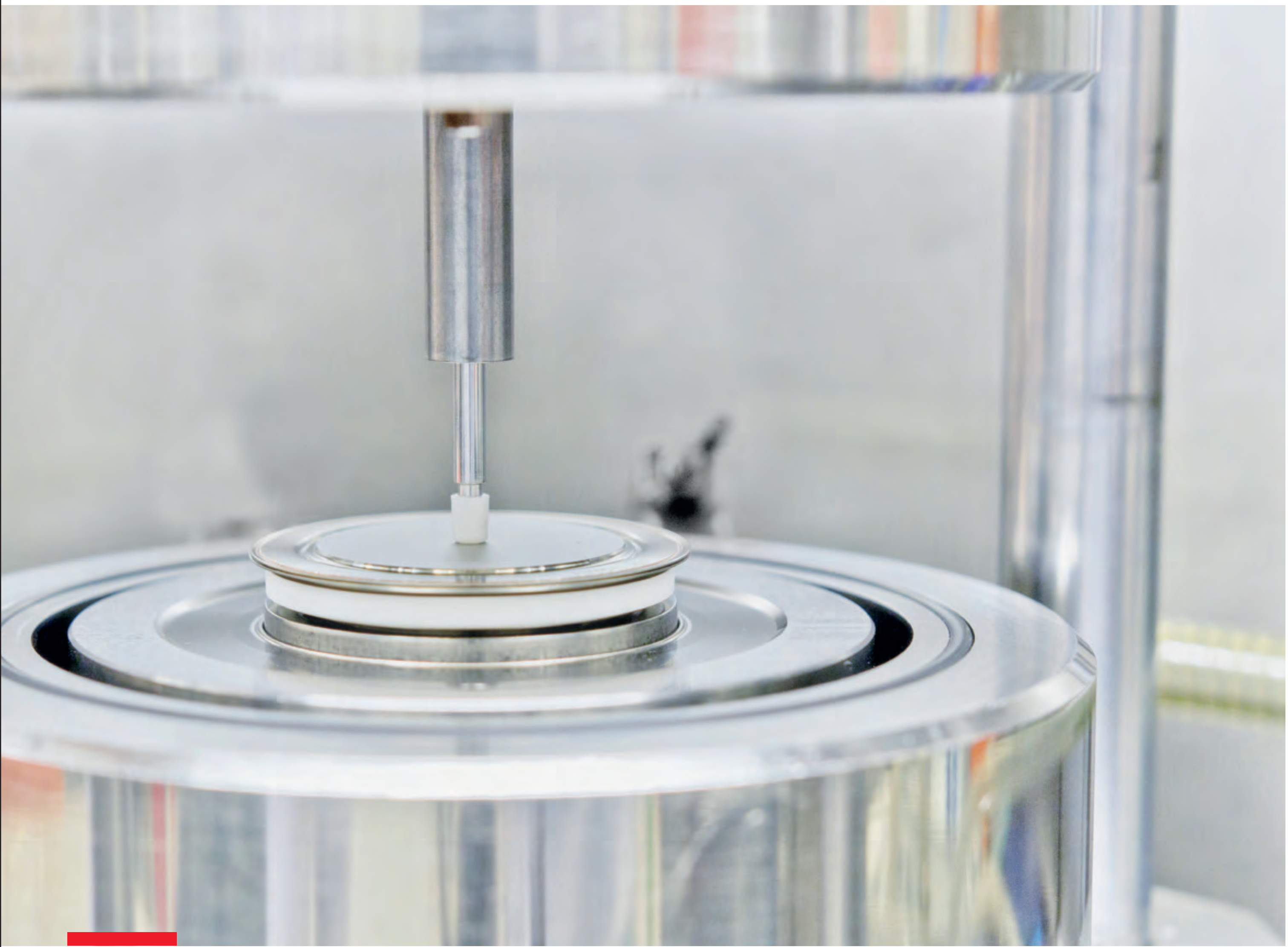

Power semiconductors

Proven reliability and high quality
for best performances

ABB is a leading supplier of power semiconductors with production facilities in Lenzburg, Switzerland, and Prague, Czech Republic, as well as a new research laboratory for wide bandgap semiconductors in Baden-Dättwil, Switzerland.

ABB's success story in power electronics began more than 100 years ago with the production of mercury-arc rectifiers in Switzerland. Over the past 60 years, ABB has played a pivotal role in the development of power semiconductors and their applications.

This brochure provides high level details information on ABB's range of thyristor and IGBT power semiconductors.

For more technical information contact ABB or download the following from www.abb.com/semiconductors:

- Product catalog
- Application notes
- Data sheets
- SEMIS – ABB's semiconductor online simulation tool

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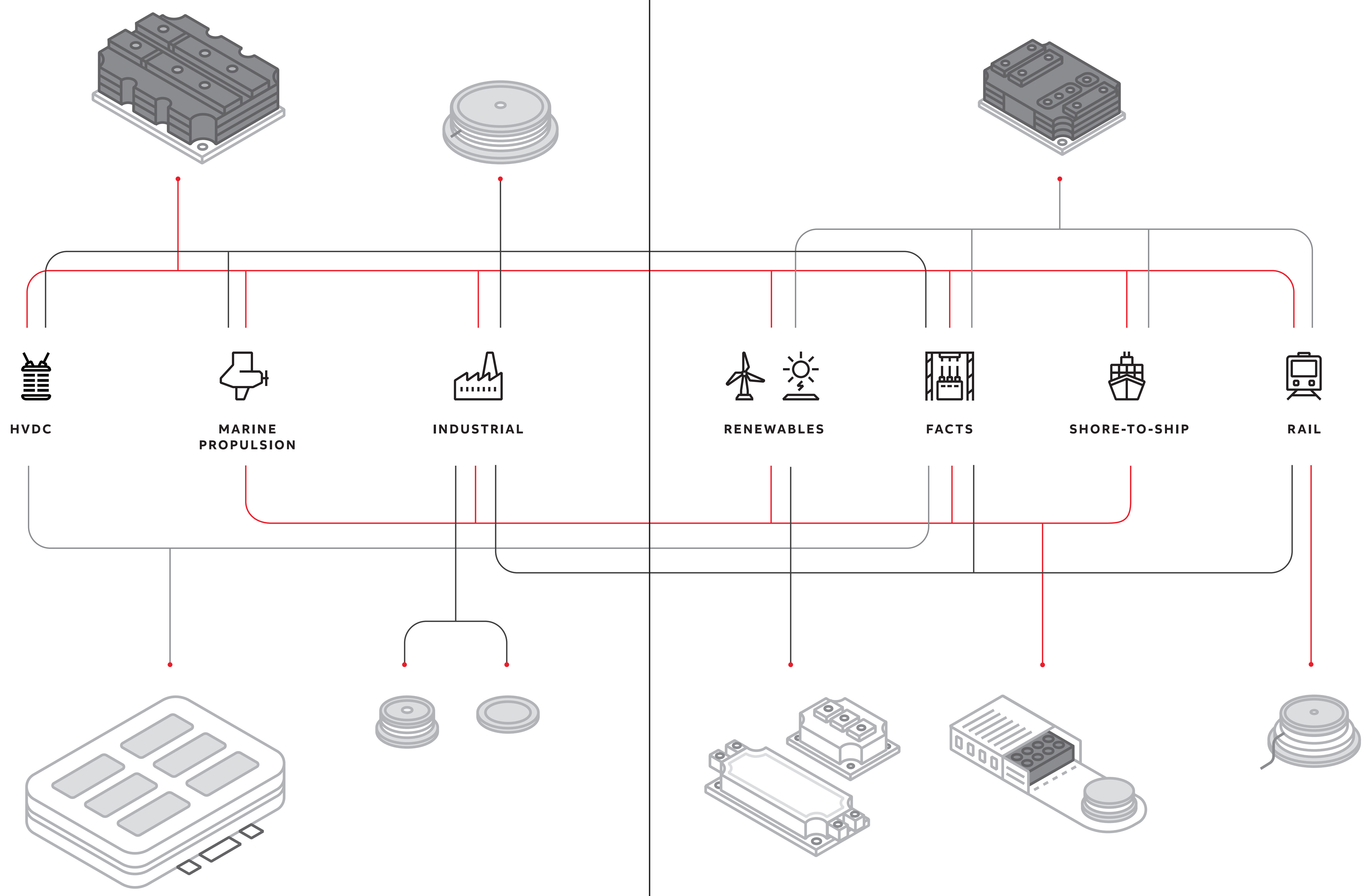
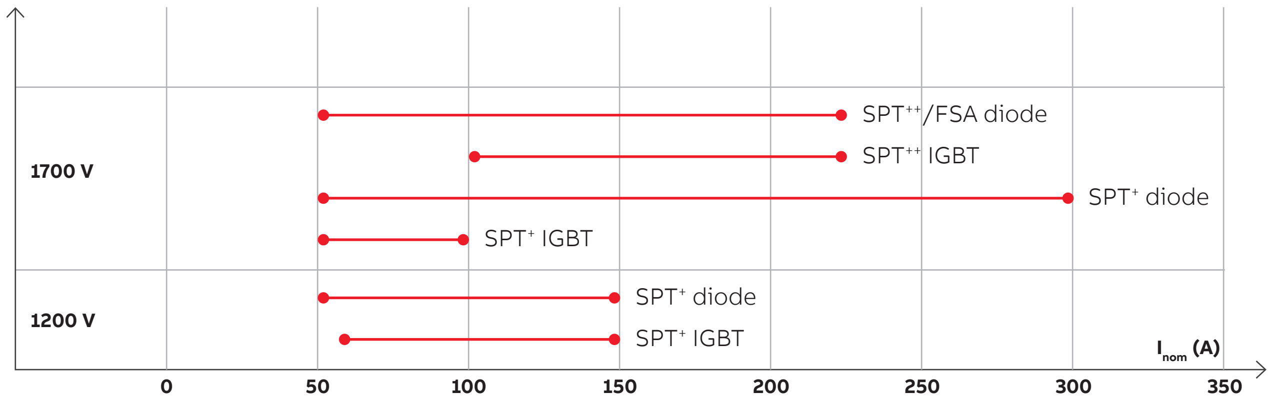

HVDC
MARINE PROPULSION
INDUSTRIAL
RENEWABLES
FACTS
SHORE-TO-SHIP
RAIL

IGBT and diode dies

ABB Semiconductors' range of SPT+ and SPT++ (soft punch through) IGBT and diode chips is available at 1200 and 1700 V, ranging from 50 to 300 A.

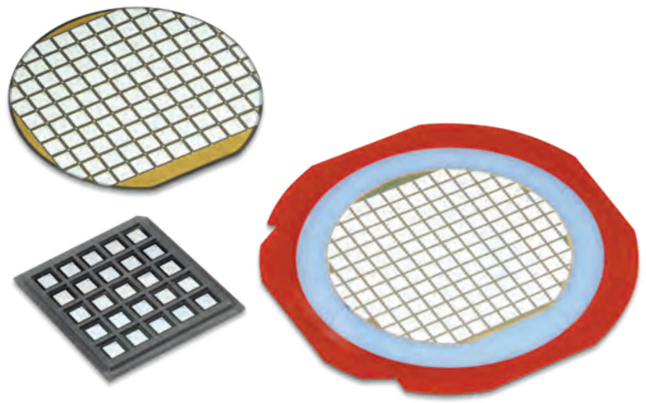
Applications include power converters for industrial drives, solar energy, battery backup systems (UPS), electrical vehicles, wind turbines and traction converters.

Power map



IGBT and diode dies

1. IGBT and diode dies



ABB's IGBT and diode chips with soft punch through (SPT) planar technology, feature the highest switching performance, ruggedness and reliability.

ABB Semiconductors offers the most complete product portfolio of any supplier of high power semiconductors.

Its power semiconductor BiMOS chipsets, comprising IGBTs and free-wheeling diodes, offer the best switching performance, ruggedness and reliability. Through moderate chip shrinkage and thus larger die area, ABB provides the highest output power per rated ampere in the industry.

The new 1700 V SPT++ chipset is the world's first to offer an operational junction temperature of up to 175 °C, enabling a significant increase in the power density of power modules.

