Power semiconductors

Proven reliability and high quality for best performances
Over 100-years ago our journey into power electronics started in Switzerland with the production of mercury-arc rectifiers. Today, we offer one of the most diverse semiconductor offerings including thyristors, diodes, GTOs, IGCTs and IGBTs, manufactured at our Lenzburg, Switzerland and Prague, Czech Republic facilities.

Our advanced semiconductor technology has created almost unlimited control possibilities in HVDC transmission systems. We lie at the heart of traction converters driving high speed trains, metros and diesel-electric locomotives. And the many pumps, fans, roller tables, hoist and winches found throughout industry, rely on us. In future we are powering the next generation of e-vehicles enabling people to enjoy greener mobility.

For more technical information contact us or download/use the following from www.hitachiabb-powergrids.com/semiconductors:

• Product catalog
• Application notes
• Data sheets
• SEMIS – Online simulation tool
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RoadPak SiC e-mobility module

RoadPak is the first module for e-mobility applications in our proven portfolio of power semiconductors that takes full advantage of silicon carbide (SiC) technology.

The RoadPak modules feature an innovative housing to comply with automotive and e-mobility requirements.

Typical applications include:
- xEv Drive Train
- E-Bus
- E-Truck
- Charging stations
- Aux. Converters in Railway
- Marine
- Aviation

Power map
Thanks to its exceptional low stray inductance (<6nH), the RoadPak is the ideal package to demonstrate the performance of high-power SiC. Hitachi ABB Power Grids offers in addition optimized gate units for RoadPak as well as a cooler for 3 RoadPaks in 3-phase-inverters configuration for any water / glycol mixture. Our RoadPak modules feature lowest switching losses, highest performance and excellent robustness.

<table>
<thead>
<tr>
<th>Features</th>
<th>Customer value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC chipset</td>
<td>Highest switching frequencies with lowest losses, lowest size and highest current density</td>
</tr>
<tr>
<td>Sintered die-attach</td>
<td>Best thermal as well as best power cycling behaviour</td>
</tr>
<tr>
<td>Copper bond wires</td>
<td></td>
</tr>
<tr>
<td>Pin-Fin structure</td>
<td>Best cooling performance while using cooling liquids</td>
</tr>
<tr>
<td>Ultrasonic welded main and aux.</td>
<td>Robust and reliable connections</td>
</tr>
<tr>
<td>contacts</td>
<td></td>
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<tr>
<td>High temperature encapsulation</td>
<td>Protection against humidity</td>
</tr>
<tr>
<td>molding</td>
<td></td>
</tr>
</tbody>
</table>
IGBT and diode chips

Hitachi ABB Power Grids’ range of SPT+ and SPT++ (soft punch through) and TFP (Trench Fine Pattern) 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.
2. IGBT and diode chips

Hitachi ABB Power Grids’ IGBT and diode chips with soft punch through (SPT) planar technology, feature the highest switching performance, ruggedness and reliability.

Hitachi ABB Power Grids 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, Hitachi ABB Power Grids 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 Planar 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 $V_{CESAT}$ of half a volt was possible.

The Trench IGBT

Starting 2021 we will also offer IGBT chips based on a Trench Fine Pattern (TFP) technology. They build on the N-enhancement technology that we mastered with the SPT++ chips and add a very compact fine patterned trench cell to further improve the conduction and switching losses by more than 30 percent compared to the SPT++ technology.
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.

![On-state curves of the 150 A 1700 V SPT++ IGBT](image)

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.

![IGBT turn-off](image)

**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 diodes.

![Schematic cross-section of the diode](image)
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.

**Reliability**

Chipset reliability is confirmed using a combination of standard tests. These include HTRB (high temperature reverse bias), HTGB (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

Hitachi ABB Power Grids enhances its successful IGBT module range into the medium-power segment. Starting with the 62Pak and the LoPak1, Hitachi ABB Power Grids brings the proven high quality and reliability of the HiPak modules to the medium-power IGBT segment.

