Third Generation Press-Pack IGBTs and Diodes for Megawatt Applications

Press-pack IGBT technology has come of age with the introduction of the latest generation of soft punch through die. Background to the evolution of the new generation and its enhanced characteristics are introduced for the largest member of the product family. With high reliability and low losses, the new device is ideal for today's demanding environment of high efficiency and renewable energy sources. **A. Golland and F. Wakeman, Westcode Semiconductors Ltd, Chippenham, UK**

First introduced twelve years ago, as a high reliability solution for hostile environments, the press-pack IGBT has evolved towards the product of choice in many high power applications. The first European made devices were targeted at induction heating power supplies, a 1.8kV medium frequency device, offered as a solution to overcome the punishing thermal stress of such applications. These new introductions were both expensive to produce and very application specific. However, the robust nature of the design attracted wider appeal and new products were introduced with higher voltage and less application specific characteristics.

A first generation high voltage device, with current rating up to 900A, saw favour in traction applications [1]. Limitations of die technology meant these early high voltage devices, required snubbers and were more suited to GTO thyristor circuit topologies. A second generation of 4.5kV die followed, based on soft punch through technology, which offered more classical IGBT characteristics giving a wide appeal for a broader range of applications including drives, traction and utility applications. Now a third generation die set is launched with improved forward voltage and SOA performance. This new die set, in conjunction with larger package options, is an ideal solution for the needs of the latest generation of medium voltage drives.

Press-pack encapsulation of small die

The concept behind the press-pack housing is to keep it simple; all pressure contact, no solder or bonded joints [2]. However, to achieve this takes a great deal of control of materials and the manufacturing process. The key element of the press-pack IGBT evolution was the introduction of the single die cell with the first generation of high voltage devices [3]. Each individual IGBT die is mounted in its own cell, which can be pre-tested before assembly into the package, under clean room conditions. Among the latest generation of products the largest device boasts a 125mm contact electrode and 42 individual dies in hard parallel configuration (Figure 1). The multichip bondless technology offers unrivalled ruggedness, with thermal cycling

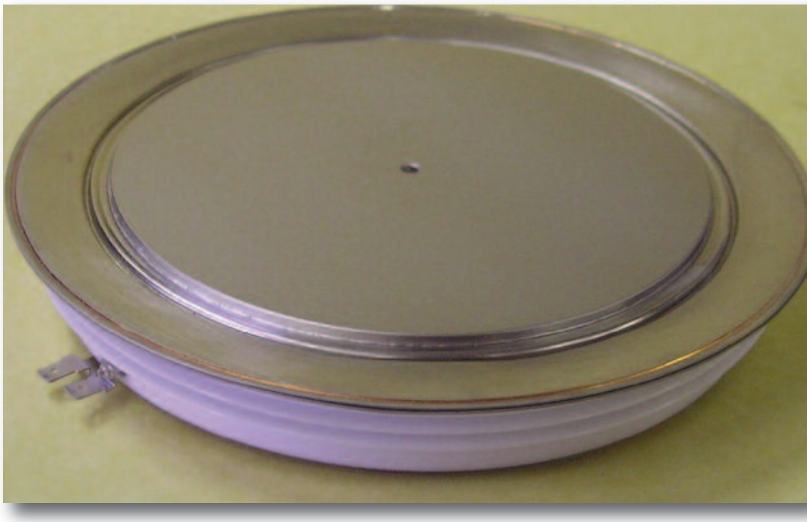

Figure 1: **Latest generation of IGBT press-packs boasting a 125mm contact electrode and 42 individual dies in hard parallel configuration**

