A tiny dot can change the world

High-Power Technology for IGCTs

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To improve performance, reduce the size and cost of power electronic systems and allow more flexibility in designing power-electronic applications, the development trend in high-power semiconductors is toward higher current and voltage ratings. The integrated gate-commutated thyristor (IGCT) is the unit with the highest power ratings, but due to its large geometry, is the most challenging to switch. ABB's new High-Power Technology (HPT) has paved the way to ratings of IGCTs that were impossible to reach before.

The integrated gate-commutated thyristor (IGCT) is a power semiconductor switch designed for use in power-electronics applications at the highest power levels. Thanks to its thyristor design inheritance, it can switch large amounts of electric power in one single component. Due to this capability, the IGCT has been used in medium-voltage drives, electric grid interties, static compensators (STATCOMs), solid-state breakers, and choppers.

When the IGCT was introduced in the 1990s as a hard-driven gate turn-off thyristor (GTO), its basic design still bore many resemblances to the standard GTO Factbox. The main difference was the switching mode – the hard drive – a means of turning off the thyristor exclusively in p-n-p transistor mode, like the IGBT.1)

Because the p-n-p switching is more homogeneous than the GTO's n-p-n-p, operation without protective "snubbers" and a design using low-loss silicon are possible. In the on-state, the IGCT behaves like a latched thyristor, which gives it very low on-state losses and a wide design window for tuning its properties to fit the application.

Extending the range for safe operation

The challenge of IGCT technology has always been to scale up its turn-off capability, described by its reverse bias safe operating area (RBSOA).2) In small-area IGCTs, RBSOA has been shown to exceed 1 MW/cm^2, well above the limit where other parameters, like losses and surge-current capability are more limiting. The larger the area gets, the lower the specific power-handling capability becomes. A reasonable approximation is that RBSOA scales with the square-root of the device area. The RBSOA of ABB's most current 4 inch diameter IGCT (5SHY 35L4510) has been specified to 3,500 A at 2.8 kV DC. With the state-of-the-art High Power Technology (HPT) described below, its specification increases to 5.5 kA – close to twice the old capability. The actual HPT capability exceeds 7 kA.

With the High-Power Technology IGCT, ABB introduces a new design feature – the corrugated p-base.

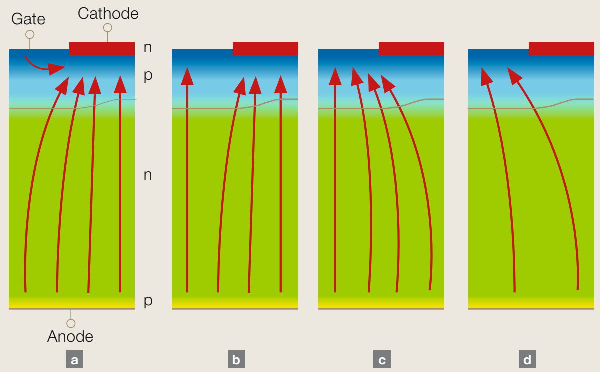
IGCT in operation

The rationale for the sub-linear scaling of RBSOA lies in the details of how the IGCT is turned off. The schematic layout of an IGCT consists of the main switching element, the GCT and the gate unit, which controls the bias of the p-n junction between the cathode (n) and gate (p) contacts. In the on-state, the gate unit provides a small forward current that keeps the thyristor latched 1. During turn-off, the gate unit reverse-biases the p-n junction by activating its turn-off channel (marked in red in 3). The turn-off channel is a low-inductive voltage source biased just below the reverse-blocking capability of the p-n junction. It forces the cathode current into the gate circuit at a rate governed by the stray impedance of the gate circuit (2 shows this current increase during t_{com}). The entire load current must be diverted from the cathode until the device functions as a p-n-p transistor.

In addition to handling the full anode currents, the gate unit has to complete the commutation in much less than 1μs. Once this time has elapsed, the IGCT starts to build up voltage (after completion of t_{com} and t_{desat} 2); it is essential for safe operation that the device now operates in the p-n-p transistor mode.

Looking at the IGCT as a discrete power device, there apparently is a macroscopic speed condition that must be fulfilled for safe operation: the hard-drive limit. This is the crossover point in the graph in 4. It is a characteristic of the GCT wafer because different wafer designs react at different speeds ($t_{com}+t_{desat}$), as well as of the gate unit (t_{com}) because of its stray impedance.

1 The current flow (red arrows) of an IGCT segment during different stages of turn-off. The phases (a-d) are indicated in 2.



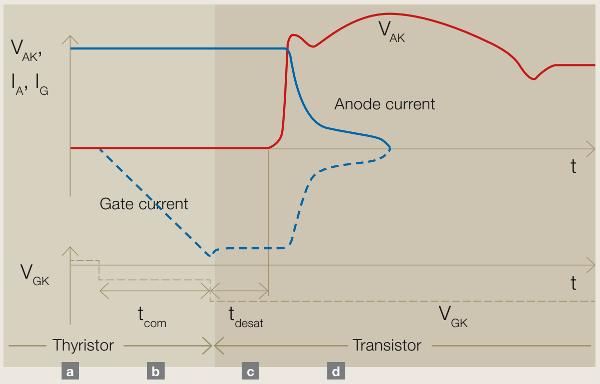
a On-state. The load current flows from anode to cathode, and the gate unit supplies a small gate current.

b The gate unit has initiated turn-off and starts to redirect the anode current to the gate.

c The gate commutation is finished; the entire load current now flows through the gate unit during t_{desat}.

d When the DC-link voltage is reached, the GCT current decreases to zero, which concludes turn-off.

