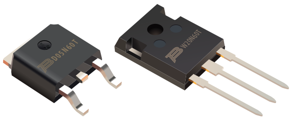
APPLICATION NOTE

Considerations When Specifying Insulated Gate Bipolar Transistors (IGBTs) for Electric Motor Controls



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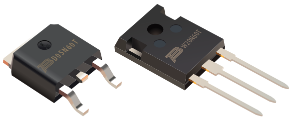
INTRODUCTION

With the increased focus on operational efficiency of electric motors for all applications, the need for high efficiency drives is becoming more important. Also, designs using motor drives, such as for electric motors, pumps, and fans, have the need to reduce the overall costs as well as decrease energy consumption in these same electric motor applications. Therefore, specifying highly efficient designs for the electric motors and their drives that are suited to each particular application becomes even more critical.

Widely-known and used as proven switching device solutions, Insulated Gate Bipolar Transistors (IGBTs) are an excellent choice for today's electric motor drive applications requiring higher voltage or higher current and lower frequencies. Since most motors operate at lower frequencies, require a robust Safe Operating Area (SOA) and short circuit rating, and have the need to maximize efficiency, IGBTs with co-packaged diodes are well-suited for these applications. These factors – including an IGBT's current-handling and peak-voltage ratings – determine whether a specific IGBT can support the motor's load requirements.

The various advantages of employing IGBTs for motor controls will be covered in this application note. It discusses the role IGBTs play in an industrial motor drive design, how switching and conduction performance affect the IGBT selection and the importance of understanding short circuit withstand times. This application note will highlight why designing with advanced discrete IGBTs from Bourns can help increase operational life and boost efficiency for the drives and electric motors in an industrial system application.



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MAXIMIZING EFFICIENCY IN INDUSTRIAL MOTOR DRIVES

A typical motor drive consists of several sections. Figure 1 shows a typical motor drive application that uses power from the AC mains and applies it to the electric motor according to user inputs. A Power Factor Correction (PFC) rectifier is made using IGBTs, like in the Uninterruptable Power Supply (UPS) designs. The motor brake circuit consists of IGBTs that dissipate power from the motor or route the excess energy back to the AC input as it stops to accomplish regenerative braking. The motor drive inverter changes the DC voltage energy stored in capacitors to the AC waveforms at the specified voltage and frequency to control the motor at the desired speed and torque.

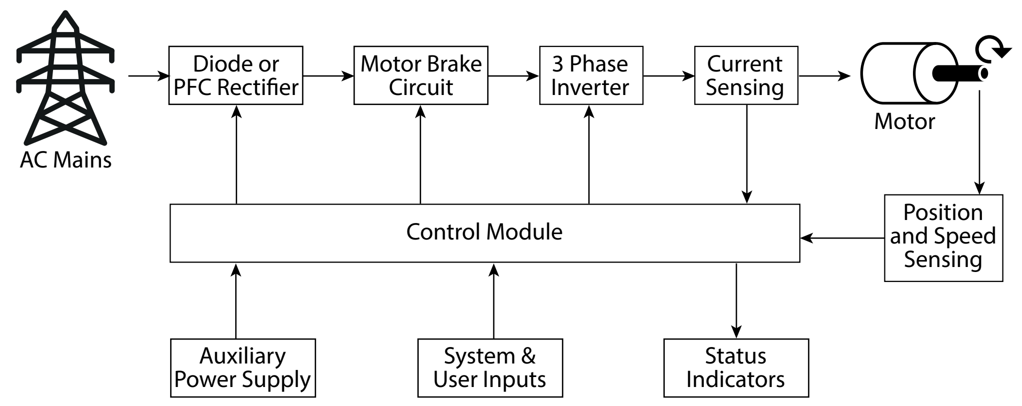
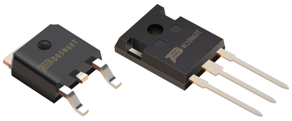


Figure 1. *Typical motor drive block diagram using a Power Factor Correction (PFC) input rectifier*

In order to sustain an IGBT below its SOA rating in the different motor drive design sections, heat must be removed from the transistor package. Bourns® Model BID Series IGBTs feature enhanced thermal dissipation TO-247 power packages. These packages provide effective heat dissipation for the power loss due to switching transients and forward conduction in the IGBT and FRD. In a motor control application, designers need to consider the system-wide impact of power dissipation, where ambient temperatures are high, and airflow is reduced or not available. Because Bourns® IGBTs have been designed for high efficiency, they produce less heat that needs to be dissipated. This also helps in reducing the size and cost, as well as simplifying the thermal management design.