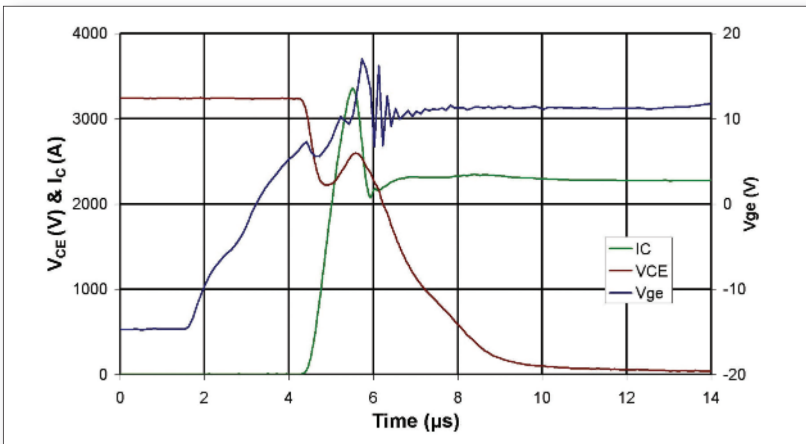

Figure 2: **Turn-on transient of the IGBT under nominal switching conditions**

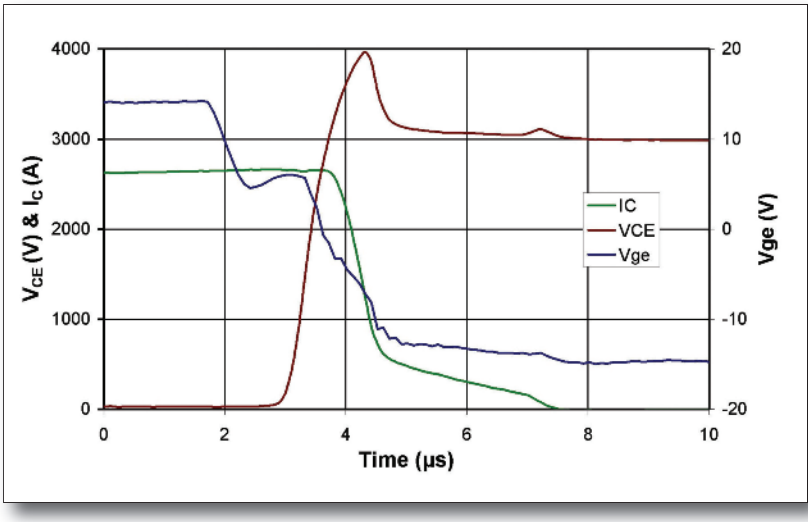

Figure 3: Turn-off transient of the IGBT under nominal switching conditions

capabilities beyond that of larger bondless monolithic devices or alternative multichip packaging concepts [4]. The fully hermetic double side cooled package makes the device suitable for all cooling systems; air, liquid and even full immersion. Also failure to short circuit and a predictable rupture rating give more options in system protection.

Improved die technology

The new chipset technology is the latest evolution of our soft punch through planar cell design, which has been proven in press-pack applications over the last seven years. The new enhanced cell design features the addition of an N-enhancement layer, along with further optimisation and tight control of the emitter structure. This gives a significantly improved carrier concentration under the emitter. The more favourable carrier distribution leads to 25% reduction in $V_{ce(sat)}$ (typically 3.6V at nominal current and $T_{j\,max}$) without any appreciable increase in the turn-off losses, when compared to the previous generation.

Careful optimisation of the deep low concentration buffer and anode gives a positive temperature coefficient throughout the entire current range, which is important for very large area devices and also ensures excellent short circuit performance, well in excess of typical requirements. We are now able to offer technology with on-state losses broadly comparable to that available with typical trench designs, while retaining the superiour Reverse Bias Safe Operating Area (RBSOA), Short Circuit Safe Operating Area (SCSOA), soft switching behaviour and easy driving characteristics associated with our planar technology. Similarly, a new diode chip complements the new IGBTs in our reverse conducting parts, along with our third generation HP Sonic-FRD monolithic diodes to support the asymmetric parts and clamping applications.

2400A / 4500V asymmetric device performance

To fully evaluate and qualify the T2400GB45E IGBT, an extensive range of measurements has been carried out. The device has a nominal current rating of 2400A, which equates to a current density of 57A/cm^2, and nominal DC-link voltage of 2.8kV, with RBSOA testing carried out up to 4800A and 3200V. All switching waveforms are shown with an E2400TC45C freewheeling diode and unclamped (stray) inductance of approximately 180nH. Junction temperatures are 125°C for the IGBT and 150°C for the diode unless stated otherwise.