The medium-power IGBT offering includes:
- 1200 V LoPak1 dual/phase leg module, rated at 600, 900 A
- 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 medium-power IGBT modules include:
- Trench fine pattern TFP chipset for 1200 V
- Ultra low-loss and rugged SPT++ chipset for 1700 V
- Smooth switching SPT++ chipset for good EMC
- Cu baseplate for low thermal resistance
- Industry standard packages

Power map
3. 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

### Features

<table>
<thead>
<tr>
<th>Features</th>
<th>Customer value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacers for substrate solder, homogeneous solder thickness and less delamination.</td>
<td>Longer lifetime under cyclic loads (e.g. thermal cycles).</td>
</tr>
<tr>
<td>Pre-bowed and stamped baseplate, reduced gap and lower interface resistance.</td>
<td>Higher thermal utilization more power and longer lifetime.</td>
</tr>
<tr>
<td>Spacers for main terminal solder, homogeneous and thus stronger solder layer.</td>
<td>Longer lifetime under cyclic load and more robust against vibrations.</td>
</tr>
</tbody>
</table>

4. LoPak1 IGBT modules

The LoPak1 module is 100 percent mechanically compatible with the EconoDual™ type IGBT modules. Hitachi ABB Power Grids' LoPak1 sets a benchmark with full switching performance up to 175 °C.

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

### Features

<table>
<thead>
<tr>
<th>Features</th>
<th>Customer value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special treated Cu-baseplate, controlled bow and reduced airgap to heat sink.</td>
<td>Higher thermal utilization, more power, longer lifetime.</td>
</tr>
<tr>
<td>Spacers for substrate solder, homogeneous solder thickness and less delamination.</td>
<td>Longer lifetime under cyclic loads (e.g. thermal cycles).</td>
</tr>
<tr>
<td>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.</td>
<td>Simplified attachment of gate driver saves manufacturing costs. Higher reliability compared to solder connection.</td>
</tr>
<tr>
<td>Copper wire bonds for high current terminal and substrate inter-connects.</td>
<td>Lower connection, resistance/losses</td>
</tr>
</tbody>
</table>

Note: EconoDUAL™ is a registered trademark of Infineon Technologies AG, Germany.
LoPak TIM – Thermal Interface Material
Hitachi ABB Power Grids offers LoPak 1200 and 1700 V with an optional feature: the pre-applied Thermal Interface Material (TIM). The use of TIM improves the thermal conduction at the module baseplate/heat sink interface ensuring more stability over long-term operation.

Figure 1 below shows that heat generated by power losses during the operation of IGBT switches must be transported from the chip, through the module, to the heat sink to prevent the junction temperatures of the chips from rising beyond maximum allowable limits. The interface between the module baseplate and the heat sink can have the highest thermal resistance of all of the interfaces in that path, as seen in the chart below figure 1.

The amount of thermal material applied and its application pattern, however, significantly impact the thermal resistance of the interface. The TIM comes in a paste form and is applied using automatic stencil printing during module fabrication.

It remains solid at room temperature, reducing the potential for damage to the print pattern by accidental contact and making module handling and installation easier for the customer.

The pattern design of the TIM takes into account the locations of highest heat generation and the intentional baseplate bending of the module, while ensuring the best possible metal-to-metal contact is made between the module baseplate and the heat sink.

Comparison of thermal materials

<table>
<thead>
<tr>
<th>Appearance</th>
<th>Paste TIM Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>white or grey</td>
</tr>
<tr>
<td>Base material</td>
<td>silicone fluid with filler</td>
</tr>
<tr>
<td>Consistency @ room temperature</td>
<td>viscous</td>
</tr>
<tr>
<td>Thermal conductivity (W/(m*K))</td>
<td>0.8 – 3.0</td>
</tr>
</tbody>
</table>

Comparison of thermal materials
Heat conducting paste is applied manually using stencil printing, leading to high variability in the amount of material applied and non-uniformity of its application across the interface area. The paste also remains viscous after application.

