

# Choose Your IGBTs Correctly for Solar Inverter Applications

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The right combination of high-side and low-side bridge topology can ensure low power dissipation, high current carrying and gate-control benefits of IGBTs.

**G**iven the many varieties of advanced power devices available, choosing the right power device for an application can be a daunting task. For solar inverter applications, it is well known that insulated-gate bipolar transistors (IGBTs) offer benefits compared to other types of power devices, like high-current-carrying capability, gate control using voltage instead of current and the ability to match the co-pack diode with the IGBT.

A solar inverter is a power-electronic circuit that converts dc voltage from a solar array panel to ac voltage that can be used to power ac loads such as home appliances, lighting and power tools. However, getting the most out of such a topology requires careful analysis and the right choice of the high-side and low-side combination of an IGBT. It also requires more insight into how an IGBT works. A closer examination can show why.

## IGBT Technology

An IGBT is basically a bipolar junction transistor (BJT) with a metal oxide semiconductor gate structure. This allows the gate of the IGBT to be controlled like a MOSFET using voltage instead of current. Being a BJT, an IGBT has higher current-handling capability than a MOSFET.

An IGBT is also a minority carrier device like a BJT, meaning that the speed at which the IGBT turns off is determined by how fast the minority carrier recombines. As shown in Fig. 1, the turn-off time on an IGBT is a

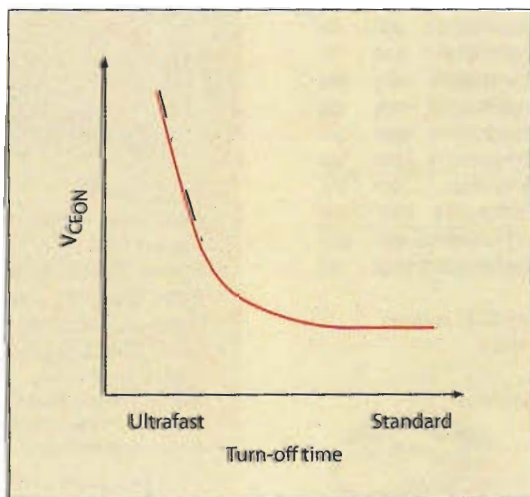
tradeoff with its voltage drop ( $V_{CEON}$ ).

As can be seen, an ultrafast IGBT has a higher  $V_{CEON}$  than a standard-speed IGBT. However, an ultrafast type switches off much faster than a standard-speed type, taking into consideration the same IGBT with identical dimensions and made from the same process technology. The tradeoff is achieved by controlling the lifetime of the IGBT's minority carrier recombination rate, which affects the turn-off time.

The parametric values of four IGBTs are shown in the table. The first three are from the same planar process technology, but with different lifetime recombination control dosage. As can be seen in the table, a standard-speed IGBT has the lowest  $V_{CEON}$ , but the slowest fall time compared to the other two fast and ultrafast planar IGBTs. The fourth IGBT is a trench-gate IGBT optimized to deliver low con-

duction and switching losses for high-frequency switching such as in solar inverter applications. Note that the  $V_{CEON}$  and total switching loss ( $E_{TS}$ ) values of the trench-gate IGBT are lower than those of the ultrafast planar IGBT.

A typical implementation of a solar inverter employs a full-bridge topology using four switches (Fig. 2). Here, Q1 and Q3 are designated as high-side IGBTs while Q2 and Q4 are designated as low-side IGBTs. The inverter is designed to produce a single-phase ac sinusoidal voltage waveform at a frequency and voltage that depend on the market application for which the inverter



**Fig. 1.** Turn-off time for an IGBT is a function of its collector-emitter voltage ( $V_{CE}$ ). Ultrafast IGBTs have shorter turn-off times than standard-speed IGBTs.