Figure 2 shows the turn-on transient of the IGBT under nominal switching conditions with a gate resistor of 1.6Ω and additional gate-emitter capacitance of 267nF. The very low input capacitance of the enhanced planar cell provides a fast voltage fall time. In this case we are able to further optimise the switching conditions for both the IGBT and diode by combination of gate resistance and additional external capacitance. Under these conditions typical turn-on losses are 7.2J.

Figure 3 shows the turn-off transient of the IGBT under nominal switching conditions with a gate resistor of 1.5Ω and additional gate-emitter capacitance of 267nF. The highly rugged cell allows high switching speed, while the carefully optimised buffer ensures a soft turn-off transient with no voltage disturbances or oscillations, even at high DC-link and stray inductance levels. Under these conditions typical turn-off losses are 7.85J.

Figures 4 and 5 show the turn-on and turn-off transients respectively under RBSOA conditions. The device can clearly be seen in figure 7 to be sustaining a large amount of energy in the dynamic avalanche mode, evident by the self-limiting of dv/dt and clamping of the peak induced turn-off voltage for a period of approximately 1.8µs; no external voltage clamps or snubbers are applied. RBSOA

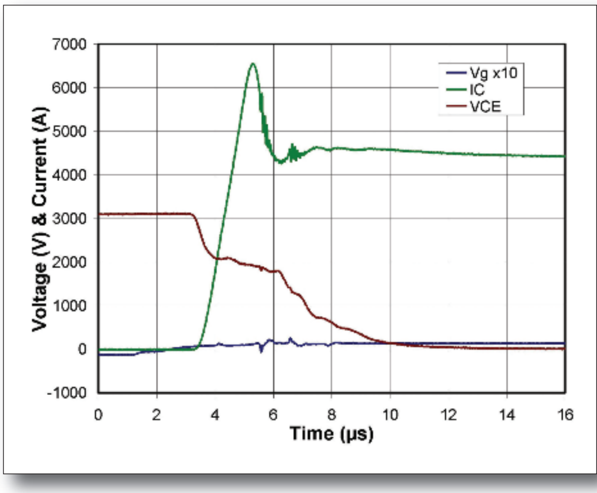

Figure 4: Turn-on transient of the IGBT under RBSOA conditions

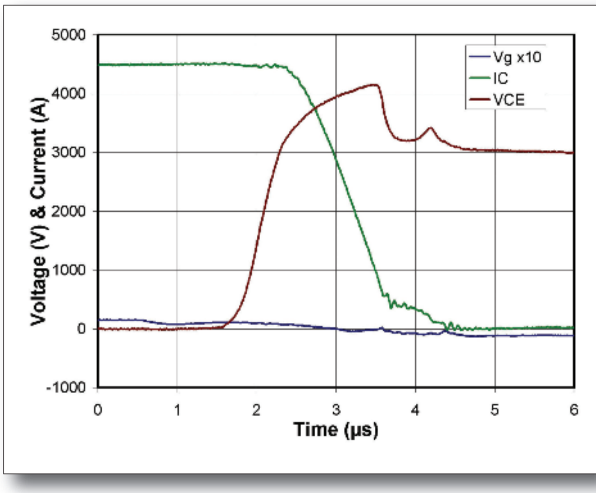

Figure 5: Turn-off transient of the IGBT under RBSOA conditions

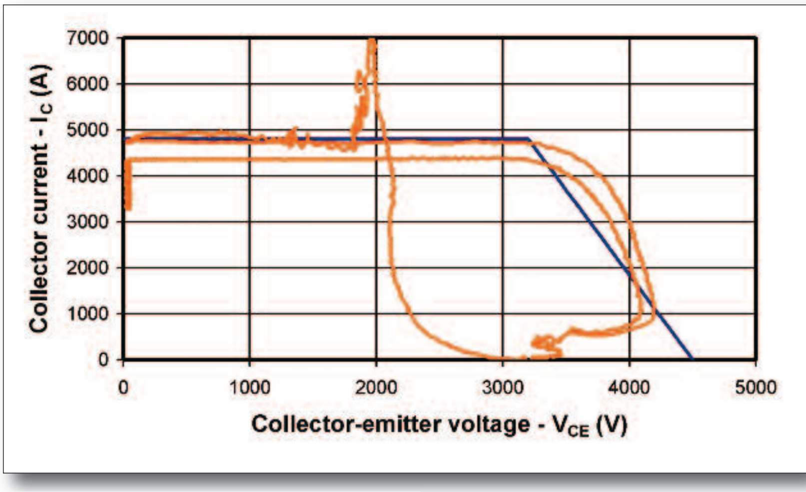