The breadth of different current ratings and sizes supports the various requirements in package design and output power. All chipsets are for solder mount-down and wire bonding in modules.

The IGBT

IGBTs using the advanced SPT+ technology benefit from a conduction loss reduction of 20 to 30 percent compared to earlier SPT technology.

Figure 1 shows the basic difference between SPT+ and SPT++. The on-state losses are reduced by introducing an N-enhancement layer surrounding the channel-P-well. This improves the plasma concentration on the emitter side and therefore, lowers the on-state losses. With the introduction of the SPT++, the profile of the said N-enhancement layer was further optimized with the main goal to make another step in conduction loss improvement. Together with thinner silicon, a reduction in $V_{CE\ SAT}$ of half a volt was possible.

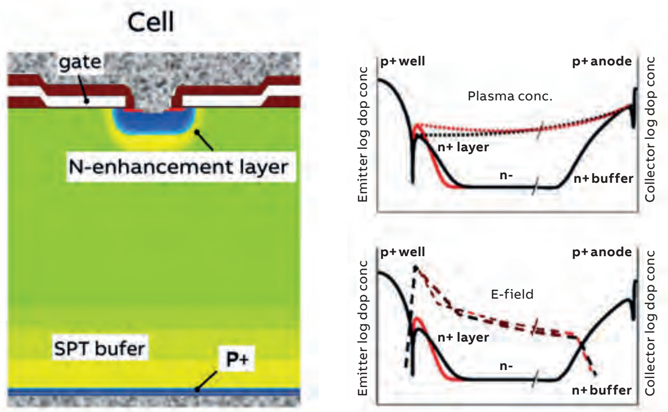


Fig. 1 SPT+ planar IGBT enhanced carrier profile

Figure 2 shows the on-state curves of the newest SPT^{++} IGBT chip with 150 A rating at different temperatures. The SPT^{+} IGBT shows a positive temperature coefficient of $V_{CE\,on}$, already at low currents. This enables a good current sharing capability between the individual chips in the module.

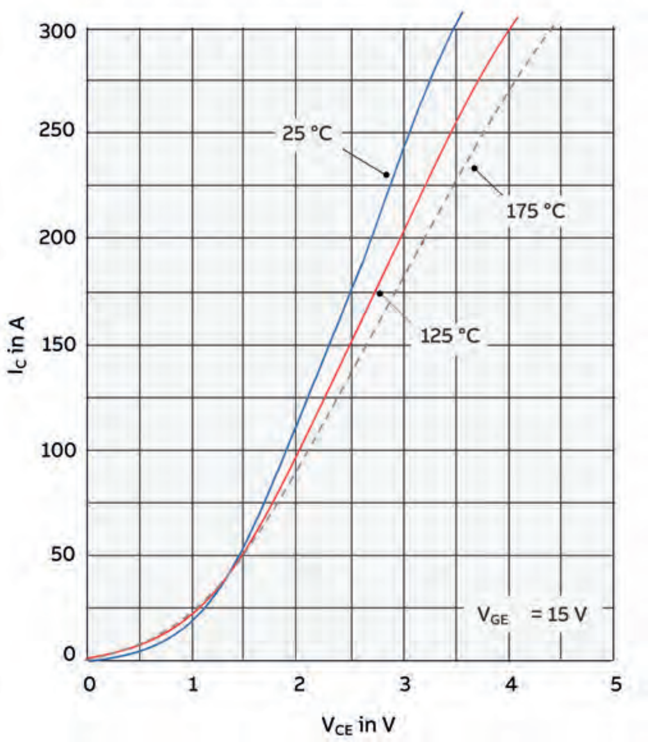


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Fig. 2 On-state curves of the 150 A 1700 V SPT^{++} IGBT

Figure 3 shows the turn-off of a 150 A 1700 V SPT^{++} IGBT under nominal conditions at 175 °C. The IGBT exhibits controlled switching characteristics as well as short current tails. This behavior is enabled by the combination of SPT buffer design and silicon resistivity used in SPT^{++} technology, which provides fast switching with low losses and low overshoot.

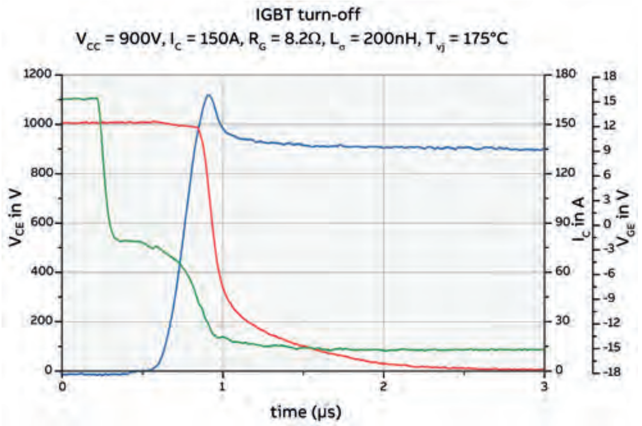

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Fig. 3 IGBT turn-off of a SPT^{++} 150 A 1700 V IGBT

The diode
The diode of the new SPT^{++} chipset is based on an advanced pin-diode design using the FSA (field-shielded anode). A schematic cross-section is shown in figure 4. In contrast to more conventional design, the FSA diode has a double anode with a deep diffused P-well that shields the field from the anode and the irradiation. Thus a significant leakage reduction can be achieved without sacrificing the excellent robustness and low losses of the ABB diodes.

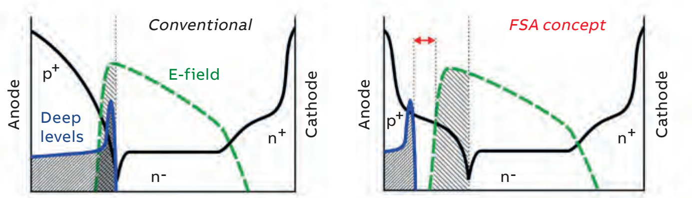

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Fig. 4 Schematic cross-section of the diode

The typical forward characteristics are shown in figure 5. Figure 6 shows the reverse recovery characteristics of a 150 A 1700 V diode under nominal conditions at 150 °C. The current transients during switching are very smooth and soft.

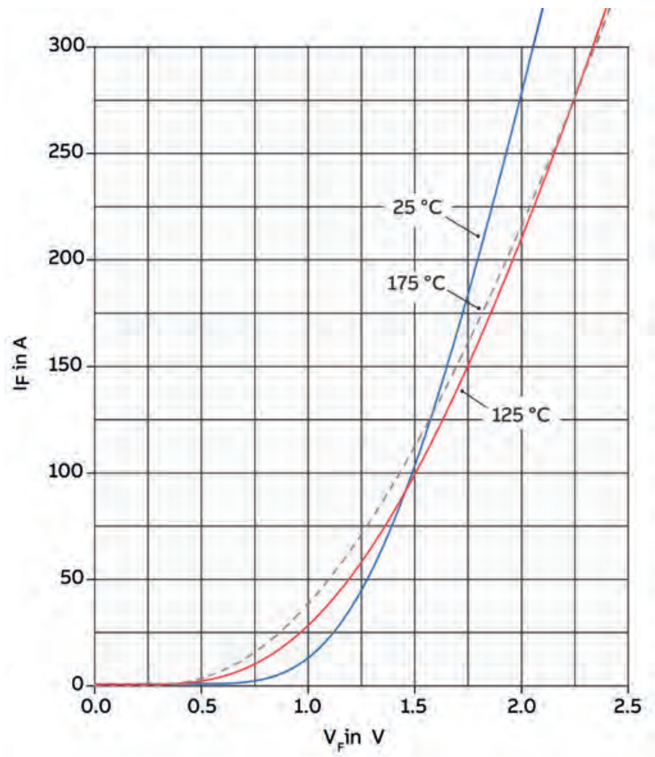

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Fig. 5 V_F curve of a 150 A 1700 V FSA diode

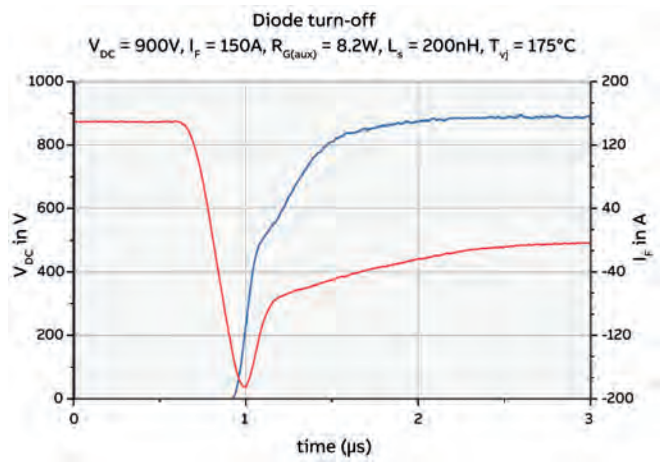

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Fig. 6 Reverse recovery of a 1700 V 150 A diode

Reliability
Chipset reliability is confirmed using a combination of standard tests. These include HTRB (high temperature reverse bias), HTG B (high temperature gate bias), THB (temperature humidity bias), cosmic ray test and a newly developed test, which combines high temperature, high humidity and high voltage.

To extend chipset reliability for extreme environmental applications, the designs feature a state-of-the-art double-layer passivation of silicon nitride and polyimide. The polyimide layer mechanically protects the first passivation layer. As such it acts, on the termination, as a delay-barrier against outside humidity and ion-penetration. It further prevents sparking across the termination during high-voltage operation.

Medium-power IGBT modules

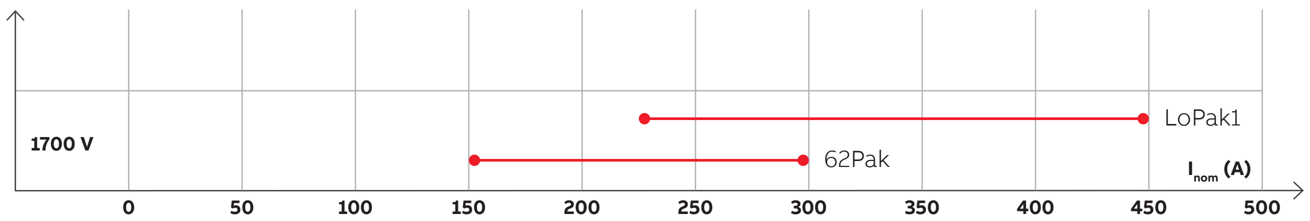
Coming from high-power semiconductors, ABB is regarded as one of the world's leading suppliers setting standards in quality and performance. ABB's unique knowledge in high-power semiconductors now expands to industry standard medium-power IGBT modules.

The medium-power IGBT offering includes:
- 1700 V 62Pak phase leg modules, rated 150, 200 and 300 A
- 1700 V LoPak1 dual/phase leg module, rated at 225, 300 and 450 A

The LoPak1 is 100 percent mechanically compatible with EconoDual type modules.

Key benefits of the ABB medium-power IGBT modules include:
- ultra low-loss and rugged SPT^{++} chipset
- smooth switching SPT^{++} chipset for good EMC
- Cu baseplate for low thermal resistance
- industry standard packages

Power map



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Medium-power IGBT modules

2. 62Pak IGBT modules

The 62Pak modules feature an industry standard housing, very low losses and highest operating temperatures.

Typical applications include:
- Variable speed drives
- Power supplies
- Power quality
- UPS
- Renewable energies

Feature	Customer value
Spacers for substrate solder	
homogeneous solder thickness, less delamination	higher lifetime under cyclic loads (e.g. thermal cycles)
Pre-bowed and stamped baseplate	
reduced gap and lower interface resistance	higher themal utilization more power, higher lifetime
Spacers for main terminal solder	
homogeneous and thus stronger solder layer	higher lifetime under cyclic load and more robust against vibrations

3. LoPak1 IGBT modules

The LoPak1 module is 100 percent mechanically compatible with the Econo-type dual IGBT modules. The ABB LoPak1 sets a benchmark with full switching performance up to 175 °C.

It is specifically designed for excellent internal current sharing offering optimal thermal utilization and increased robustness. Thus customers can expect larger safety margin and increased lifetime.