Fig. 1 Heat flow pathway through module and layer contributions

Fig. 2 Base plate bottom surface with applied TIM
**Improved performance using TIM**

The better thermal stability of TIM compared to heat conductive pastes can be seen during power cycling, a standard test to simulate the degradation of the module over its lifetime by thermo-mechanical stress. The test was run for 9,400 cycles, in line with the JESD51-14 specification, using the maximum allowable junction temperature of 150 °C, with a total cycle time of 120 seconds ($t_{on} = t_{off} = 60$ s).

The results of this testing showed:

- A 7 percent improvement in the average thermal resistance for the entire pathway from the IGBT junctions to ambient when the TIM is used instead of heat conductive pastes
- An 11 percent improvement in the average thermal resistance from the case to ambient when the TIM is used instead of heat conductive pastes

<table>
<thead>
<tr>
<th>Thermal resistance, average over 9400 cycles (K/kW)</th>
<th>Paste</th>
<th>TIM</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction to ambient</td>
<td>114.75</td>
<td>106.66</td>
<td>7%</td>
</tr>
<tr>
<td>Case to ambient</td>
<td>73.92</td>
<td>65.93</td>
<td>11%</td>
</tr>
</tbody>
</table>

**Performance of TIM compared to heat conductive paste**

The impact of using the TIM rather than the heat conductive paste can be seen by looking at data from the test for the partial thermal resistance from the case to the heat sink (where the TIM is located) and for the entire path between the transistor junction and the heat sink. While the initial thermal conductivity of pre-applied TIM is comparable with the heat conductive paste, the modules using TIM show no increase in thermal resistance with cycling, while those using the heat conductive paste show increasing thermal resistance during the test.

**Fig. 3 Comparison of TIM and heat conductive paste stability**
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. Moreover, SiC LinPaks are offered as demonstrators for the highest required power and operational frequency.

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

HiPak, StakPak and LinPak
5. 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
We have 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.

<table>
<thead>
<tr>
<th>LinPaks</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlSiC / (Cu)</td>
<td>1700</td>
<td>2 x 1000</td>
</tr>
<tr>
<td>AlSiC</td>
<td>3300</td>
<td>2 x 450</td>
</tr>
</tbody>
</table>

* 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.

Using the very low stray inductance of the LinPak modules and the commutation circuit, the use of a novel semiconductor material, the Wide Band Gap (i.e. SiC) is now possible. We are offering demonstrators rated at 1700 V and 3300 V, in the range of 500 A up to 1800 A.
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:

1700 V LinPak turn-on switching curves

1700 V LinPak turn-off switching curves
6. 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 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+ chip-sets (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.

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.

HiPak IGBT modules

HiPak MOS cell

HiPak N-enhancement layer

HiPak Trench-gate

HiPak SPT buffer

Fig. 1 V_{CE, SAT} for different IGBT cell technologies on SPT silicon at 125 °C. (current density of SPT range, same E_off)

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, Hitachi ABB Power Grids offers a HiPak module with 1800 A nominal current.

The Hitachi ABB Power Grids 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:

\[ V_{ac} = 3600V, I_{ac} = 5500A, T_a = 150°C, I_s = 100kh, \eta = 4.70, n_{Cf} = 330n \]

The 6500 V and 4500 V SPT++ IGBTs serve 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 connection**

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).

**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.

**SPT++ technology for 6500 V and 4500 V**

For the highest 6500 V, Hitachi ABB Power Grids 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 at 6500 V and 1500 A at 4500 V rated IGBT modules. Like their predecessors, the 6500 V and 4500 V SPT++ designs offer 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.

\[ V_{ac} = 4500V, I_{ac} = 2500A, T_a = 150°C, I_s = 150kh, \eta = 150nkh, \eta_{Cf} = 220n \]

![Fig. 4 New redundant aluminum wire bond connection of gate and auxiliary emitter](image)
Wire bonding
The emitter side wire bonding parameters are improved and stitch-bonds (figure 5) being used. This results in an improvement of factor 4 in intermittent operating life (IOL) (target 2 Mcycles $T = 60 \, \text{K}$, $T_{j_{\text{max}}} = 150 \, ^\circ\text{C}$).