Figure 6: Switching loci of a double pulse RBSOA test overlaid on the device data sheet limit characteristic

does not increase linearly with device voltage and for high voltage devices this parameter becomes technically challenging.

Furthermore as the device current increases, the insertion and therefore total commutation loop inductance tends to increase due to larger package size and larger busbar requirements; this in turn dramatically increases the energy stored in the unclamped inductance that each individual die must sustain (in an ideal situation the inductance would reduce linearly as the number of die increases to maintain the same effective inductance per die or per ampere). The advanced low loss technology combined with the superiour thermal performance of the press-pack construction change the fundamental limits for typical inverter designs. No longer are designs limited by average current, rather commutation or peak currents (RSOA) become the limiting factor.

Figure 6 shows switching loci of a double pulse RBSOA test overlaid on the device data sheet limit characteristic. Figure 7 shows an additional RBSOA test conducted as a burst of 10 pulses at a frequency of 10kHz from an initial voltage of 3.6kV with current increasing to 4kA, further demonstrating the outstanding robust nature of these devices.

Figure 8 shows a typical type I short

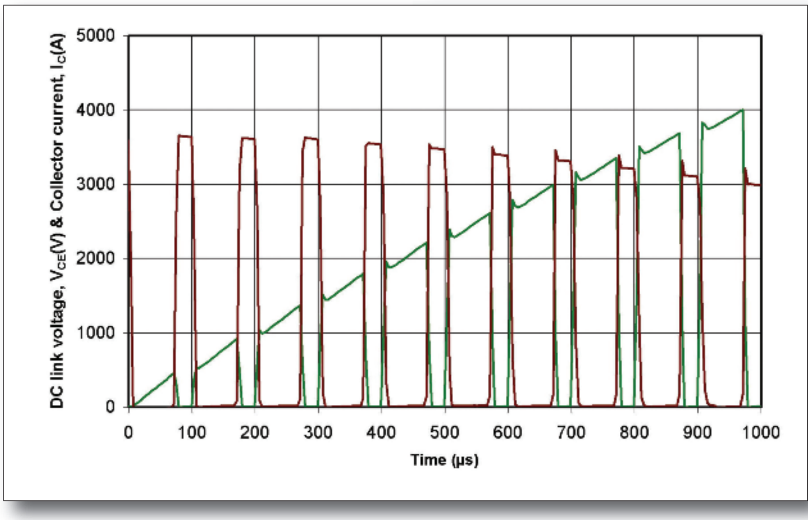

Figure 7: Additional RBSOA test conducted as a burst of 10 pulses at a frequency of 10kHz from an initial voltage of 3.6kV