Typical applications include:
- Wind power converters
- Variable speed drives
- Power supplies
- Power quality
- UPS
- Renewable energies

Feature	Customer value
Special treated Cu-baseplate	
controlled bow and reduced airgap to heat sink. This yields to a lower thermal interface resistance and significantly reduce grease pump-out	higher thermal utilization, more power, higher lifetime
Spacers for substrate solder	
homogeneous solder thickness, less delamination	higher lifetime under cyclic loads (e.g. thermal cycles)
Press-fit auxiliary connections	
Press-fit auxiliary pins allow a solder-free connection to the gate-driver PCB. Press-fit pins can also be soldered.	Simplified attachment of gate driver saves manufacturing costs. Higher reliability compared to solder connection
Copper wire bonds for high current terminal and substrate inter-connects	lower connection resistance/losses

High-power IGBT modules

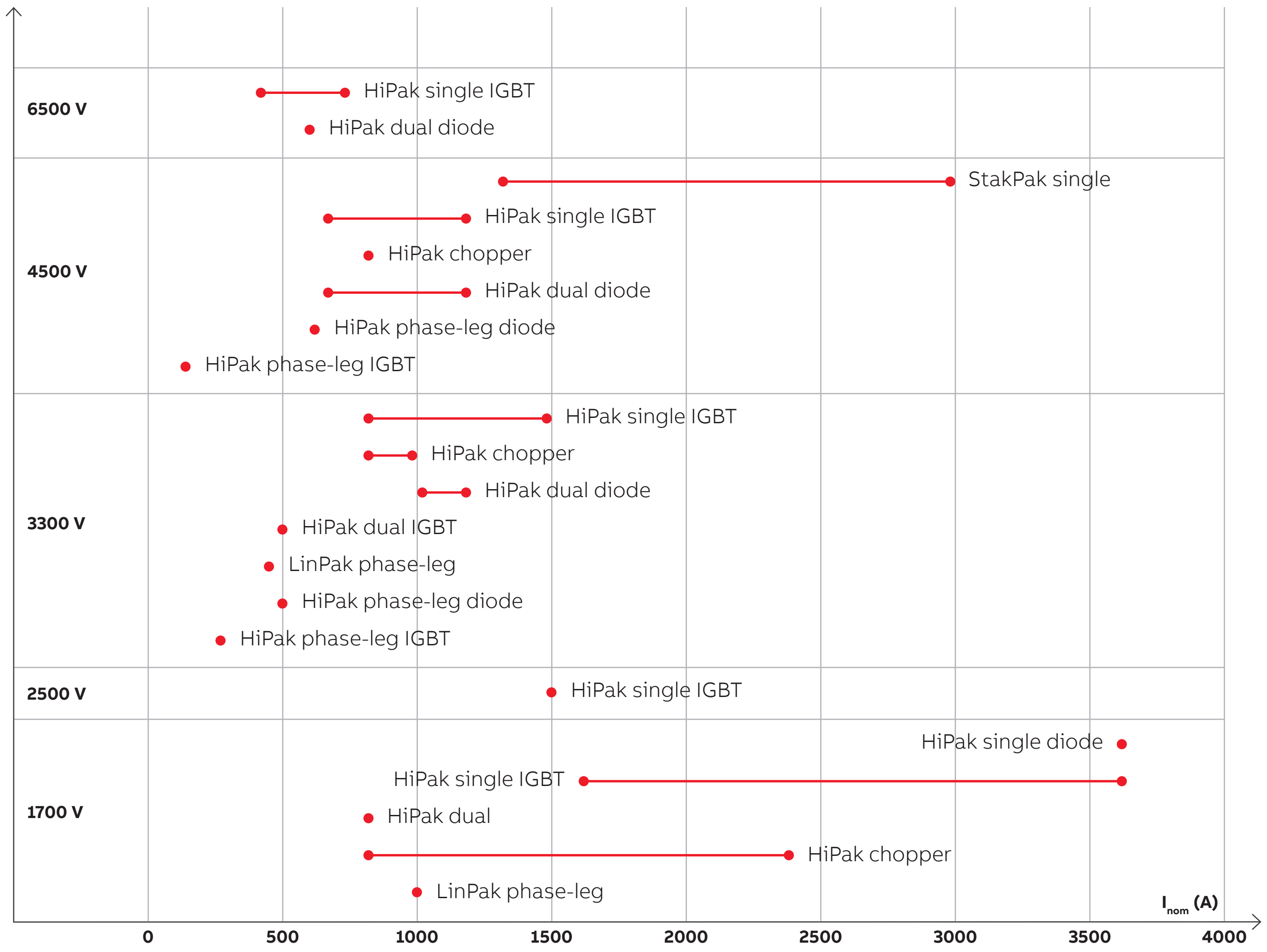
Three high-power IGBT and diode module families - LinPak, HiPak and StakPak – are available in single and dual chopper and phase leg configurations, from 1700 to 6500 V and 150 to 3600 A.

The LinPak is an enabler for more reliable, efficient and compact inverter designs in traction applications such as used in regional trains and metros, as well as locomotives and high-speed trains. LinPak also serves markets such as OHV (off-highway-vehicle) and industrial converters for drives and wind power.

HiPak type modules are the perfect match for demanding high-power applications such traction, renewable energy (wind, solar), industrial drives and T&D.

StakPak modules are suited for multiple-device stacks found in high-voltage DC transmission (HVDC) or FACTS applications.

Power map



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HiPak, StakPak and LinPak

4. LinPak IGBT modules

LinPak is a new open standard, phase leg IGBT module, rated 1700 and 3300 V, offering exceptionally low stray inductance. Its separated phase- and DC-connections allows for simpler inverter designs.

Features
The very low-inductive internal module design and the massive DC-connection enables a very low-inductive busbar design with a high current carrying capability. Both are essential requirements for state-of-the-art silicon chipsets and future SiC solutions.

LinPak modules feature excellent internal and external current sharing, making them especially suitable for paralleling. Thus with just one module type a large range of inverter ratings is possible. LinPak features an integrated temperature sensor and a dedicated mounting area for a gate drive adapter board. For harsh environments in traction or off-highway vehicle applications, the adapter board can be additionally fixed with four screws in the module corners.

The LinPak offers a fast and low switching loss 1700 V SPT^{++} and 3300 V SPT^{+} chipset that ideally fits to the LinPak module.

LinPak is the first up to 3300 V rated module with an integrated temperature sensor and offers unrivalled reliability thanks to well-matched materials such as aluminum nitride (AlN) insulation and aluminum silicon carbide (AlSiC) baseplate, as well as advanced wire bonding techniques and particle free ultrasonic welded main connections.

LinPak is suitable for more reliable, efficient and compact inverters for use in regional trains and metros and locomotives and high-speed trains. It also serves markets such as OHV (off-highway-vehicle) and industrial converters for drives and wind power.

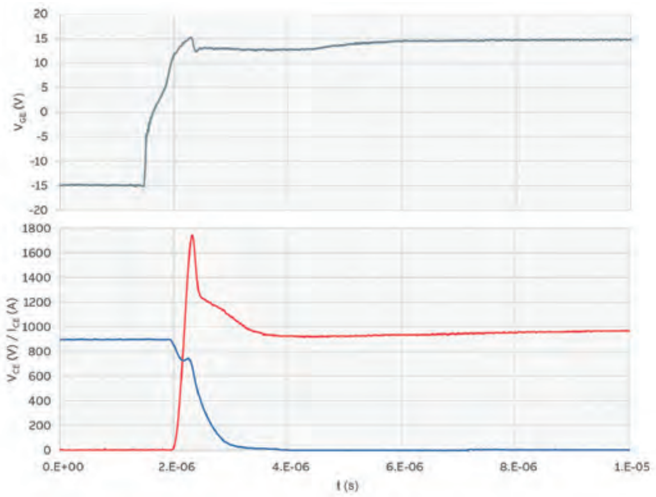
Developments
ABB has developed highly reliable traction rated modules including:
- 1700 V / 2 x 1000 A
- 3300 V / 2 x 450 A
- Cu-based industrial versions at 1700 V and later 1200 V are targeted

High-voltage versions ranging from 3300 V up to 6500 V with the same footprint, but rearranged electrical connections to cope with the higher clearance and creepage requirements, are in development.

LinPaks	Voltage (V)	Current (A)
AlSiC / (Cu*)	1700	2 x 1000
AlSiC	3300	2 x 450

*Copper version in consideration

Exemplary nominal switching waveforms
The exemplary switching waveforms at nominal current show the benefit of the low overall stray inductance. Despite the fast switching and the very low switching losses of the 1700 V SPT^{++} IGBT chipset, the overvoltage remains at a very low level. The current and voltage waveforms are free of oscillations. In the present setup, a total stray inductance including capacitors, busbar and module of less than 25 nH per 1000 A phase leg has been attained.



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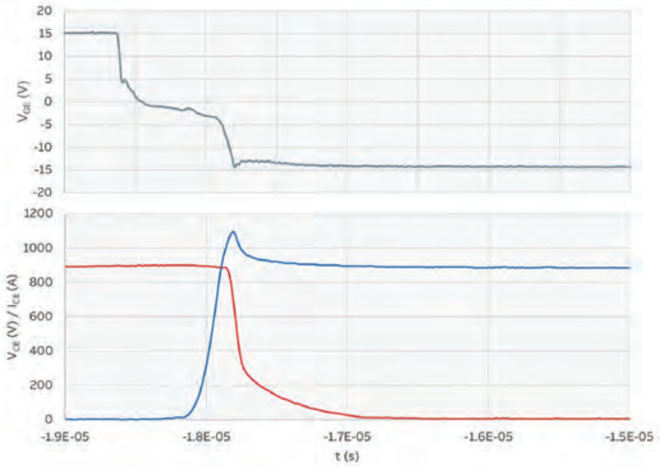
1700 V LinPak turn-on switching curves



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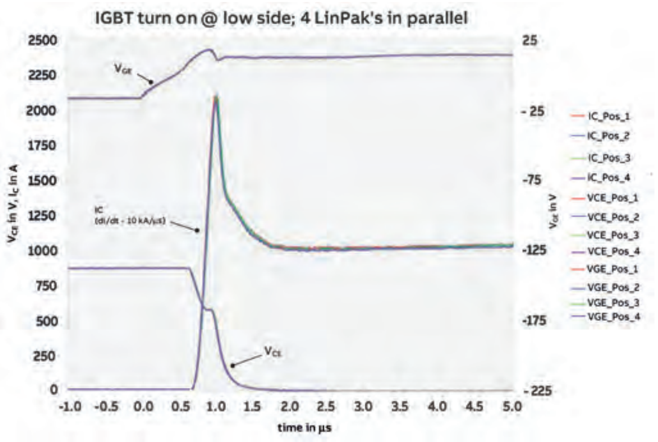
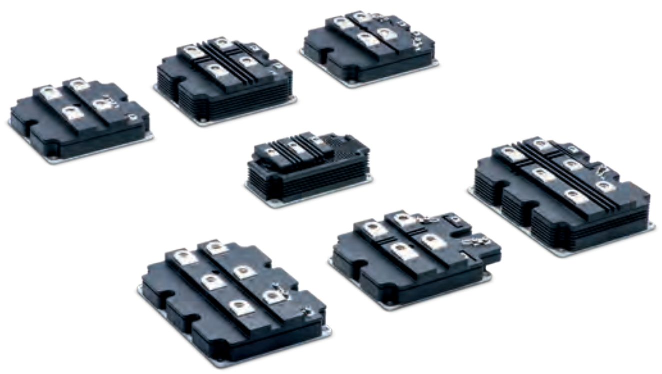
1700 V LinPak turn-off switching curves

Parallel connection
As there is practically no current mismatch between paralleled modules, LinPak is ideal for parallel connection. See the exemplary turn-on switching curve of four paralleled modules:



5. HiPak IGBT modules



HiPak high-power IGBT modules come in industry standard housings measuring 190 x 140 mm, 130 x 140 mm and 140 x 70 mm. The modules are suitable for demanding high-power applications such as traction, transmission & distribution, renewable energy (wind, solar) and industrial drives.

HiPak modules are available in 4, 6 and 10.2 kV_{RMS} standard isolation voltages and a variety of circuit configurations.