Smart power semiconductors
The conditions under which power modules operate can deviate significantly from those assumed in the data sheet or product specifications. Condition monitoring techniques, predominantly to monitor the junction temperature, $T_j$, have therefore been developed to ensure reliability.

More recently there has been a focus on the effects of humidity on semiconductor and converter reliability, particularly in applications such as rail traction systems, to address the risk of condensation triggering corrosion of metallic conductors, electrochemical migration, degradation of junction passivation and conductive anodic filament formation on PCBs. Many modern modules for the traction industry are now equipped with humidity sensing to detect potentially harmful condensation events occurring during operation. Figure 3 shows the Hitachi ABB Power Grids LinPak and HiPak modules equipped with a condition monitoring platform that includes humidity and temperature sensing, on-board memory and wireless communication.

The condition monitoring platform is divided into two parts: the measurement electronics (integrated into an IGBT module) and a data logger built into a converter for long-term data storage. The measurement electronics are powered by the gate drive.

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

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

Figure 1: Hitachi ABB Power Grids LinPak and HiPak modules equipped with a condition-monitoring platform that includes humidity and temperature sensing, on-board memory and wireless communication.
7. StakPak press-pack IGBT and BIGT modules

StakPak high-power IGBT and BIGT 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. This problem was solved 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.

BIGT StakPak
Additionally to the standard IGBT/ Diode choice, Hitachi ABB Power Grids is also offering StakPaks with Bi-mode Insulated Gate Transistor (BIGT). Besides offering a state of the art current density, the BIGT is improving reliability by reducing the temperature ripples and massively increases diode surge current capability.

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.

Hitachi ABB Power Grids 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, Hitachi ABB Power Grids 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 3: conventional technology) and chips contacted by individual springs (figure 4: StakPak technology).
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 Hitachi ABB Power Grids’ 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 6. 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 thyatron replacement

**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.
BiPolar power modules

Hitachi ABB Power Grids’ diode and thyristor modules feature industry standard housings and very low losses together with the highest operating temperatures. They provide the ultimate in reliability whether efficiently driving industrial motors, smoothly accelerating fans and pumps, or supply power to demanding applications.

Power map
8. 60Pak modules

After successfully launching IGBT medium power modules, Hitachi ABB Power Grids is introducing a BiPolar power module perfecting the art of ultimate reliability – the 60Pak.

The key benefits of the new 60Pak are highest performance, outstanding reliability and increased overload capability. All highest quality Hitachi ABB Power Grids’ assets wrapped in a standard industrial housing.

Features low voltage diode & thyristor modules
- Precious pressure contacts for high reliability
- Industry standard housing
- Insulated baseplate by AIN ceramic
- UL recognized
- Forward current up to 890 A

Typical diode applications
Uncontrolled line frequency bridge arm in medium voltage drives, input rectifiers in AC/AC converters and DC power supply for applications such as industrial and renewables.

Typical thyristor applications
AC motor soft starters and variable speed drives in applications such as industrial and renewables.

Portfolio outlook
The BiPolar thyristor and diode modules lineup will be expanded rapidly to different voltages and configurations in the coming years.

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Target ratings 60Pak

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Ampere (A)</th>
<th>Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>620</td>
<td>TT, DD, DT, TD</td>
</tr>
<tr>
<td>2200</td>
<td>890</td>
<td>DD</td>
</tr>
<tr>
<td>5000</td>
<td>650</td>
<td>DD</td>
</tr>
<tr>
<td>6000</td>
<td>480</td>
<td>DD</td>
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1 Product qualified

<table>
<thead>
<tr>
<th>Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD</td>
</tr>
<tr>
<td>Dio / Dio</td>
</tr>
<tr>
<td>TT</td>
</tr>
<tr>
<td>Thy / Thy</td>
</tr>
<tr>
<td>DT</td>
</tr>
<tr>
<td>Dio / Thy</td>
</tr>
<tr>
<td>TD</td>
</tr>
<tr>
<td>Thy / Dio</td>
</tr>
<tr>
<td>pc</td>
</tr>
<tr>
<td>Pressure contact</td>
</tr>
</tbody>
</table>

• In the coming years.
• Expanded rapidly to different voltages and configurations.
• Portfolio outlook
• AC motor soft starters and variable speed drives in applications such as industrial and renewables.
• Supply for applications such as industrial and renewables.

