Achieving Fast IGBT Reverse Recovery Loss

WHITE PAPER

Bourns® BID Series IGBTs

INTRODUCTION

During the operation of switching power converters, the voltage and current are continually switching 'OFF' and 'ON' in the Insulated Gate Bipolar Transistor (IGBT) and its associated Fast Recovery Diode (FRD) in many power conversion sections in the:

- DC battery voltage boost section to charge the DC bulk capacitor in an Uninterruptible Power Supply (UPS)
- DC high voltage to AC line frequency output for a UPS (same or different frequency from input)
- AC line frequency input to the rectifier for Power Factor Correction (PFC) DC power input
- DC high voltage to high current output for welding applications
- DC high voltage to the required application DC voltage (DC voltage changer)
- DC high voltage to high frequency output for induction heating applications

In essentially every switching cycle when the IGBT switches 'ON', the FRD changes from backward voltage bias (reverse bias) to zero volts. When this action happens, the stored charge in the PN junction has to be removed. This charge is the source of the current that flows during the switching process, termed "reverse recovery current." The lower the amount of charge to be removed reduces the loss due to this mechanism in every cycle of the switching process.

This white paper will present the benefits achieved with Bourns' new IGBT devices that were designed with the lowest loss diodes available at the time of design to be able to provide one of the fastest IGBT reverse recovery capabilities on the market. It will also illustrate how Bourns® IGBT design helps reduce the loss in virtually every switching application, since the time for reverse recovery is minimized for every switching cycle.

IGBT power switching transistors are used to implement varied types of power switching applications. The IGBTs from Bourns incorporate an FRD connected directly to the emitter and collector within the IGBT package. The benefits of Bourns® IGBT construction is well-documented in the Company's IGBT product data sheets.

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FAST RECOVERY BY DESIGN

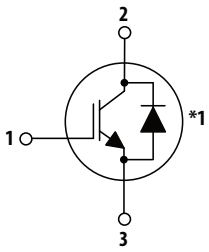

Figure 1. | *IGBT schematic.*

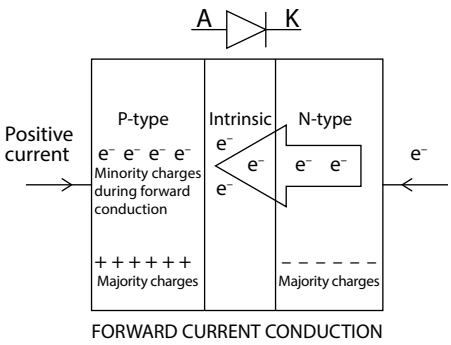

Figure 2. | *Forward current in the FRD PN junction.*

The close attachment of the FRD to the emitter and collector leads, shown in Figure 1, provides optimal protection for the switching element and the IGBT, and significantly contributes to the device's greatly reduced loss capabilities. Power losses in a power-switching device consist primarily of conduction losses (when the IGBT is 'ON' and conducting current), turn-ON switching losses, and turn-OFF switching losses. However, the FRD adds a loss component of its own; the reverse recovery loss. Including the FRD within the IGBT package helps minimize the loss added by this mechanism.

The reverse recovery current occurs as the FRD switches from forward conduction (IGBT collector voltage is negative in relation to the emitter) to blocking reverse voltage (the collector goes positive). To the IGBT, the FRD forward current is a reverse current, which flows when the collector is at a negative voltage relative to the emitter and is displayed in Figure 2. This usually occurs when switching OFF an inductive load connected to the collector. The minority carriers (electrons) in the P-type silicon side of the FRD's PN junction must be cleared before the forward current will stop flowing.

The FRD reverse recovery loss is minimized by using an ultra-fast diode with low forward conduction voltage. The reverse recovery time, t_{rr}, is reduced by the design of the diode and the circuit design where it is used. The Bourns® IGBT data sheet specifies the measurement conditions and typical values for t_{rr}, the time for reverse recovery to take place, and the reverse recovery charge Q_{rr}, which is the total charge that is removed from the FRD to stop conduction.

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OPTIMIZING IGBT SWITCHING TIMES

The amount of turn-OFF energy loss mainly depends on the reverse recovery behavior of the recovery diode. Several technologies have been developed that attempt to optimize the IGBT switching times and forward voltage drop while providing rugged short circuit capability. An offline, power conversion application is used to demonstrate waveforms typically encountered with IGBTs. The reverse recovery is illustrated in Figure 3.