IGBT	Process	Speed	$V_{CE(on)}$ at $I_C = 20$ A and $150^\circ\text{C}$	$T_F$ at $I_C = 20$ A and $150^\circ\text{C}$	$E_{TS}$ at $I_C = 20$ A and $150^\circ\text{C}$	$Q_G$	$R_{TH}$
IRG4PC40SPBF	Planar	Standard	1.2 V	700 ns	8.0 mJ	100 nC	$0.77^\circ\text{C/W}$
IRG4PC40FDPBF	Planar	Fast	1.5 V	270 ns	4.0 mJ	100 nC	$0.77^\circ\text{C/W}$
IRG4PC40UDPBF	Planar	Ultrafast	1.7 V	130 ns	1.8 mJ	100 nC	$0.77^\circ\text{C/W}$
IRGP4063DPBF	Trench	Ultrafast	1.6 V	40 ns	1.2 mJ	95 nC	$0.45^\circ\text{C/W}$

Performance characteristics of four types of IGBTs.

is intended. One such market is inverters for residential installation tied to the power grid, with net metering benefits in some regions. This application requires the inverter to produce a low-harmonics ac sinusoidal voltage, because power is being injected into the grid.

One way to achieve this requirement is by pulse-width modulating the IGBTs at or above 20 kHz at a certain modulation frequency of 50 Hz or 60 Hz. By using pulse-width modulation, output inductors L1 and L2 can be kept reasonably small and will suppress the harmonics effectively. Audible noise from the inverter also can be minimized since the switching frequency is above the normal human hearing spectrum.

What is the best way to pulse-width modulate these IGBTs that will give the lowest-possible power dissipation? One way is to only pulse-width modulate the high-side IGBTs and to commutate the opposite low-side IGBTs at 50 Hz or 60 Hz.

Fig. 3 shows a typical gate-voltage signal. Here, Q1 employs pulse-width modulation while Q4 is kept on during the positive half-cycle. Q2 and Q3 are kept off during this positive half-cycle period. During the negative half-cycle, Q3 is pulse-width modulated while Q2 is kept on. Q1 and Q4 are kept off during this negative half-cycle. Fig. 3 also shows the resulting ac sinusoidal voltage waveform across output-filter capacitor C1.

This switching technique has several advantages:

- Current does not freewheel on the high-side co-pack diodes, minimizing unnecessary losses.
- Low-side IGBTs only switch at a line frequency of

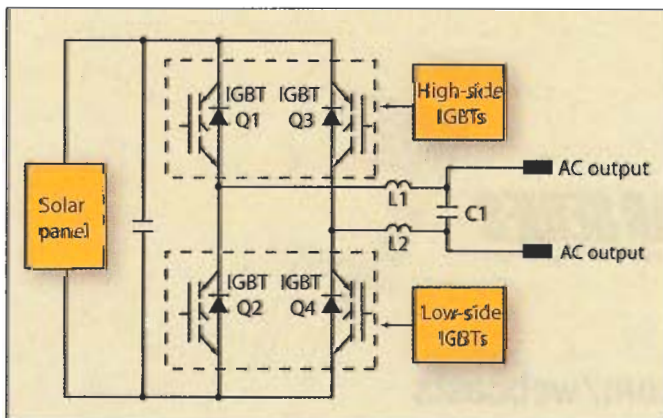


Fig. 2. A typical implementation of a solar inverter circuit using a full-bridge IGBT topology.

50 Hz or 60 Hz; conduction loss dominates these IGBTs.

- There is no possibility of bus shoot-through because IGBTs on the same leg never switch in a complementary fashion.
- Co-pack diodes across the low-side IGBTs can be optimized to minimize losses during freewheeling and reverse recovery.

### High- and Low-Side IGBTs

Let's assume a 1.5-kW solar inverter is being designed with a 230-Vac output. Which IGBT shown in the table will give the lowest power dissipation at 20 kHz? Fig. 4 shows the breakdown of power dissipation of the IGBTs switching at 20 kHz as discussed earlier. One can see that the ultrafast planar IGBT has the lowest total power dissipation compared to the other two planar IGBTs.

This is obviously due to the fact that at 20 kHz, switching loss becomes a very important component to the total power dissipation of the IGBT. As can be seen, the standard-speed IGBT has the lowest conduction loss, but its highest switching loss makes the device unsuitable for the high-side IGBTs.