---
Diode press-packs

Hitachi ABB Power Grids’ range of press-pack diodes covers
- Fast recovery diodes from 4500 to 6000 V and 175 to 2620 A (GTO free-wheeling, IGBT and IGCT diodes)
- Standard rectifier and avalanche diodes from 1700 to 8500 V and 662 to 7385 A
- Welding diodes for medium and high frequencies from 200 to 400 V and 7110 to 13526 A.

Power maps
<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>8500</td>
<td>Standard rectifier</td>
</tr>
<tr>
<td>6000</td>
<td>Standard rectifier</td>
</tr>
<tr>
<td>5500</td>
<td>Standard rectifier</td>
</tr>
<tr>
<td>5000</td>
<td>Avalanche</td>
</tr>
<tr>
<td>4000</td>
<td>Standard rectifier</td>
</tr>
<tr>
<td>3800</td>
<td>Avalanche</td>
</tr>
<tr>
<td>3200</td>
<td>Avalanche</td>
</tr>
<tr>
<td>2800</td>
<td>Standard rectifier</td>
</tr>
<tr>
<td>2600</td>
<td>Avalanche</td>
</tr>
<tr>
<td>2400</td>
<td>Standard rectifier</td>
</tr>
<tr>
<td>2300</td>
<td>Avalanche</td>
</tr>
<tr>
<td>2000</td>
<td>Avalanche</td>
</tr>
<tr>
<td>1700</td>
<td>Avalanche</td>
</tr>
<tr>
<td>400</td>
<td>High-frequency welding</td>
</tr>
<tr>
<td>200</td>
<td>Medium-frequency welding</td>
</tr>
</tbody>
</table>

Rectifier and welding diodes
9. Fast recovery diodes

A wide range of fast recovery, low loss diodes such as 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, clamp, neutral-point clamping (NPC) and free-wheeling diodes (FWDs) often limit optimum equipment design.

Recognizing this and the growing trend to eliminate voltage snubbers on semiconductors, Hitachi ABB Power Grids 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.

Features
• Free-wheeling diodes
• Clamp diodes
• Snubbered types
• Unsnaubbered 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:
1. inductive commutation
whereby the active switch is considered «perfect»
(eg a thyristor) and an inductance determines \( di/dt \).

\[ \text{Category} \quad \text{Application} \quad \text{Snubber type} \quad \text{Commutation characteristics} \quad \text{Required diode characteristics} \]

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

**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 IGCTs, free-wheeling diodes, snubber diodes and clamp diodes operating from a 2.8 kV DC link, would require that the IGCTs 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».
Hitachi ABB Power Grids' reliable high-power rectifier diodes are first choice in many demanding applications in industry and traction.

We offer 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 8500 V
- High average forward current rating from 700 A to 7400 A
- Excellent surge current capabilities up to 121 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
11. Welding diodes

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 $\Delta T_{jc}$ 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.

Hitachi ABB Power Grids 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, Hitachi ABB Power Grids has gathered great experience in the utilization of diodes to reach optimal reliability and electrical performance. Hitachi ABB Power Grids' 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.

Fig.1 Achievable load cycling capability of welding diodes, as a function of diode's junction to heat sink temperature ($\Delta T_{jc}$).
Bypass and phase control thyristor press-packs

Hitachi ABB Power Grids offers a full range of thyristors including:
- Bypass thyristor with blocking voltage of 8400 V and long term short circuit mode.
- Phase control thyristors (PCTs), from 1800 to 8500 V and 340 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