The modules exclusively use AlSiC baseplate material and AlN isolation with low thermal resistance. This specific material combination offers an excellent power cycling performance due to its matched thermal expansion coefficients (CTE).

All HiPak modules feature ABB's advanced SPT and SPT^+ (soft punch through) chip technology. The technology combines low losses with soft switching performance and a record breaking safe operating area (SOA).

HiPak SPT chips are optimized for reliable operation under harsh conditions through smooth switching characteristics and rugged operation (high SOA) which translates into operational safety margins for the equipment.

Furthermore, the SPT^+ chipsets (IGBT and diode) at 1700 V and 3300 V blocking voltages are improved to operate at higher junction temperatures up to 150 °C within the HiPak modules.

SPT technology
SPT is a well-established planar IGBT technology extending from 1200 V to 6500 V. It is characterized by smooth switching waveforms and exceptional robustness which is of importance at higher voltages and currents, where stray inductances are not easily minimized.

SPT^+ technology
SPT^+ retains all the features of the SPT technology but reduces $V_{CE\,SAT}$ by up to 30 percent according to the curve in figure 1 – an achievement previously possible only with trench technology.

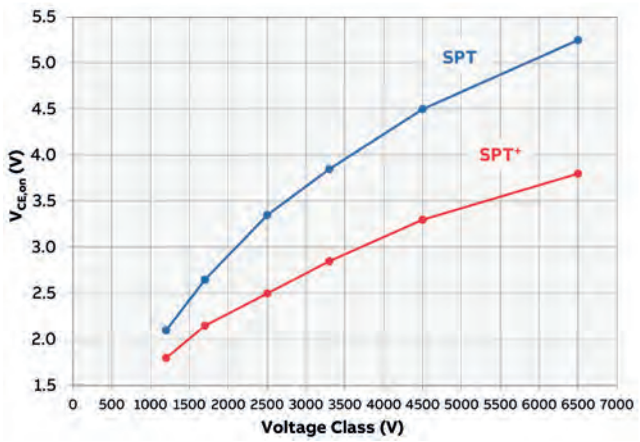


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Fig. 1 $V_{ce\,sat}$ for different IGBT cell technologies on SPT silicon at 125 °C. (current density of SPT range, same E_{off})

TSPT$^+$ technology
The enhanced Trench cell technology combines the merits of the SPT$^+$ with its n-enhancement layer and the latest Trench-cell technology. Figure 2 shows a cross-section through the cell.

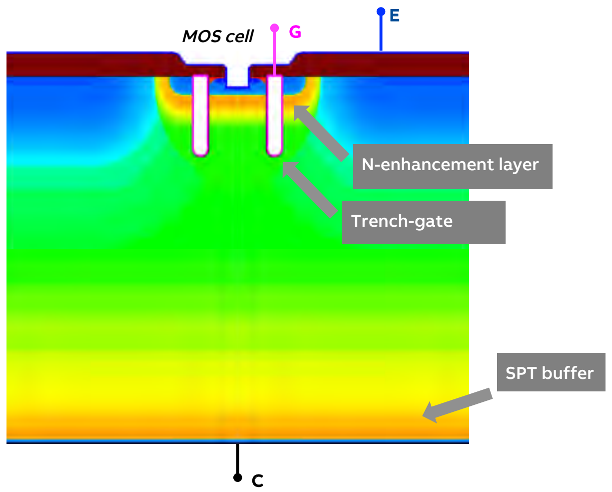

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Fig. 2 TSPT$^+$ Enhanced Trench cell design

This shows reduced conduction losses and a further increase of the current density of up to 20 percent compared to previous designs. First employed in the 3300 V class, ABB offers a HiPak module with 1800 A nominal current.

The ABB Trench cell offers highest ruggedness, avoiding unwanted degradation effects in the usual operating area that are often attributed to high voltage Trench cell designs.

The enhanced Trench TSPT$^+$ technology offers superior turn-off capability with large margins to the normal operation area. Figure 3 shows the turn-off SOA of the 3300 V TSPT$^+$ with more than 3x nominal current:

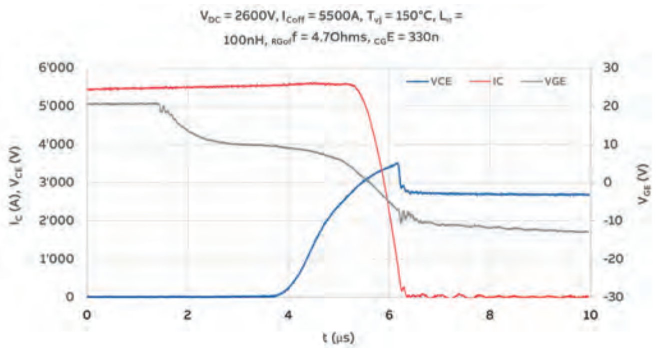

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Fig. 3 3300 V TSPT$^+$ HiPak2 IGBT module with >3x nominal current turn-off at 150 °C

SPT^{++} technology for 6500 V
For the highest 6500 V, ABB has further improved the enhanced planar design, resulting in exceptionally low switching losses and increased current density by up to 30 percent: achieving a 1000 A rated IGBT module. Like its predecessors, the 6500 V SPT^{++} design offers unrivalled robustness with minimum design-in risks.

Proof of this capability is represented by the full 150 °C operation temperature capability with a large safe operating area (SOA). Figure 4 shows the turn-off SOA of the 6500 V SPT^{++} IGBT with 2.5x nominal current at 150 °C.

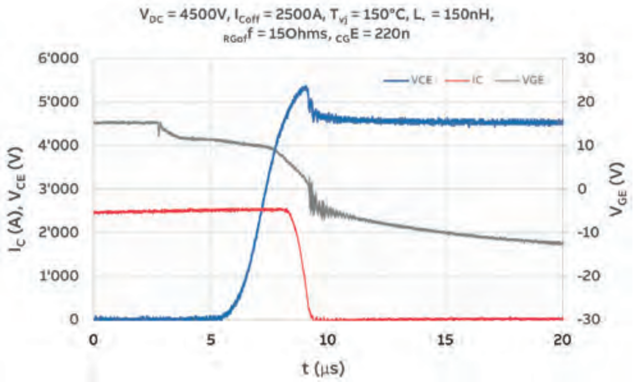

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Fig. 4 6500 V SPT^{++} HiPak2 IGBT module with 2.5x nominal current turn-off at 150 °C

The 6500 V SPT^{++} IGBT serves as an easy upgrade for existing converter designs, either to increase power or to reduce the inverter size.

Increased reliability with improved HiPak
The improved HiPak modules are a direct one-for-one replacement with identical electrical and thermal characteristics. The principal electro-mechanical layout remains unchanged. The improvements are realized by the following features:

Housing construction:
For low-voltage (LV) HiPak modules the epoxy casting is removed, allowing case temperature rating to increase to $T_{C\,max}$ = 150 °C. The new package complies with the latest fire and smoke requirements for traction applications. This applies to the low- and high-voltage versions:
- NFF 16-101/102 I3 – F2,
- EN 45545-2 R23: >HL1, R24: >HL2

Internal auxiliary connections:
Internal solder connections between the gate-print and the substrate will be substituted by standard aluminum wire bonding. This well-established technology allows for higher reliability and offers a redundant double wire connection (figure 4).

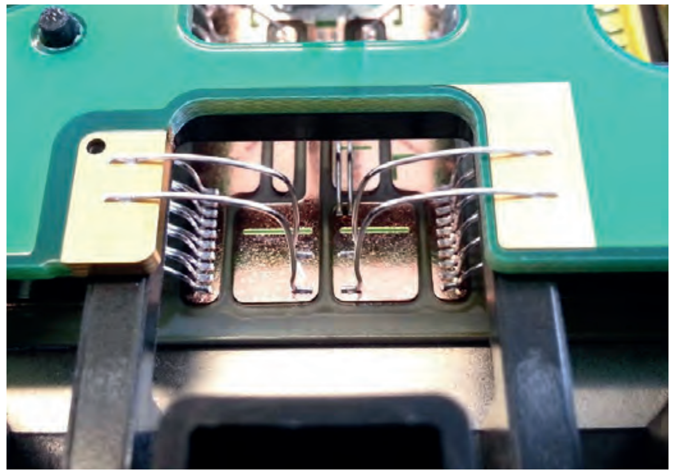

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Fig. 4 New redundant aluminum wire bond connection of gate and auxiliary emitter

Terminal foot:
The main terminals offer an improved solder foot with specifically designed spacers that achieve a homogenous solder layer thickness. This allows for an improved temperature cycling performance.

Wire bonding:
The emitter side wire bonding parameters are improved and stich-bonds (figure 5) being used. This results in an improvement of factor 4 in intermittent operating life (IOL) (target 2 Mcycles T = 60 K, $T_{vj\,max}$ = 150 °C).

—
Fig. 5 Stich-bond layout and improved bonding parameters boost the power cycling capability

The new design is subjected to relevant testing including shock and vibration, temperature cycling, IOL and Temperature Humidity Biased (THB).

6. StakPak press-pack IGBT modules

StakPak high-power IGBT press-pack modules feature advanced modular housing that ensures uniform chip pressure in multiple-device stacks.

For applications requiring series connection, press-pack modules are preferred. Press-pack are easy to connect electrically and mechanically in series and have an inherent ability to conduct in the shorted state – an essential feature where redundancy is required.

Since IGBT modules feature multiple parallel chips, there is a challenge – with conventional press-packs – in assuring uniform pressure on all chips. ABB has solved this problem with an advantageous spring technology.

The StakPak, optimized for series connection, features a modular concept based on sub-modules fitted in a fiberglass reinforced frame (figure 1). Thus a range of products can be developed for different current ratings and IGBT / diode ratios.

Fig. 1 Submodules in a 6-pocket StakPak module

StakPak product range
StakPak modules, unlike standard IGBT modules, fail into a stable short-circuit failure mode (SCFM). SCFM capable StakPaks are suitable for applications with series connections with redundancy. In such applications, additional devices are inserted in the series string so that a device's failure will not interrupt converter operation.

The failed device continues to conduct current for a period greater than the equipment's planned service interval. This period, during which load current must flow in the failed device without external degradation of the housing or internal degradation of the electrical contact, is a function of the load current time-dependence.

ABB offers SCFM ratings for users requiring this feature and who are able to specify the load current waveforms and profiles. For applications not requiring a stable short over a longer period, ABB can provide non-SCFM rated modules.

Furthermore, although a non-SCFM rated StakPak module fails into a short, a stable short can only be guaranteed up to one minute. This is still sufficient time to engage an external bypass or take other measures.

Press-pack technologies
Two basic multi-chip press-pack technologies exist: chips contacted by common pole-pieces (figure 2: conventional technology) and chips contacted by individual springs (figure 3: ABB StakPak technology).

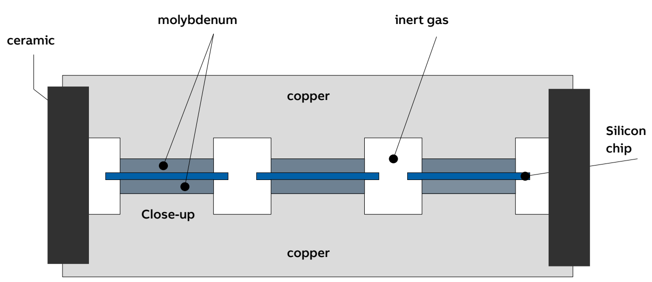


Fig. 2 Sectional view of conventional multi-chip press-pack with common pole-pieces: each chip bears the device force divided by the number of chips.

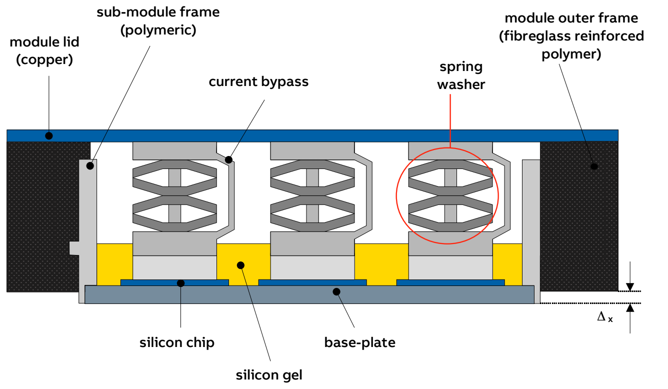


Fig. 3 Sectional view of ABB multichip press-pack with individual spring contacts: the chip bears the force determined by the spring; excess force is borne by the housing walls. The drawing illustrates one multichip submodule in one press-pack housing.

