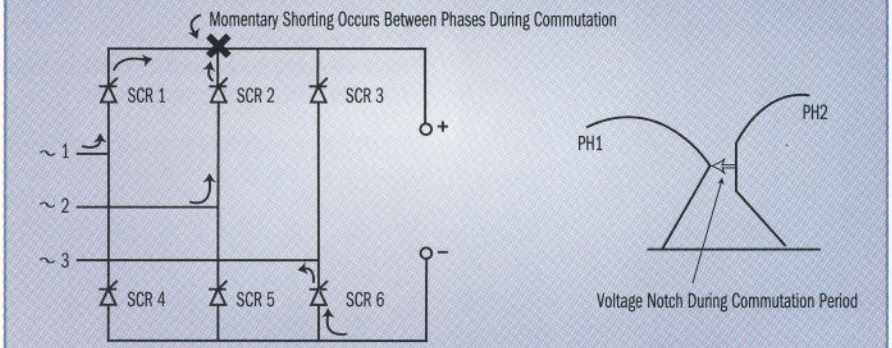
Thanks to the high-speed switching action, the company has revised what it calls the UPS "rectifier" to a "converter." The unit generates less than 3 percent reflected current total harmonic distortion (THD) at 100 percent load, and a maximum of 5 percent reflected current THD at 50 percent load. Total power factor is said to be in the range of 99 percent (between 50 percent and 100 percent load).

The Federal Aviation Administration (FAA) is using an IGBT/IPM-equipped unit on one of its radar facilities. Accord-

Advantages of Using IGBTs with UPS

- Insulated-gate bipolar transistors (IGBTs) in both the converter and inverter.
- Low input harmonics:
  4 percent typical (100-percent load).
  5 percent typical (75-percent load).
  7 percent typical (50-percent load).
- Input power factor:
  1-to-1 ratio.
- Efficient high-speed IGBT switching (16KHz):
  The higher efficiency means lower cost per kilowatt to the hospital.
- Extended battery life:
  With IGBTs in the converter and inverter, step loading is no longer a drain on batteries.
- Quiet operation (55db).

FIGURE 3. THREE-PHASE BRIDGE-RECTIFIER CIRCUIT



The figure shows an example of a three-phase bridge-rectifier circuit.

ing to a FAA spokesperson, the unit outperformed all other equipment in a competitive run-off, offering the lowest conducted and reflected harmonics and low audible noise while connected to an existing generator.

Another benefit of the IGBT/IPM hybrid is its ability to provide power to the inverter without drawing from the battery bank even at 100-percent step-load changes. Changes in DC-load conditions are quietly sensed by the feedback loop, manipulated by the field-proven pulse-width modulator (PWM) control method circuit and corrected by the gating of the IGBT without discharging the battery bank.

Static UPS vs. Generators

When certain brands of UPS are used, one must oversize generators to compensate for high harmonics and low power factor. Such concerns have popped up frequently enough to stimulate one manufacturer to issue a 22-page guideline on understanding static UPS systems and generator set applications.

According to the document:

1. The generator source is not equivalent to the utility. It is a high-resistance source that cannot be oversized in a practical manner to equate to the utility.
2. Nonlinear loads cause voltage distortion (not the generator).
3. UPS' using SCRs require a filter.
4. Harmonics may have adverse effects upon the power source or other loads connected to the same source.
5. Conditions assuring stable operation are complex. The generator-set supplier cannot guarantee a value of harmonics distortion with a UPS load.

From these points, it's clear that the generator-UPS relationship must be a major concern of the system design engineer. For six- or 12-pulse SCR systems, the company has established minimum-size generators to contain waveform distortion, as follows:

- For six-pulse rectifier/chargers: Minimum standby rated generator set = UPS input kilowatts (kw) x 1.6.
- For 12-pulse rectifier/chargers: Minimum standby rated generator set = UPS input kw x 1.4.

Voltage supplied by the generator is sinusoidal; however, SCR rectifiers charging a battery draw an almost square wave current pulse. The original sine-wave voltage now becomes distorted. Magnitude of voltage waveform distortion caused by nonlinear current demand of the rectifier/charger is a function of source impedance. The source impedance value is not easily defined, as following a sudden load change, generator reactance varies with time. Typically, a standby generator is of higher impedance than a transformer.

So while a nonlinear load may work fine with the utility, the performance may be entirely different with a generator set. These factors, added to conditions previously noted, cause the generator supplier to recommend a doubling of generator rating to reduce reactance by one-half. Adding a low-pass filter at the generator output is not a practical solution.

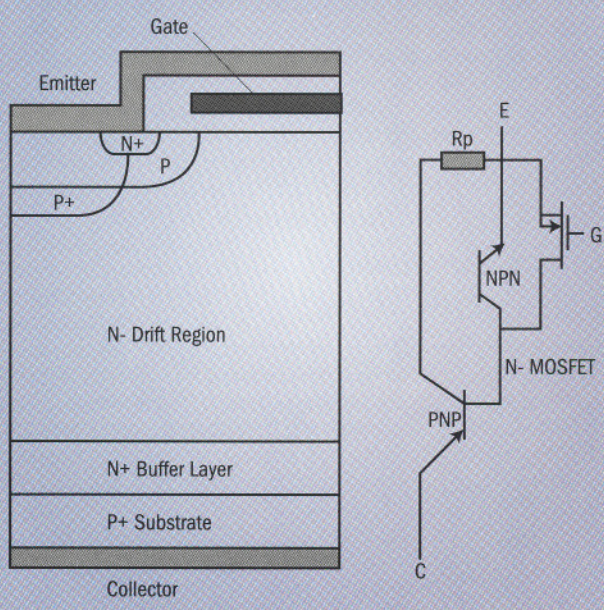
Also note that the generator contains a regulating circuit controlled by SCRs. If the UPS uses SCRs, circuits must be supplied to prevent the load SCRs from triggering the regulator SCRs.

An approach such as the IGBT/IPM eliminates the SCR concerns. Instead of the SCR-driven need for generator oversizing, the IGBT/IPM permits a 1-to-1 relationship, i.e., the kw rating of the generator can be made equal to the kilovolt-ampere rating of the UPS. With IGBT/IPM front end on the UPS, the power factor is 0.99. This means that the current draw will be less for the same kw, thus permitting designers to downsize the input conductors, switchgear and transformers.

Breakthrough Technology

Using the IGBT in both the converter and inverter represents the most significant change in UPS technology in 20 years. The savings in equipment and installation costs are significant; however, the 1-to-1 relationship and greatly improved overall compatibility between the UPS and generator represent the real technological breakthrough.

FIGURE 4. IGBT STRUCTURE



A cross section of an asymmetric IGBT structure and its equivalent circuit.

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