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SWITCHING AND CONDUCTION PERFORMANCE

The switching and conduction performance of IGBTs is a function of device structure. The asymmetric structure of Bourns® IGBTs helps to optimize ON-state losses and switching speed in motor control applications. The key attribute of this structure is the field-stop layer created by an n+ type buffer region that is added beneath the n- drift region and above the lower p-doped layer. This buffer region serves to support the electric field and allows for a thinner n- drift region, which significantly helps to decrease conduction losses.

The overall compromise between switching losses (E_{off}) and conduction losses ($V_{CE(sat)}$) is shown in Figure 2. This illustrates how understanding system requirements is key to specifying the right device to meet specific motor system controller requirements. Bourns' new generation of IGBTs uses advanced Trench-Gate Field-Stop (TGFS) technology that enables increased cell density for enhanced $V_{CE(sat)}/E_{off}$ curve performance.

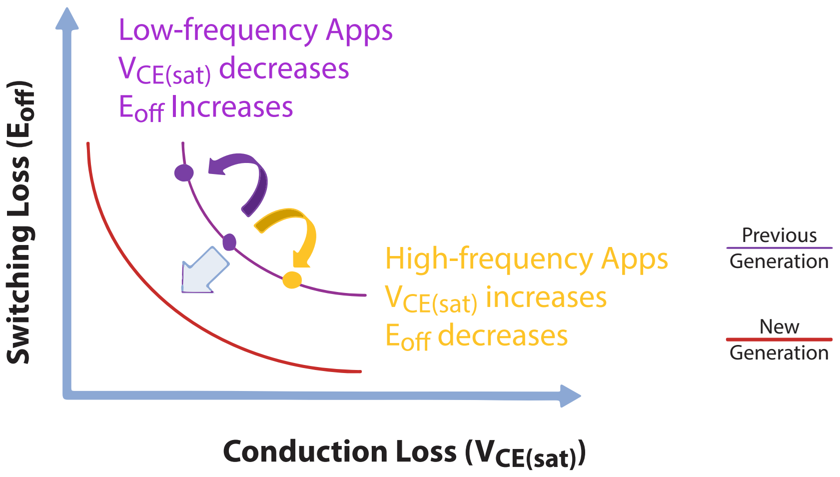
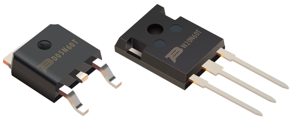


Figure 2. | *Trade-off of switching loss (E_{off}) and conduction loss ($V_{CE(sat)}$)*



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SHORT CIRCUIT IN THE INDUSTRIAL ENVIRONMENT

In a motor control application, an IGBT switch can experience a short circuit path from the DC voltage bus to ground (as shoot-through current) or across one motor phase to another phase or to earth. An IGBT must be able to withstand these failures for the time interval that is required by the end application to detect them. Motors are generally capable of absorbing very high current levels for relatively long periods (milliseconds to seconds); however, IGBTs frequently specified for motor drive inverters typically have short circuit withstand times on the order of microseconds. Certain Bourns® IGBT models feature a short circuit withstand capability of 10 μs. Motor control applications require high robustness and reliability, as they operate in harsh conditions with high stresses on the IGBTs, which are known to lead to transient short circuit conditions.

IGBTs with increased short circuit current levels and the necessary reduced short circuit withstand time in the 5 μs range (e.g., Bourns® Model BIDNW30N60H3) are the trade-off for lower conduction loss and also contributing to reduced overall BOM costs. The good news is that some of the differences in short circuit withstand time are offset by certain advancements in IGBT design and packaging technology. Higher transconductance and lower thermal resistance lead to lower conduction loss and higher application efficiency, bringing benefits to the motor control application design even if the chosen IGBT has reduced short circuit withstand time.