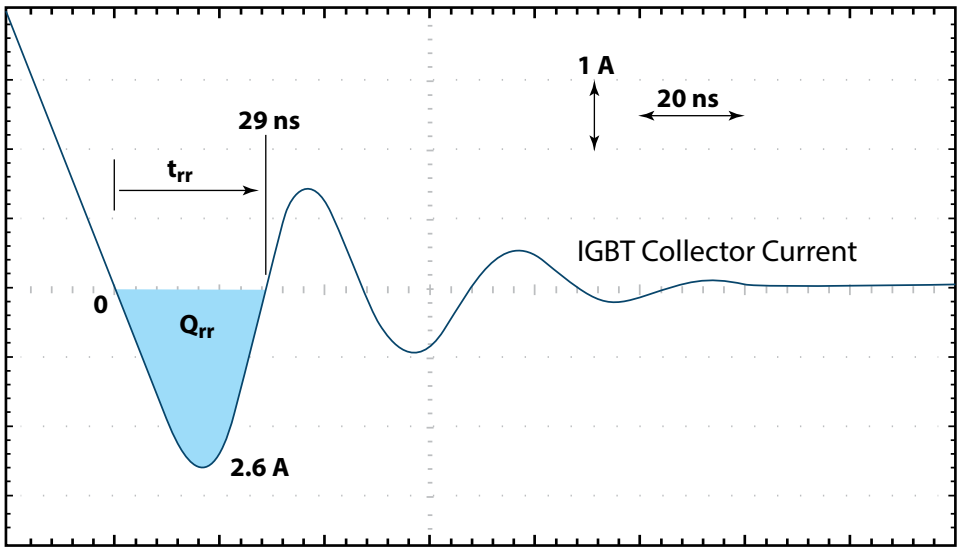

Figure 3. | *Reverse recovery current measurement.*

The reverse recovery current multiplied by the forward voltage of the FRD shows the power loss in every cycle when the IGBT switches the load OFF.

When switching from the conducting to the blocking state, the FRD has stored charge that needs to be removed before the diode blocks reverse current. This discharge takes a finite amount of "Reverse Recovery Time (t_{rr})". During this time, the diode current flows in the reverse direction. The amount of charge that is removed is the "Reverse Recovery Charge (Q_{rr})".

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OPTIMIZING IGBT SWITCHING TIMES (Continued)

Below are the diode switching features from the data sheet for the Bourns® IGBT Model BIDNW30N60H3:

Diode Switching Characteristics (T_C = 25 °C, unless otherwise specified)

Parameter (T_C = 25 °C)	Symbol	Conditions	Value			Unit
			Min.	Typ.	Max.	
Reverse Recovery Time	t_{rr}	dI_F/dt = 200 A/μs I_F = 5.0 A	—	40	—	ns
Reverse Recovery Charge	Q_{rr}		—	80	—	nC

Figure 4. FRD switching specifications for Bourns® IGBT Model BIDNW30N60H3.

The charge is calculated by Q = I * T (coulombs = current multiplied by time in seconds). Since time is the base of the triangle, the peak current is the height of the triangle, the area is ½ times the base times the peak current: Q = 2.6 * 0.5 * 29 ns = 38 nC This is lower than the more typical 55 nC. The exact recovery time and charge depends on the FRD temperature and the circuit configuration where the FRD is placed.

Model Number	Package	Application	V_{CES} Max. (V)	I_c @ T_C=100 °C Max. (A)
BIDW20N60T	TO-247	Frequency conversion, Servo, Stepper motor, etc.	600	20
BIDNW30N60H3	TO-247N	Air conditioning PFC	600	30
BIDW30N60T	TO-247	Frequency conversion, Servo, UPS	600	30
BIDW50N65T	TO-247	Frequency conversion, Servo, UPS	650	50
BIDD05N60T	TO-252	Refrigerator, Range hood, Motor application field	600	5

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CONCLUSION

This white paper presented the reduced loss and rapid reverse recovery advantages that are derived from Bourns incorporating fast recovery diodes into its recently-announced IGBT product series. The FRD is designed with a switching power supply to rectify high frequencies of tens of kilohertz (kHz) or hundreds of kHz, while improving efficiency. This makes Bourns® IGBTs ideal for use in nearly every type of switching application.

IGBT power switching transistors, due to their switching speed and compact size coupled with the ability to handle high currents and voltages, are used in many types of power switching applications. IGBT transistors are ideal for power switching applications due to their high current, voltage, and power handling capability. Bourns® IGBT devices integrate FRDs that are connected directly to the emitter and collector within the IGBT package, which helps to minimize the switching losses. Please see Bourns' IGBT data sheets for full performance details.

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