Clamping operation:

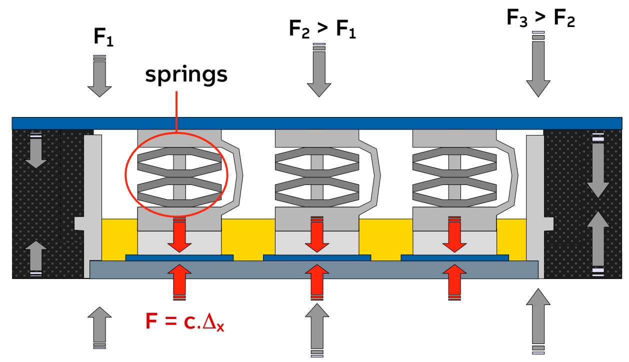


Fig. 4 Principle of individual emitter pressure contacts. F is the force, c the spring constant and Δx the travel distance.

The individual spring contacts reduce the heat sink flatness tolerance and the pressure uniformity requirement within the stack that would otherwise be needed. This reduces the stack's mechanical construction costs and greatly increases field reliability. The spring acts as an «independent suspension», so that only the correct force is applied to each chip. This allows excess force to be transferred to the StakPak's housing wall (figure 4). The force needed for a long stack may indeed be far higher than that tolerated by the silicon chips being contacted via their sensitive surface microstructures.

The rigidity and stability of a stack subjected to shock or vibration in service or during transportation depends on a mounting force that may not always coincide with that required by the encapsulated chips. It is, therefore, important to decouple the two forces, allowing the optimal force on the chips to be lower than the optimal force on the stack. The individual springs of ABB's StakPak allow this.

Applications
Press-pack modules are favored in applications where devices are series-connected mechanically and/or electrically. An example of a long stack requiring SCFM can be seen in the HVDC valve of figure 5. Other press-packs applications include:
- HVDC & FACTS (Flexible AC Transmission Systems)
- Topologies in which open circuits are not possible (e.g., current-source systems)
- Multi-level inverters with 6 or more devices mechanically in series
- Frequency converters operated directly from the 15 or 25 kV AC traction catenary
- Pulse-power applications, such as thyratron replacement

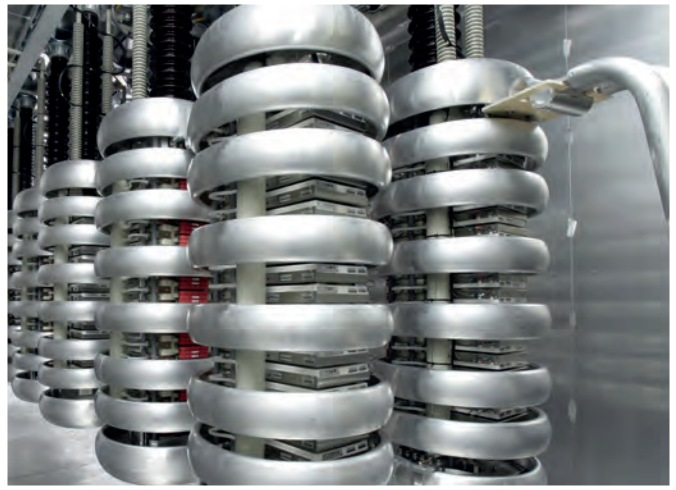


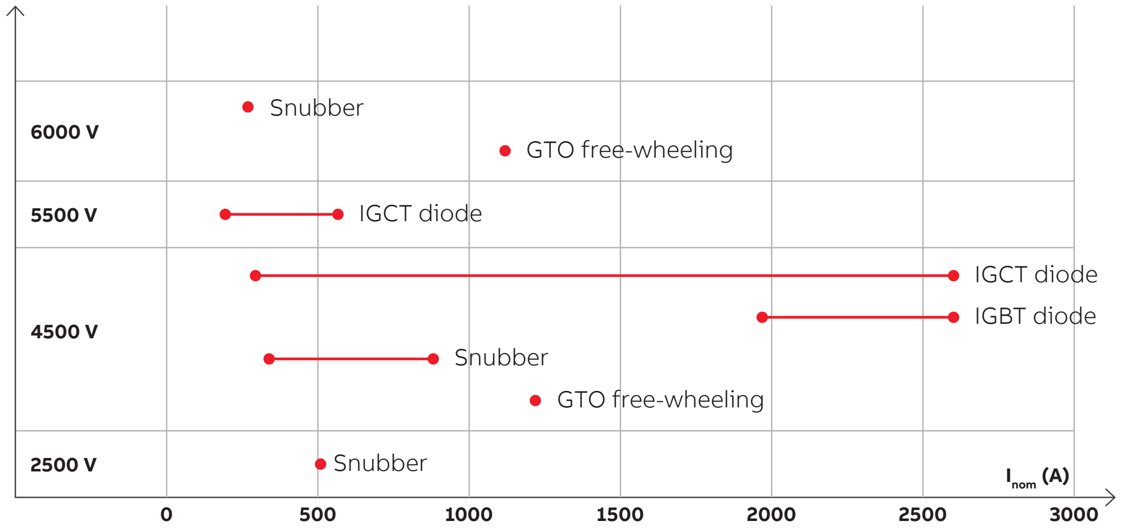
Fig. 5 Standard IGBT valve for VSC, HVDC and STATCOM

Summary
StakPak technology is a well proven IGBT press-pack concept that reduces cost and enhances reliability in systems requiring several press-packs in one stack. StakPak's modularity allows the product range to be configured from several standard parts, enabling rapid response to market needs. The newly introduced 4500 V rated modules feature the state-of-the art SPT+ chipset for lowest system losses and highest ruggedness and reliability.

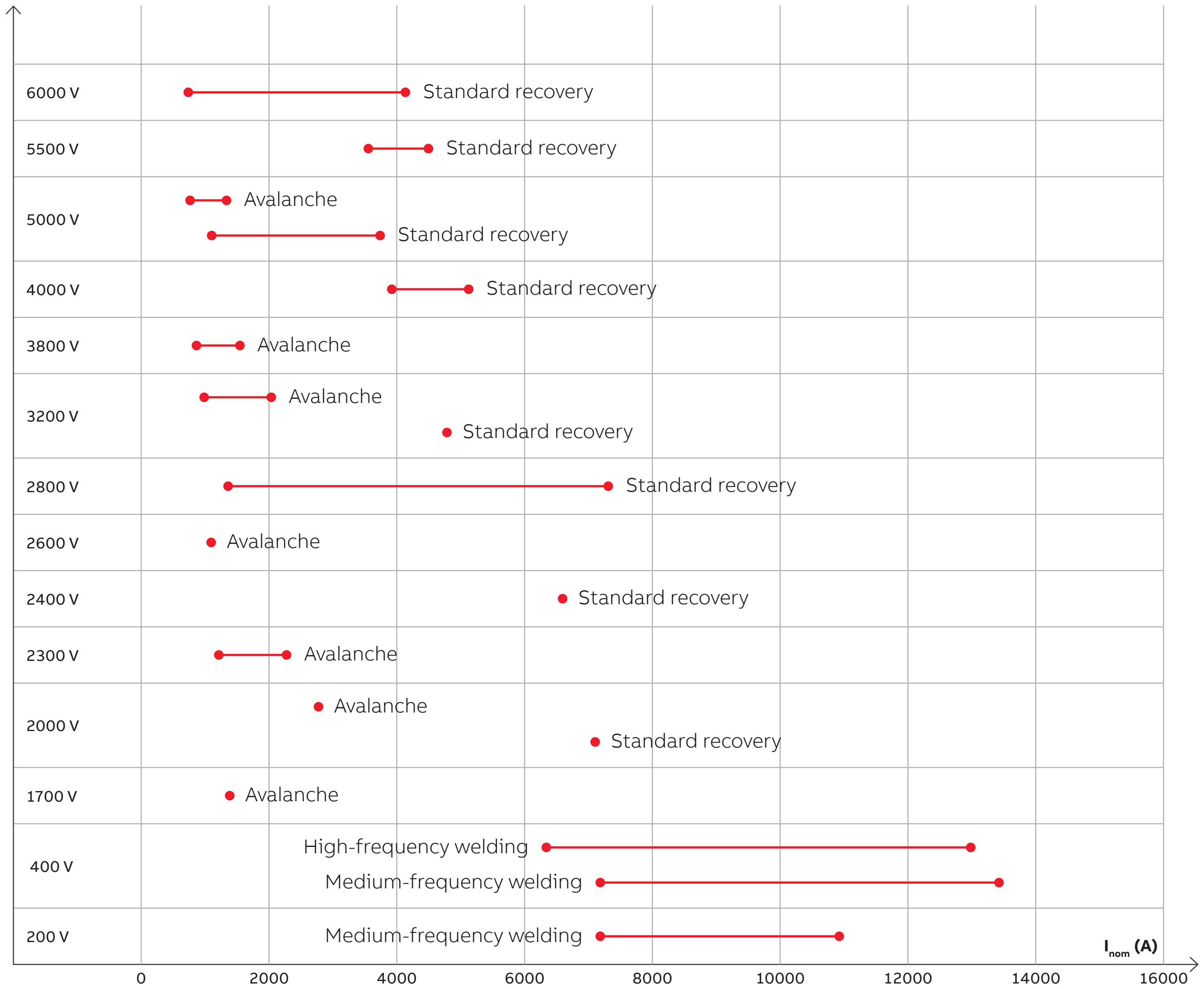
Diode press-packs

ABB's range of press-pack diodes covers
- Fast recovery diodes from 2500 to 6000 V and 175 to 2620 A (GTO free-wheeling, snubber, IGBT and IGCT diodes)
- Standard rectifier and avalanche diodes from 1700 to 6000 V and 662 to 7385 A
- Welding diodes for medium and high frequencies at 200 and 400 V and from 6.2 to 13.5 kA.

Power maps



Fast recovery diodes

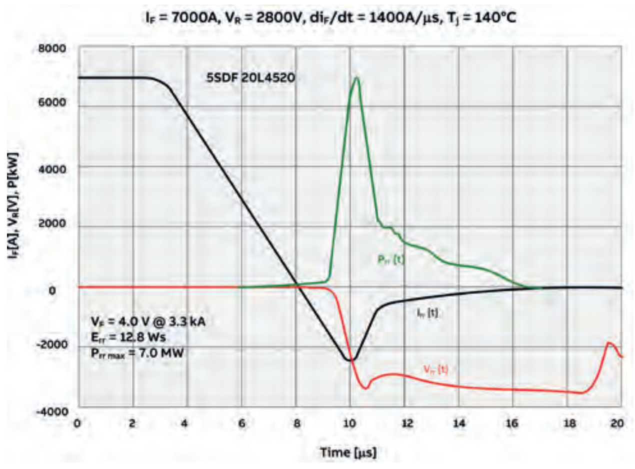


Rectifier and welding diodes

7. Fast recovery diodes

A wide range of fast recovery, low loss diodes such as snubber, clamping and free-wheeling diodes in various configurations are available, to enable full performance of the IGCTs, IGBTs and GTOs in demanding applications.

Fast recovery diodes, though an integral part of inverter design, have seldom received the same attention as turn-off devices such as IGBTs, IGCTs or GTOs. As a result, snubber, clamp, neutral-point clamping (NPC) and free-wheeling diodes (FWDs) often limit optimal equipment design. Recognizing this and the growing trend to eliminate voltage snubbers on semiconductors, ABB has developed a full range of fast diodes offering enhanced safe operating areas (SOA) and controlled (soft) recovery at very high di/dt and dv/dt levels. The growing demand for switching capability (ratings) and not just recovery charge or losses (characteristics) imposes new constraints on diode design and production test equipment to ensure cost-effective delivery of robust and reliable components. In contrast to turn-off devices, thyristors and diodes are traditionally tested for their characteristics only and classified accordingly. New generations of high-performance fast diodes, as 5SDF 20L4520 / 21 and 5SDF 28L4520 / 21, are now tested for their dynamic characteristics and ratings on production test equipment that accurately reproduces the main commutation modes required of today's fast diodes. The fast diodes 5SDF 20L4521 and 28L4521 are developed to operate safely in power electronic circuits employing IGBT and IEGT press-packs, where di/dts up to 5 kA/µs are especially required.