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Bypass</th>
<th>Phase control</th>
<th>Bi-directional</th>
<th>Phase control</th>
<th>Bi-directional</th>
<th>Phase control</th>
<th>Bi-directional</th>
<th>Phase control</th>
</tr>
</thead>
<tbody>
<tr>
<td>8500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8400</td>
<td>• Bypass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7200</td>
<td></td>
<td></td>
<td></td>
<td>• Phase control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6500</td>
<td></td>
<td></td>
<td>• Bi-directional</td>
<td></td>
<td>• Phase control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5200</td>
<td></td>
<td></td>
<td>• Bi-directional</td>
<td></td>
<td>• Bi-directional</td>
<td>• Phase control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4200</td>
<td></td>
<td></td>
<td>• Bi-directional</td>
<td></td>
<td>• Bi-directional</td>
<td>• Phase control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2800</td>
<td></td>
<td></td>
<td></td>
<td>• Bi-directional</td>
<td></td>
<td>• Phase control</td>
<td>• Bi-directional</td>
<td></td>
</tr>
<tr>
<td>1800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Phase control</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bypass, phase control thyristors (PCT) and bi-directional controlled thyristors (BCT)
12. Bypass thyristor

The bypass thyristor is a new semiconductor device that offers three modes of operation:

- Normal operation: Device is blocked permanently.
- Protection mode: Device is irreversibly shorted by a surge current event (I_{thd} / I_{T}) triggered through the gate.
- SCFM mode: Continuous stable long-term short circuit mode.

The wafer design is based on an existing thyristor wafer type. The approach taken was to constrict the current to a small central portion of the wafer using a high-dose electron irradiation of the rest of the active area.

A typical application is short-circuiting faulty cells in a multilevel converter topology (MMC). Due to its special design, the thyristor housing will not rupture when passing currents up to, or exceeding, 363 kA or 217 MA-s. After a fault, the device operates as a stable short circuit for more than a year.
13. Phase control and bi-directionally controlled thyristors (PCT and BCT)

Hitachi ABB Power Grids’ 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.

With the introduction of 6” thyristor for HVDC applications, we offer today 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.

Hitachi ABB Power Grids’ PCT product range includes press-pack devices rated 1800 V to 8500 V and 340 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.

**Outlook**

Our next generation of industrial thyristor will improve device current performance significantly. The first product, a 6.5 kV device in N-housing with a 100 mm pole piece, offers a performance increase by more than 25% compared to actual device. The new thyristor uses leading Snowflake gate design structure and latest backend technology features.
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 $I_{\text{eam}}$ and $R_{\text{th}}$ are given for one «thyristor-half» of the device. $I_{\text{rms}}$ 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.

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 $V_{\text{DWM}}/V_{\text{VRM}}$ and to superimpose a narrow pulse of amplitude $V_{\text{DRM}}$, as shown in figure 3. 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 $V_{\text{DRM}}$ and $V_{\text{RRM}}$).

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 Hitachi ABB Power Grids’ high-voltage thyristors, $V_{\text{DWM}}/V_{\text{RRM}} > 4500$ V. In the data sheets, the level for $V_{\text{DWM}}/V_{\text{RRM}}$ 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».

<table>
<thead>
<tr>
<th>Application</th>
<th>Power level</th>
<th>Anticipated average volume improvement (%)</th>
<th>Anticipated average parts count reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-drive</td>
<td>800 kw</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>DC-drive</td>
<td>2000 kw</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Soft starter</td>
<td>250 kw</td>
<td>25%</td>
<td>20%</td>
</tr>
<tr>
<td>Soft starter</td>
<td>450 kw</td>
<td>30%</td>
<td>20%</td>
</tr>
<tr>
<td>SVC</td>
<td>50 MVar</td>
<td>35%</td>
<td>35%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Replacement of PCTs by BCTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>5STB 24Q2800</td>
</tr>
<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 24H2800</td>
</tr>
<tr>
<td>5STB 24N2800</td>
</tr>
<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 24H2800</td>
</tr>
<tr>
<td>5STB 18N4200</td>
</tr>
<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 18H4200</td>
</tr>
<tr>
<td>5STB 17N5200</td>
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<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 17H5200</td>
</tr>
<tr>
<td>5STB 13N6500</td>
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<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 12K6500</td>
</tr>
<tr>
<td>5STB 25U5200</td>
</tr>
<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 25L5200</td>
</tr>
<tr>
<td>5STB 18U6500</td>
</tr>
<tr>
<td>replaces two</td>
</tr>
<tr>
<td>5STP 18M6500</td>
</tr>
</tbody>
</table>

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 ($V \times I$) 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.