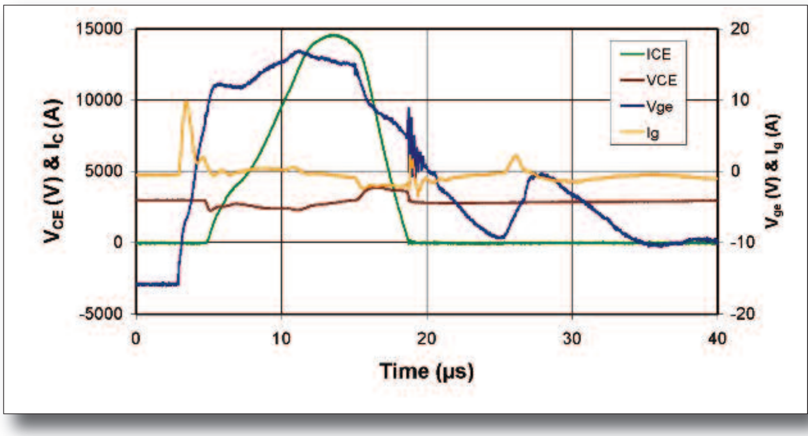

Figure 8: Typical type I short circuit test waveform at DC-link voltage of 3kV and nominal pulse width of 13µs

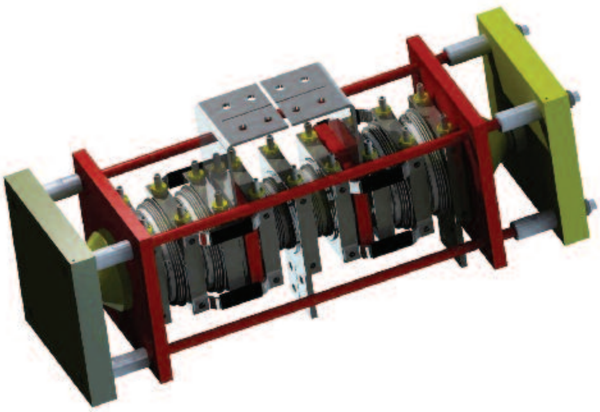

Figure 9: Typical phase leg arrangement for a 1600A, 3.3kV neutral point clamped inverter phase leg

circuit test waveform at DC-link voltage of 3kV and nominal pulse width of 13μs using a soft turn-off gate resistor of 10Ω. The device is able to withstand both type I and II short circuit events with gate voltages up to 18V across the full operating temperature range.

Multi-megawatt applications

The high current rating and high DC-link rating make this device a natural fit for medium applications in the multi-megawatt power range. In particular the press-pack construction lends its self well for multilevel water-cooled converters where extremely high power density is achievable. Figure 9 shows a typical phase leg arrangement for a 1600A, 3.3kV neutral point clamped inverter phase leg and Figure 10 shows the possible configuration of an 18MW, 6.6kV variable speed drive. These ratings fit well to a wide range of applications including high performance motor drives, high-speed locomotive traction, railway interties, utility scale VAr and power quality compensators and renewable grid converters, to name a few.

Of specific emerging interest is the current trend toward medium voltage machines for the next generation of wind turbines. Particularly in offshore applications, where ratings of 6-8MW are in development employing full-scale power conversion at 3.3kV, for both machine and grid side connection. The very high power density converter solutions possible with the press-pack IGBT, combined with high reliability and fully hermetic construction make this an extremely attractive solution to the unique challenges of these next generation turbines.

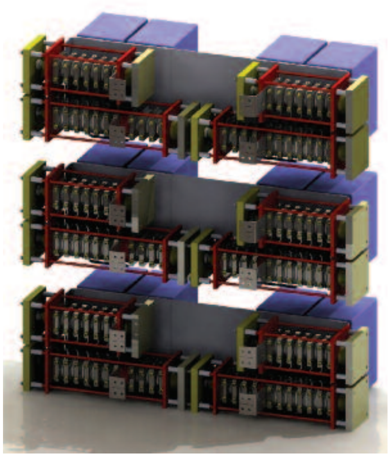

Figure 10: Possible configuration of an 18MW, 6.6kV variable speed drive

Literature

[1] F. Wakeman & A. Golland, "Press-pack IGBTs for traction applications", Power Electronics Europe, issue 1, 2004.

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[3]. F. Wakeman, G. Li & A. Golland, "New family of 4.5kV Press-pack IGBTs" PCIM Europe 2005.

[4] F. Wakeman, D. Hemmings, W. Findlay & G. Lockwood, "Pressure contact IGBT, testing for reliability", PCIM Europe 2000.