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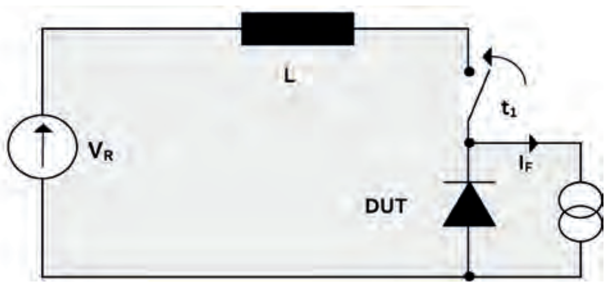
Typical diode turn-off in IGCT circuit.

Features:
- Free-wheeling diodes
- Clamp and snubber diodes
- Snubbered types
- Unsnubbered types
- Soft recovery
- High SOA
- Cosmic ray resistance capability

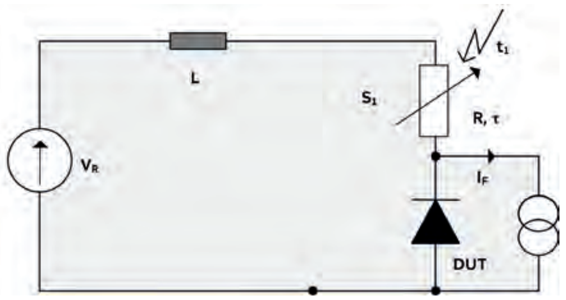
Benefits:
- High operating temperature range up to 140 °C
- Optimized forward and reverse recovery characteristics
- Excellent softness and enhanced SOA
- Cosmic radiation withstand rating
- Press-pack devices

Applications
Fast diodes of a given blocking voltage and silicon wafer diameter are designed using five basic variables: resistivity, thickness, uniform lifetime control, profiled lifetime control and emitter efficiency. Combining these variables allows diodes to meet the requirements of five different commutation modes encountered in voltage source and current source inverters (VSIs and CSIs). These are defined in table 1. One of the basic principles influencing the nature of a commutation is the origin of the di/dt. There are two types of commutation:

– inductive commutation
whereby the active switch is considered «perfect» (eg a thyristor) and an inductance determines di/dt



– resistive commutationn
whereby the active switch is considered as a time-dependent resistor (eg a transistor) and this controls di/dt.



Category	Application	Snubber type	Commutation characteristics	Required diode characteristics
I	FWD and NPC diodes for GTOs and IGCTs in low frequency VSIs	RCD	• inductive • unclamped • snubbered • low dv/dt	• uniform lifetime • high cosmic ray resistance capability • low V_{FM}
II	Snubber diode in RCD circuits	R	• inductive • unclamped • snubbered	• profiled lifetime • soft recovery at low I_F
III	• Snubber diodes in Undeland, Marquardt and McMurray VSIs • Clamp diodes	none	• resistive • unclamped • unsnubbered	• profiled lifetime • soft recovery at low I_F
IV	• Commutation diodes in CSIs • High frequency series-connected IGCTs	RC	• inductive • unclamped • snubbered	• profiled lifetime • medium cosmic ray resistance capability
V	FWD and NPC diodes in snubberless high frequency VSIs	none	• inductive • clamped • high dv/dt	• profiled lifetime • high cosmic ray withstand capability • high SOA • soft recovery at low I_F

Cosmic ray resistance capability
An important parameter for the rating of any semiconductor in a converter is the voltage to which it is exposed. This has two reasons: the stability of the leakage current at rated temperature and the potential failures provoked by ionizing cosmic particles – events whose probability of occurrence increases exponentially with field strength but only linearly with voltage duty cycle. The various functions within power conversion equipment may be exposed to different voltages and duty cycles even though the peak voltages might be the same. Thus, an inverter containing 4.5 kV GTOs, free-wheeling diodes, snubber diodes and clamp diodes operating from a 2.8 kV DC link, would require that the GTOs and snubber diodes have a 2.8 kV DC rating.

The snubber and clamp diodes, however, due to their infrequent exposure to the DC link (duty cycle of approximately 5 percent), would be better served with diodes of lower DC rating (thinner silicon), thus endowing them with superior dynamic properties (fast forward and reverse recovery, low losses, no snap-off). For further information see application note 5SYA2061 «Failure Rates of Fast Recovery Diodes due to Cosmic Rays».

8. Rectifier diodes

ABB Semiconductors' reliable high-power rectifier diodes are first choice in many demanding applications in industry and traction.

ABB offers two families of high-power rectifier diodes, standard rectifier diodes and avalanche diodes, both with the following features:
- Reverse repetitive voltage from 1700 V to 6000 V
- High average forward current rating from 700 A to 7400 A
- Excellent surge current capabilities up to 87 kA
- Operating temperature from -40 °C to 190 °C
- High current handling capabilities
- Diodes for parallel or series connection available
- Hermetically sealed press-pack devices

Standard rectifier diodes
Optimized for line frequency and low forward losses.
Applications:
- Input rectifiers for large AC-drives
- Aluminum smelting and other metal refining
- Rectifier traction substations

Avalanche diodes
Self-protected against transient over-voltages, offering reduced snubber requirements and maximum avalanche power dissipation.
Applications:
- Input rectifiers in traction converters
- High voltage power rectifiers

9. Welding diodes

ABB Semiconductors has accumulated impressive expertise in the design and manufacturing of rectifier diodes for high-current-resistance welding machines. The diodes operate at frequencies beyond 1 kHz with welding currents over 10 kA. Despite these severe conditions, a load cycle capability of millions of cycles, corresponding to years of device operation, is achieved.

Through cooperation with many of the major welding equipment manufacturers, ABB has gathered great experience in the utilization of diodes to reach optimal reliability and electrical performance. ABB's welding diodes (WD) include encapsulated, hermetically sealed and housing-less welding diodes (HLWD) in various sizes and ratings.

Encapsulated and hermetically sealed
The semiconductor diode chips are alloyed to a molybdenum disk. The low 200 or 400 V rating enables the use of thin silicon to reduce the conduction losses of the devices. The silicon-molybdenum disk is placed inside the hermetic housing between two copper electrodes. Since the requirements for air strike and creepage distance are low, thin housings with low thermal resistance are used. An added advantage of WDs is their small size and low weight; a welcome feature for welding equipment mounted on a robot arm in the automotive industry.

Housing-less
The housing-less welding diodes are constructed with a reduced number of layers to improve their thermal performance. In HLWDs, the silicon chips are covered by a copper electrode on the cathode side, which works as a mechanical buffer, the anode side is the hard molybdenum disk, which serves as a HLWD case. Although HLWDs are more susceptible to environmental conditions, their advantages are higher current density, lower weights and geometric sizes compared to WDs.

Medium- and high-frequency welding diodes
The medium-frequency welding diodes can operate at frequencies up to 7 kHz. However, their optimal and reliable frequency range is up to 2 kHz. To meet the demands of higher frequencies up to 10 kHz, a new group of high frequency welding diodes with high current capabilities combined with excellent reverse recovery characteristics is available. They offer the following features:
- high operating frequency up to 10 kHz
- high operating temperature up to 190 °C
- high current capability combined with excellent reverse recovery characteristics
- available in standard or housing-less versions
- excellent surge current ratings
- very low thermal resistance
- press-pack devices

Load cycling capability and welding current
The load cycling capability of the welding diodes is crucial for the choice of application components. Each welding cycle represents a load cycle for the diode used in the application. The load cycling capability is determined by the temperature swing the diode undergoes during the cycle. To keep the temperature swing as low as possible during the welding cycle, the diodes must be designed for lowest possible losses and thermal impedance.

Figure 1 demonstrates the number of load cycles as a function of ΔT_{jh} obtained experimentally in collaboration with welding equipment manufacturers. The dependence is valid for the entire welding diode product range. The lifetime curve indicates how many cycles can be reached in case of right mounting and proper cooling of diodes under test. Since the experiment is time consuming, the number of tested devices is limited. This fact could slightly affect the accuracy of the lifetime trend.

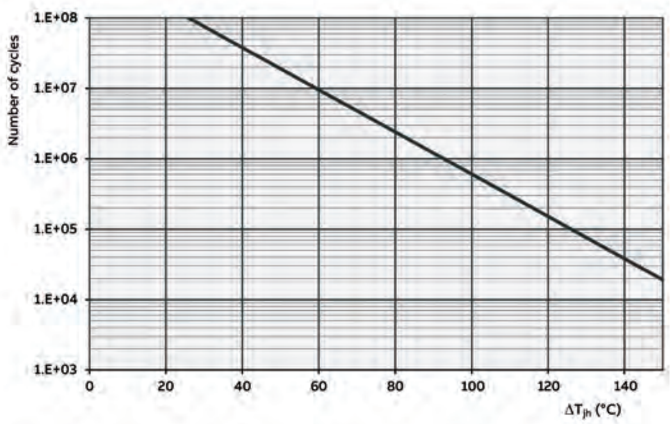


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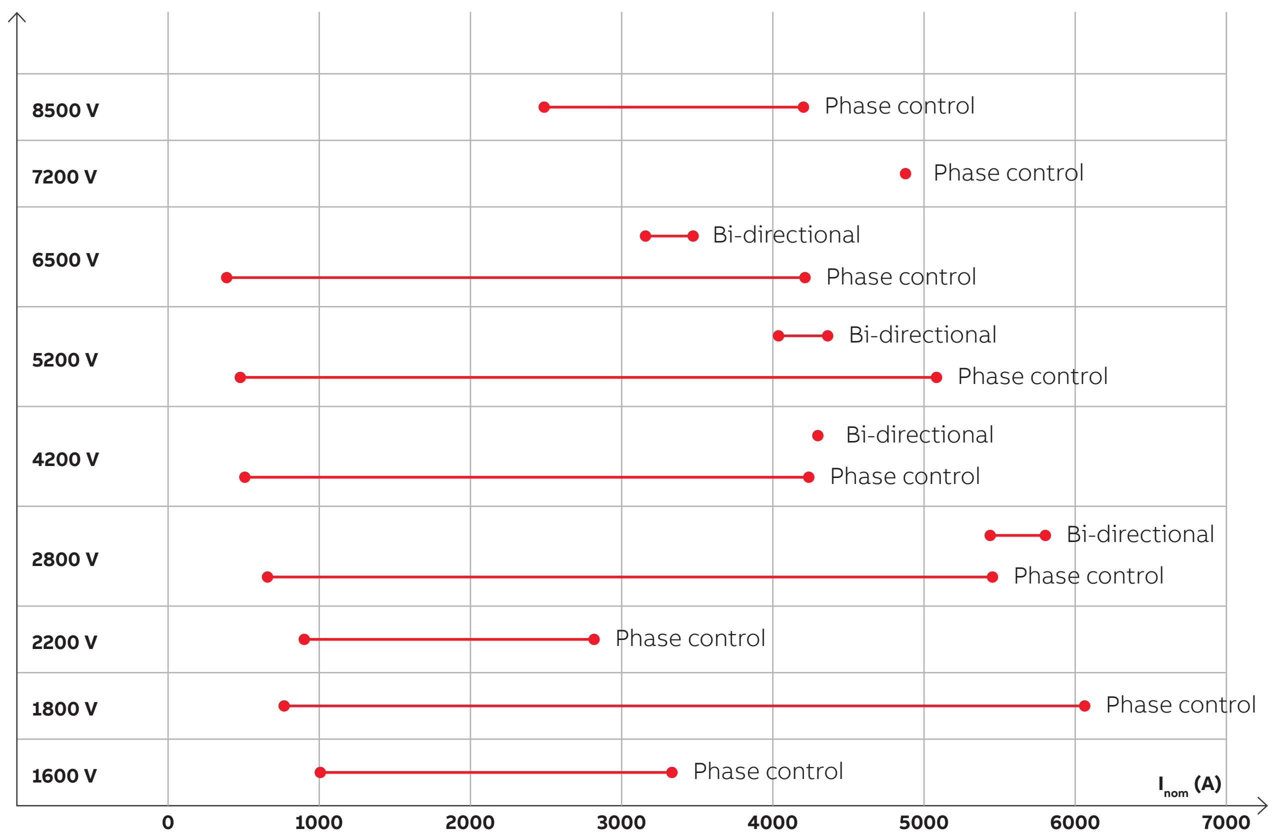
Fig.1 Achievable load cycling capability of welding diodes produced in ABB Ltd. Semiconductors, as a function of diode's junction to heat sink temperature (ΔT_{jh}).