The latest 600-V trench IGBT is optimized for switching at 20 kHz. It can be seen that this IGBT has lower total power dissipation compared to the previous-generation planar IGBT (Fig. 4). We can conclude that the highest efficiency possible for a solar inverter design, a trench-gate

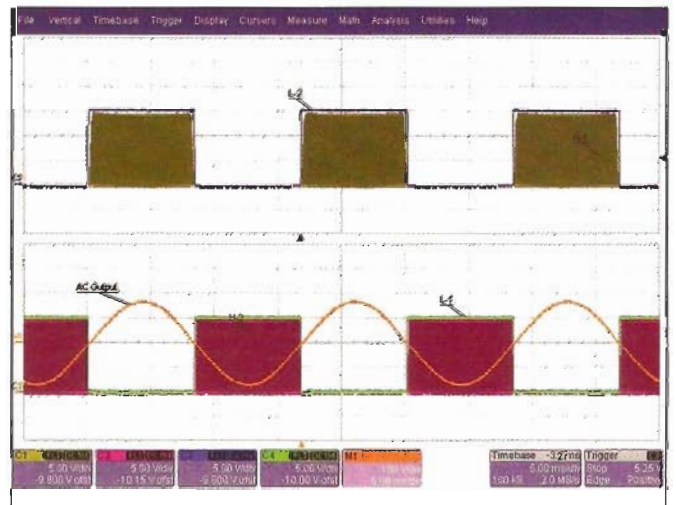
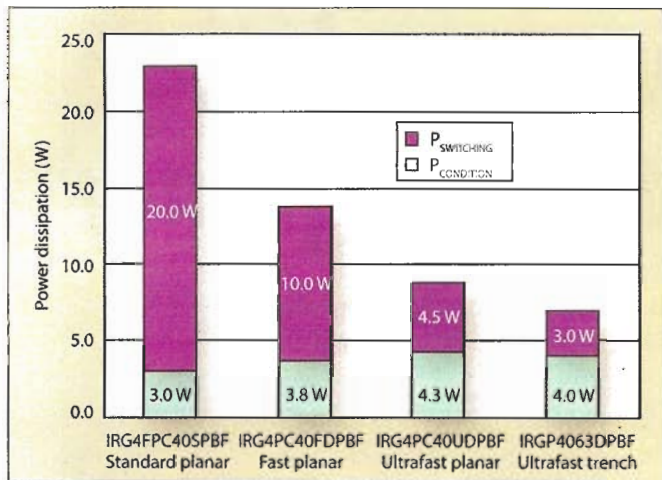


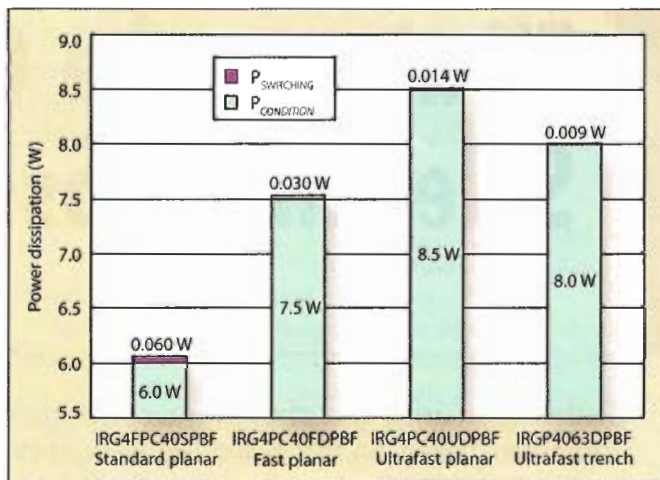
Fig. 3. Gate-drive signals for IGBTs Q1 to Q4 in Fig. 2 and the output ac sinusoidal voltage at the filter formed by L1, L2 and C1.



**Fig. 4.** Ultrafast IGBTs switching at 20 kHz provide the lowest power-dissipation levels compared to fast and standard-speed devices. And of the two ultrafast types shown on the right, a trench-gate IGBT dissipates the least amount of power.

IGBT, is the device of choice for the high-side IGBTs.

The same question arises for the low-side IGBTs. Which IGBT is the best device that will give the lowest power dissipation? Since these IGBTs switch at only 50 Hz or 60 Hz, a standard-speed IGBT will provide the lowest power-dissipation level (Fig. 5).



**Fig. 5.** Switching at 60 Hz, the lowest level of power dissipation from a low-side IGBT is achieved using standard-speed IGBTs.

Although a standard-speed IGBT shows some switching loss, the loss value is so insignificant that the total power dissipation of this IGBT is not affected by its switching loss component. In fact, the latest trench-gate IGBT still features higher power dissipation, because this generation is targeted at high-frequency applications with balanced switching and conduction losses. Thus, for low-side IGBTs, a standard-speed planar IGBT is still the device of choice.