IGBT TRADE-OFFS

Choosing a device that offers high switching frequencies due to lower switching losses will result in higher conduction losses. Higher conduction losses cause higher power dissipation that require a larger and often bulky heatsink, which adds system cost and undesired space to the design. Conversely, a device with lower conduction losses operates efficiently at lower frequencies, but its short circuit withstand capability decreases. This trade-off is illustrated in Figure 3.

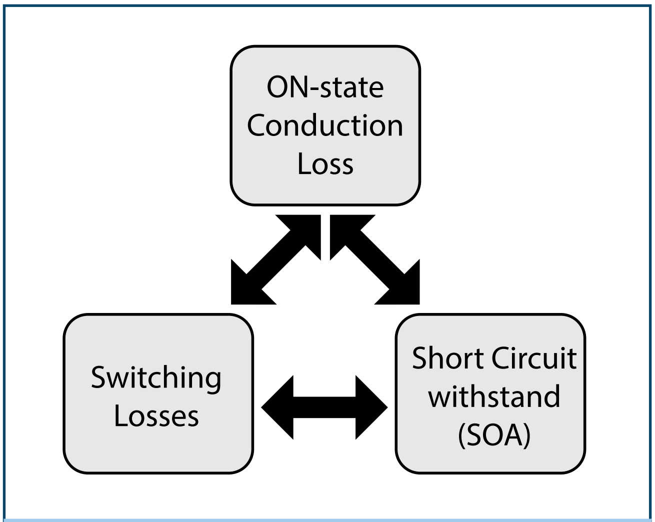
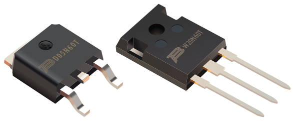


Figure 3. *Motor control design trade-offs of conduction loss, switching loss, and short circuit withstand capability with reference to the associated Safe Operating Area*



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SAFE OPERATING AREA (SOA) CONSIDERATIONS

IGBTs that operate near their current and voltage maximums require careful consideration in how to safely keep those parameters within data sheet specifications. The main concern is to keep the collector current below the maximum, and at the same time, hold the voltage from collector to emitter below the data sheet value. When operating in the forward biased condition in the Forward Bias Safe Operating Area (FBSOA), there is an additional consideration that needs to be taken for the maximum pulsed collector current based on the pulse width and the impedance of the thermal design. The FBSOA defines the maximum saturated collector current for the maximum collector-emitter voltage, which is usually used for inductive loads. In the reverse-biased condition in the Reverse Bias Safe Operating Area (RBSOA), the maximum current is a function of the peak voltage between collector and emitter during turn-off. Adhering to maximum limits is necessary to protect the fast recovery diode at the maximum junction temperature.

CONCLUSION

Utilizing IGBTs for inverters in electric motor control applications helps designers meet lower system cost goals as these devices have a smaller die size that enables a higher current density design. In particular, Bourns® discrete IGBTs support higher temperature operation and provide the enhanced ability to remove heat from the IGBT packages. Along with their thermally efficient design, Bourns® IGBTs combine the benefits of lower operational loss along with greater overload and higher short circuit current withstand capabilities to offer a superior switching solution.

Furthermore, optimization is required to balance the IGBT between conduction losses and switching losses and to tune for a specific application requirement based on the type of motor used in the end product. For motor control applications, a 600 V/650 V rated Trench-Gate Field-Stop (TGFS) IGBT+FRD co-packaged in a TO-247 footprint is considered the ideal device solution. These IGBT device features provide heightened thermal performance, low $V_{CE(sat)}$, and high efficiency due to lower total power dissipation, while delivering high reliability as compared to previous generation planar IGBTs.

ADDITIONAL RESOURCES

- Product Page: Bourns® Discrete IGBTs
- Technical Library: Bourns® Discrete IGBTs
- White Paper: Understanding IGBT Data Sheet Parameters
- White Paper: Achieving Fast IGBT Reverse Recovery Loss
- White Paper: Measuring IGBT Conduction Loss to Maximize Efficiency
- White Paper: Bourns® IGBT vs. MOSFET - Determining the Most Efficient Power Switching Solution

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