Thyristor press-packs

ABB offers a full range of thyristors including
- Phase control thyristors (PCTs), from 1600 to 8500 V and 350 to 6100 A.
- Bi-directionally controlled thyristors (BCTs) from 2800 to 6500 V and 3120 to 5840 A.

Applications range from kW-rated DC-drives and MW-rated load commutated frequency converters to GW-rated HVDC transmission converters.

Power maps



Phase control thyristors (PCT) and bi-directional controlled thyristors (BCT)

10. Phase control and bi-directionally controlled thyristors (PCT and BCT)

ABB Semiconductors' phase control thyristor has been the backbone of the high-power electronics industry since its introduction almost 50 years ago. Offering best cost, reliability and efficiency performance, the thyristor lies at the heart of equipment used for energy transmission and distribution.

ABB was the first company to introduce 6” thyristor for HVDC applications and today offers the most complete range of high-power thyristors. New thyristor products continue to be developed with focus on minimizing overall losses and maximizing power rating of the device.

ABB’s PCT product range includes press-pack devices rated 1600 V to 8500 V and 350 A to 6100 A for use in demanding applications such as HVDC, FACTS and DC-drives. These components have set benchmark reliability records over many years.

The bi-directionally controlled thyristor
Since many medium and high voltage applications use anti-parallel connected thyristors as AC controllers, ABB has introduced the bi-directionally controlled thyristor (BCT). The device consists of two monolithically integrated anti-parallel thyristor functions on one silicon wafer. The two thyristor halves are individually triggered and have a separation region enabling the design of high voltage devices with the dynamic capability of discrete devices. Figure 1 shows a cross-section of the BCT’s silicon wafer.

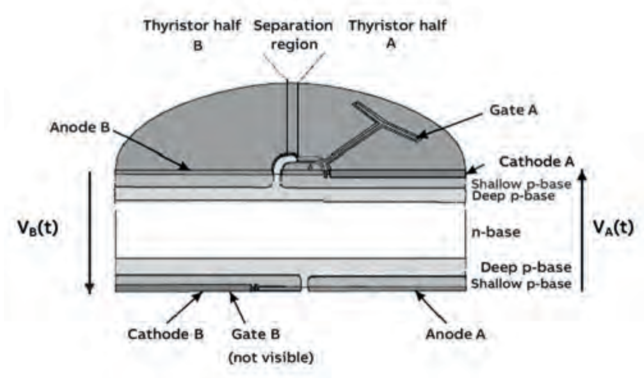


Fig. 1 Cross-section of a BCT.

The BCT is designed, manufactured and tested using the same philosophy, technology and equipment as the well-established PCT, thus reaching the same levels of performance and reliability. This enables manufacturers of equipment for applications such as SVC, 4-quadrant DC-drives and soft starters to reduce part count and equipment size without jeopardizing reliability and performance by introducing the BCT instead of a conventional PCT. Examples show volume improvements and part count reductions for equipment with BCTs in the magnitude of 25 percent compared with equally rated PCT solutions.

BCT product range includes two wafer sizes available in three different housings with ratings of 2800 V to 6500 V and 3120 A to 5840 A. The ratings I_{TSM}, and R_{thjc} are given for one «thyristor-half» of the device. I_{RMS} is the rms-current for a device operating in an AC-switch application.

BCT designs offer considerable volume and part count reductions over conventional PCTs. Table 1 summarizes expected improvements by application and power level. Table 2 shows the replacement of PCTs by BCTs.

Application	Power level	Anticipated average volume improvement (*)	Anticipated average parts count reduction (*)
DC-drive	800 kw	30%	30%
DC-drive	2000 kw	30%	25%
Soft starter	250 kw	25%	20%
Soft starter	450 kw	30%	20%
SVC	50 MVAr	35%	35%

Tab. 1 Summary of anticipated advantages when replacing a PCT solution with a BCT solution.
(*) Compared to conventional PCT solutions.

Replacement of PCTs by BCTs		
5STB 24Q2800	replaces two	5STP 24H2800
5STB 24N2800	replaces two	5STP 24H2800
5STB 18N4200	replaces two	5STP 18H4200
5STB 17N5200	replaces two	5STP 17H5200
5STB 13N6500	replaces two	5STP 12K6500
5STB 25U5200	replaces two	5STP 25L5200
5STB 18U6500	replaces two	5STP 18M6500

Tab. 2 One BCT replaces two PCTs.

Voltage rating definitions
The development of high-voltage thyristors has led to increased values of dissipated power in the off-state (due to higher voltages) even if the leakage currents have remained at similar levels to devices with lower blocking capability. This can cause problems when such devices are characterized and measured in outgoing inspection at elevated temperature (e.g. 125 °C). This is because the entire device is heated to a constant temperature (not just the junction). As a result, no temperature gradient exists to sink the generated heat away from the junction, resulting in thermal runaway during testing. Here, the applied voltage causes a leakage current and the product (V x I) heats the device. As the device gets hotter, leakage current increases exponentially, as does the heating. If the cooling of the device is not adequate, the device will get progressively hotter and will ultimately fail.

This is in strong contrast to real-world applications. Here the junction temperature may indeed reach a maximum value of 125 °C but the case temperature never exceeds, say, 110 °C. This allows leakage current losses to be cooled away across the temperature gradient between junction and case.

A more realistic method of measuring power semiconductors is to have a sinusoidal 50 or 60 Hz wave of peak value V_{DWM}/ V_{RWM} and to superimpose a narrow pulse of amplitude V_{DRM}, as shown in figure 2. This pulse corresponds to repetitive voltage peaks as typically caused by commutation transients (though the RC-circuit limiting them should be designed to give a peak voltage below rated V_{DRM} and V_{RRM}).

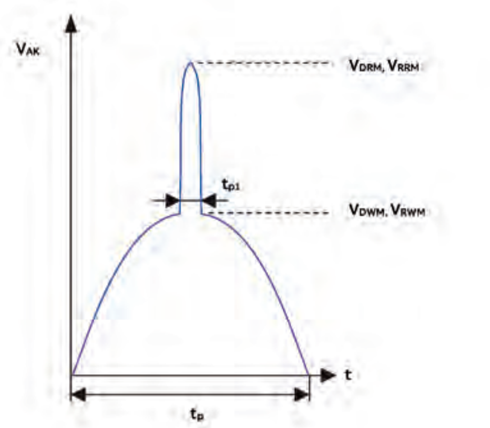


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Fig. 2 Voltage definitions for high voltage PCTs and BCTs.

By using this method, the voltage capability is tested at application-like conditions and in conformance with international standards, without thermal runaway. This method of rating is applied to ABB's high-voltage thyristors, V_{DRM}/ V_{RRM} > 4500 V. In the datasheets, the level for V_{DWM}/V_{RWM} is selected as the maximum expected working voltage for a device chosen according to the recommendations in Application Note 5SYA2051 «Voltage ratings for high power semiconductors».

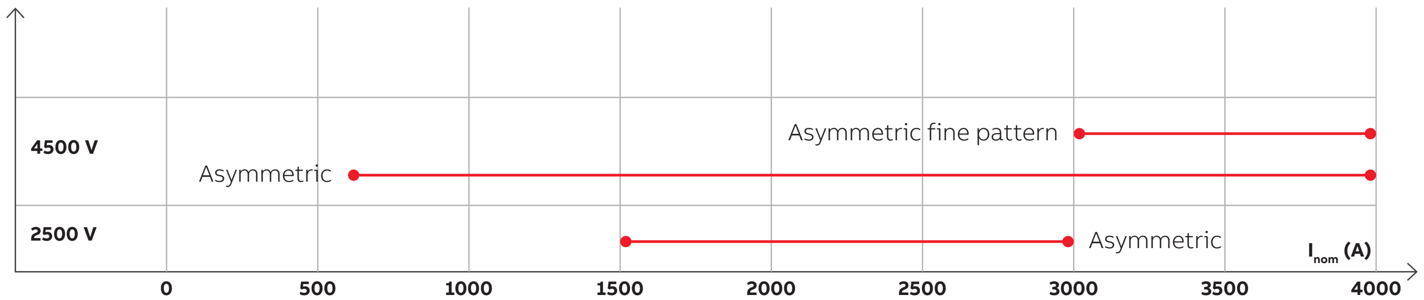
GTO and IGCT press-packs

Reverse conducting and asymmetric IGCTs are available rated between 4500 to 6500 V and 3600 to 5000 A. Asymmetric GTOs are also available rated between 2500 or 4500 V and 600 and 4000 A.

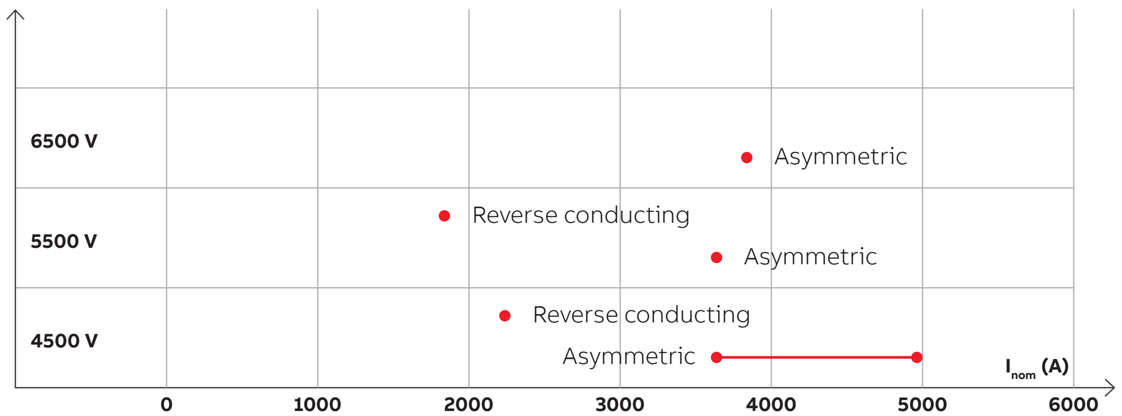
IGCT applications include medium voltage drives, wind power converters, STATCOMs, co-generation and rail power supplies.

GTOs are typically used in traction and industrial applications.

Power maps



Gate turn-off thyristors (GTO)



Integrated gate-commutated thyristors (IGCT)

11. Gate turn-off thyristors (GTO)

Despite advances in IGCT and IGBT technology, the demand for GTOs remains strong today.

GTO production commenced in the mid-1980s. A GTO is a thyristor that can be turned off by applying a current to the gate in the reverse direction to that required to turn it on. GTOs are optimized for low conduction losses. The typical on-off switching frequency is between 200 to 500 Hz for most applications. GTOs are, by nature, relatively slow switches.

Typical transition times from on to off state and vice versa are between 10 to 30 microseconds. All GTOs require protective networks called «snubbers» for turn-on and turn-off. The turn-on snubber circuit, in essence an inductor, limits the rate of current rise. For turn-off, the GTO requires a device that limits the rate of voltage rise, in essence a capacitor.

All ABB GTOs are press-pack devices. They are pressed onto heat sinks, which also serve as electrical contacts to the power terminals. ABB offers a broad portfolio of asymmetric GTOs with proven field reliability in various traction and industrial applications.

Asymmetric GTOs
Asymmetric GTOs are either buffer layer or standard. Buffer layer GTOs have exceptionally low on-state and dynamic losses. Fine pattern types (5SGF) are optimized for fast switching and transparent emitter (5SGT) for low on-state losses. The standard GTOs have excellent trade-off between on-state and switching losses.