![Fig. 3 Voltage definitions for high voltage PCTs and BCTs.](image-url)
GTO and IGCT press-packs

Reverse conducting and asymmetric IGCTs are available from 4500 to 6500 V and 1800 to 5000 A. Asymmetric GTOs are also available rated 2500 or 4500 V and from 600 to 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)
14. 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 Hitachi ABB Power Grids GTOs are press-pack devices. They are pressed onto heat sinks, which also serve as electrical contacts to the power terminals. Hitachi ABB Power Grids 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. Fine pattern GTOs with buffer layer have exceptionally low on-state and dynamic losses and are optimized for fast switching.
Hitachi ABB Power Grids’ 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. IGCTs 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 converter operation with highest efficiency.

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.

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.hitachiabb-powergrids.com/semiconductors.

Applications
The integrated gate-commutated thyristor is the power-switching device of choice for demanding high-power applications such as:
- Off-shore wind power converters
- Medium voltage drives
- Marine drives
- Co-generation
- 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, more performance 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 Generation 3 or HPT “High power technology” devices. Improvements have been done at gate contact infrastructure, what was moved to the device periphery. This measure improves the switching performance thanks to a lower gate circuit impedance. The latest family of IGCTs exhibit up to 30 percent higher turn-off capability compared to previous generation devices.

By applying an outer gate ring structure, the use of a monolithic cathode side molly was possible. This allows for a more efficient and homogeneous wafer cooling on the cathode side compared to previous IGCT generation. By applying an asymmetric anode and cathode side pole piece the total thermal impedance was lowered. The result is a device with improved thermal performance and increased reliability (see fig. 3).

Demanding application with higher power rating, for instance off-shore wind, where the trend goes towards 15 MW, asks for higher voltage ratings. In addition cost pressure makes it necessary to cover wide application range by unified converter platforms. Use of scalable modules in voltage and power is essential to offer competitive solutions. A 10 kV device is the most cost effective and simplest way to increase the system voltage without adapting the well-known converter topology. Hitachi ABB Power Grids is currently developing a new technology platform consisting of 10 kV RC- and Asymmetric IGCT including a companion diode. The 10 kV IGCT platform will allow our customer to design a modular converter family, compact, highly reliable and cost optimized for the specific configuration and application.

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.

Fig. 3 Comparison of previous (left) with improved generation 3 design platform (right).
Test systems for high-power semiconductors

Hitachi ABB Power Grids designs, manufactures and offers CE compliant customized power semiconductor test systems.

Hitachi ABB Power Grids offers test systems for various environments like research & development, laboratory, production or failure analysis. Highest quality assurance, safe handling, as well as remote or on-site service capability are guaranteed.

**High-power semiconductor test systems**
Hitachi ABB Power Grids offers static and dynamic production test systems for most types of power semiconductor devices like diodes, PCTs, BCTs, GTOs, IGCTs and IGBTs. They 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.

**Parameters**
The Hitachi ABB Power Grids 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**
Our 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).
TEST SYSTEMS

BiPolar test systems 4.5 kV

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<th>GTO and diode static</th>
<th>GTO and diode dynamic</th>
<th>IGBT and diode dies static</th>
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<th>IGBT and diode modules static</th>
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<tr>
<td>Reverse recovery charge</td>
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<tr>
<td>Critical dv/dt</td>
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<td>Vcesat / Vpinch-off</td>
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<td>Turn-on / turn-off</td>
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Reliability test systems
- High temperature reverse bias
- Intermittent operating life
- Surge current

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

Product catalog, application notes and data sheets as well as SEMIS – semiconductor online simulation tool – are available at https://www.hitachiabb-powergrids.com/semiconductors.

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

### IGBT dies and modules

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### Diodes

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## IGCTs

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## GTOs

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## Environmental specifications

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