12. Integrated gate-commutated thyristors (IGCT)

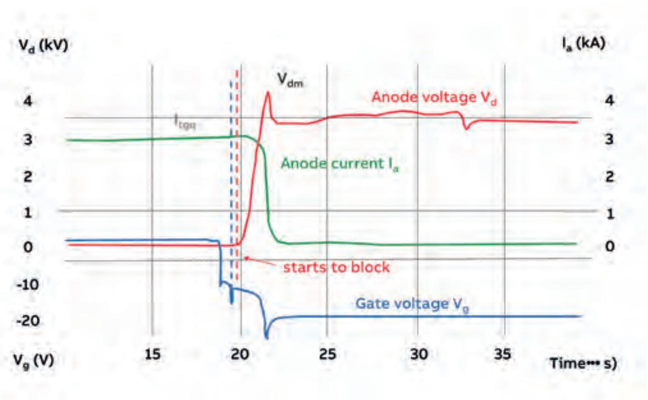


Fig. 1 IGCT turn-off exhibits same waveform and losses (Eoff) as transistor

ABB Semiconductors' IGCTs are used in a multitude of applications due to their versatility, efficiency and cost-effectiveness. With their low on-state voltage, they achieve the lowest running costs by reaching inverter efficiencies of 99.6 percent and more.

The IGCT is a gate-controlled turn-off switch, which turns off like a transistor but conducts like a thyristor with the lowest conduction losses. Figure 1 shows turn-off at 3000 A. GCTs are the only high-power semiconductors to be supplied already integrated into their gate units. The user only needs to connect the device to a 28 to 40 V power supply and an optical fiber for on/off control. Because of the topology in which it is used, the IGCT produces negligible turn-on losses. This, together with its low conduction losses, enables operation at higher frequencies than formerly obtained by high power semiconductors.

IGCTs are available as reverse conducting (RC) and asymmetric devices. The low losses allow hard-switched operating frequencies of up to 600 Hz for 6.5 kV devices and 1 kHz for 4.5 kV devices in the steady state and over 5 kHz in burst mode.

Figure 2 illustrates the basic IGCT voltage-source inverter (VSI) topology. Diode commutation is controlled by the inductance L. The free-wheel circuit of figure 2 minimizes the turn-on energy in the semiconductor by storing it in the inductance, L. The inductance is the most logical fault limitation technique in the event of catastrophic failure since, as opposed to resistors and fuses, it is inherent within the design. The IGCT's press-pack construction, combined with the inductance, makes the system resistant to explosion, even when the device's surge rating is exceeded.

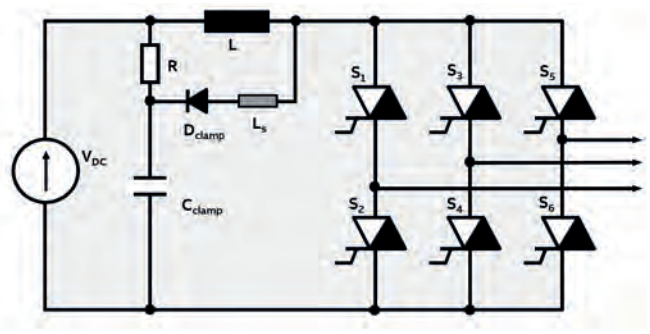


Fig. 2 Basic IGCT inverter circuitand auxiliary emitter

Turn-off dv/dt is not gate-controlled but programmed at the device manufacturing stage by anode design and lifetime engineering. The absence of dv/dt and di/dt control functionality simplifies the gate-unit design and allows a high degree of standardization. Some 60 publications exist on the use of IGCTs in many applications. These can be downloaded from www.abb.com/semiconductors.

Applications
The integrated gate-commutated thyristor is the power-switching device of choice for demanding high-power applications such as:
- Medium voltage drives
- Marine drives
- Co-generation
- Wind power converters
- STATCOMs
- DVRs (dynamic voltage restorers)
- BESS (battery energy storage systems)
- SSB (solid state breakers)
- DC traction line boosters
- Traction power compensators
- Interties

Outlook
The expansion of power electronics into new fields of energy management and renewable energy sources is driving the need for higher voltage and higher efficiency semiconductors, while increasing demands for reliability and lower costs.

The IGCT is capable of still higher currents and voltages without series or parallel connection. The first such products are introduced as «high power technology» devices. This latest family of IGCTs exhibit up to 30 percent higher turn-off capability compared to standard devices.

Currently in development are technologies to increase the rated temperature for several devices and to increase the current rating with larger silicon diameters.

Within 20 years of its introduction, the IGCT has established itself as the power device of choice for high power at high voltage by meeting the demands of a growing power electronic market. Single inverters of over 15 MVA can now be realised, without series or parallel connection, thereby achieving the highest inverter power densities in the industry.

Test systems for high-power semiconductors

ABB Semiconductors designs, manufactures and offers CE compliant customized power semiconductor test systems.

More than 30 years of experience and proximity to semiconductor development, production and application enables ABB to offer test systems for research & development, laboratory, production or failure analysis environments. Highest quality assurance, safe handling and remote or on-site service capability are guaranteed.

High-power semiconductor test systems
ABB offers static and dynamic production test systems for most types of power semiconductor devices like diodes, PCTs, BCTs, GTOs, IGCTs and IGBTs. The test systems can handle dies, substrates, submodules, modules, wafers and press-pack devices. Also reliability test systems for high temperature reverse bias, intermittent operating life or surge current tests are available. Auxiliary tester parts include clamping, capacitor discharge, pre-heating, data acquisition and parameter extraction units as well as programmable IGBT and thyristor gate units.

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Dynamic IGCT, GTO and diode test system

Parameters
The ABB test systems cover the range of up to 14 kV and 10 kA and use configurable stray inductances down to 60 nH. During testing, the clamped device under test (DUT) can be precisely heated up to 200 °C for production systems or cooled down to -40 °C in an environmental chamber for engineering systems. The clamping units can handle devices up to 240 mm in diameter and can apply a clamping force of up to 240 kN.

Automation
ABB's test systems are designed for easy integration into automated handling equipment. The test system's software is compatible to commercial control systems such as manufacturing execution systems (MES) and computer-aided quality assurance (CAQ).

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Automated IGBT and diode dies test system

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Baseplate flatness tester. Mechanical measurement under pressure (resolution up to 0.1 micrometer)

Specialized solutions

	Blocking voltage AC or DC	Gate characteristics	On-state, forward voltage	Reverse recovery charge	Critical dV/dt	Circuit-commutated turn-off time	V_{cesat} / $V_{pinch\text{-}off}$	Turn-on / turn-off
Bipolar test systems 4.5 kV								
Thyristor and diode static / dynamic	X	X	X	X	X	X		
GTO and diode static	X	X	X					X
GTO and diode dynamic	X			X				X
IGBT test systems								
IGBT and diode dies static	X	X					X	
IGBT and diode substrates static / dynamic	X	X		X			X	X
IGBT and diode modules static	X	X					X	
IGBT and diode modules dynamic				X				X
Baseplates flatness								

Reliability test systems
- High temperature reverse bias
- Intermittent operating life
- Surge current

Auxiliary unit
- Clamping unit
- Capacitor discharge unit
- Preheating unit
- Programmable IGBT and thyristor gate units
- Data acquisition and parameter extraction units

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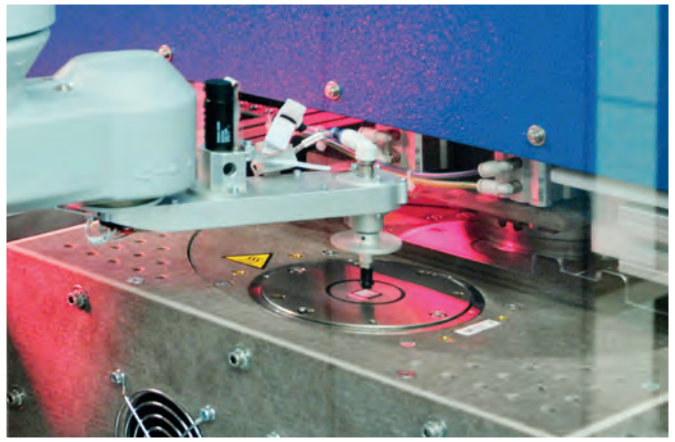
Substrate handling



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Die handling

Documentation

Product catalog, application notes and data sheets as well as SEMIS – ABB's semiconductor online simulation tool – are available at www.abb.com/semiconductors.

Additional documentation required for the reliable application of ABB's power semiconductors is available on the same site. An overview is given here.

IGBT dies and modules

Document title	Document number
Mounting instructions for StakPaks	5SYA 2037
Mounting instructions for HiPak modules	5SYA 2039
Failure rates of IGBT due to cosmic rays	5SYA 2042
Load-cycling capability of HiPak IGBT modules	5SYA 2043
Thermal runaway during blocking	5SYA 2045
Voltage ratings of high-power semiconductors	5SYA 2051
Applying IGBTs	5SYA 2053
IGBT diode safe operating area	5SYA 2057
Surge currents for IGBT diodes	5SYA 2058
Applying IGBT and diode dies	5SYA 2059
Thermal design and temperature ratings of IGBT modules	5SYA 2093
Paralleling of IGBT modules	5SYA 2098
Mounting Instructions for 62Pak	5SYA 2106
Mounting instructions for LinPak modules	5SYA 2107

Diodes

Document title	Document number
High-current rectifier diodes for welding applications	5SYA 2013
Design of RC snubbers for phase control applications	5SYA 2020
High-power rectifier diodes	5SYA 2029
Mechanical clamping of press-pack high-power semiconductors	5SYA 2036
Field measurements on high-power press-pack semiconductors	5SYA 2048
Voltage ratings of high-power semiconductors	5SYA 2051
Failure rates of fast recovery diodes due to cosmic rays	5SYA 2061
Applying fast recovery diodes	5SYA 2064
Parameter selection of high-power semiconductor for series and parallel connection	5SYA 2091

Thyristors

Document title	Document number
Bi-directionally controlled thyristors	5SYA 2006
Design of RC snubbers for phase control applications	5SYA 2020
Gate-drive recommendations for phase control and bi-directionally controlled thyristors	5SYA 2034
Mechanical clamping of press-pack high-power semiconductors	5SYA 2036
Field measurements on high-power press-pack semiconductors	5SYA 2048
Voltage definitions for phase control and bi-directionally controlled thyristors	5SYA 2049
Voltage ratings of high-power semiconductors	5SYA 2051
Switching losses for phase control and bi-directionally controlled thyristors	5SYA 2055
Parameter selection of high-power semiconductor for series and parallel connection	5SYA 2091
Surge currents for phase control thyristors	5SYA 2102

IGCTs

Document title	Document number
Applying IGCT gate units	5SYA 2031
Applying IGCTs	5SYA 2032
Mechanical clamping of press-pack high-power semiconductors	5SYA 2036
Failure rates of IGCTs due to cosmic rays	5SYA 2046
Field measurements on high-power press-pack semiconductors	5SYA 2048
Voltage ratings of high-power semiconductors	5SYA 2051

GTOs

Document title	Document number
Mechanical clamping of press-pack high-power semiconductors	5SYA 2036
Field measurements on high-power press-pack semiconductors	5SYA 2048
Voltage ratings of high-power semiconductors	5SYA 2051

Environmental specifications

Document title	Document number
Storage of diodes, PCTs, GTOs	5SZK 9104
Transport of diodes, PCTs and GTOs	5SZK 9105
Operation of pressure contact IGCTs	5SZK 9107
Storage of IGCTs	5SZK 9109
Transport of IGCTs	5SZK 9110
Storage of HiPaks	5SZK 9111
Transport of HiPaks	5SZK 9112
Operation of industry HiPaks	5SZK 9113
Handling, packing and storage conditions for sawn wafer dies and bare dies	5SZK 9114
Operation of industry press-pack diodes, PCTs and GTOs	5SZK 9115
Operation of traction press-pack diodes, PCTs and GTOs	5SZK 9116
Operation of traction HiPaks	5SZK 9120

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