2 Voltage, gate and anode current waveform during switching



Footnotes

1) For more on IGBTs, see "Performance-enhancing packaging" on page 9 and "Switching to higher performance" on page 19 of this issue of *ABB Review*.

2) A safe operating area (SOA) is defined as the voltage and current conditions over which a device can operate without self-damage. The RBSOA is the safe operating range when the device is turned off.

Challenges of the real device

Large-area devices are more challenging because the higher the current, the harder the demands regarding the gate-circuit stray impedance.

The title picture of this article shows the latest 5.5 kA GCT wafer with thousands of parallel GCT-segment connections, all of which need to be synchronously operated to avoid current redistribution. The segments are arranged in 10 segment rings on the wafer. The gate contact is ring-shaped and located between segment rings five and six.

Factbox GTOs

Normal thyristors can only be turned on but cannot be turned off. Thyristors are switched on by a gate signal, but even after the gate signal is removed, the thyristor remains in the on-state. A gate turn-off thyristor (GTO), on the other hand, can also be turned off by a gate signal of negative polarity.

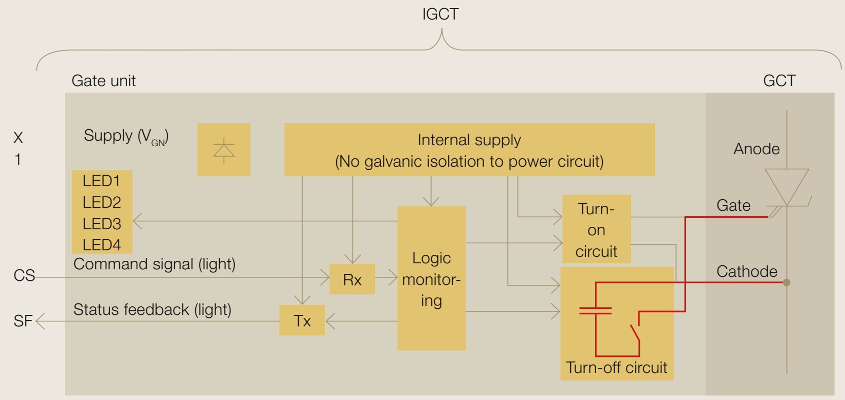
Turn-on is realized by a positive current pulse between the gate and cathode connections. To keep the GTO in on-status, a small positive gate current must be provided.

Turn-off is made by a negative voltage pulse between the gate and cathode. About one-third to one-fifth of the forward current is diverted, which induces a cathode-gate voltage and transfers the GTO into the blocking status. The turn-off phase takes some time until all charges are removed from the device. The maximum frequency for GTO application is thus restricted to about 1 kHz.

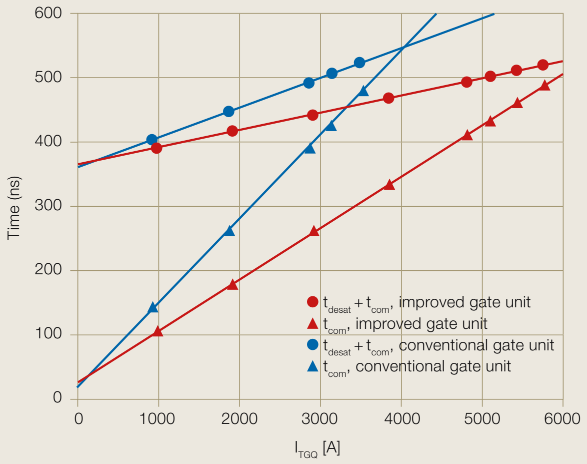
Unavoidably, these segment rings have slightly different impedances to the gate unit. A simulation of the wafer, housing and gate-unit geometry reveals the different stray inductance load of individual segment rings dependent on the ring number 5. This imbalance results only from the constraints on how the current flows from the wafer to the gate unit. Considering that the active area of a segment ring increases with the square of the ring number, the current is by far the largest in the outermost rings. Hence it is to be expected that the impact of this imbalance affects primarily the outermost rings. This is also confirmed by experiments – the vast majority of segment rings resulting in RBSOA failures are the outermost rings.

This inductance imbalance is a result of mechanical constraints in the IGCT package assembly. Subsequently, the GCT device will inevitably be subject to some current redistribution as the gate signal propagates over the wafer. This is the second reason why scaling up the area makes life tougher for the IGCT: The cells remotest from the gate contact become loaded with a higher stray inductance. The only antidote from a silicon-technology perspective is to make a wafer that shows less sensitivity to impedance imbalance.

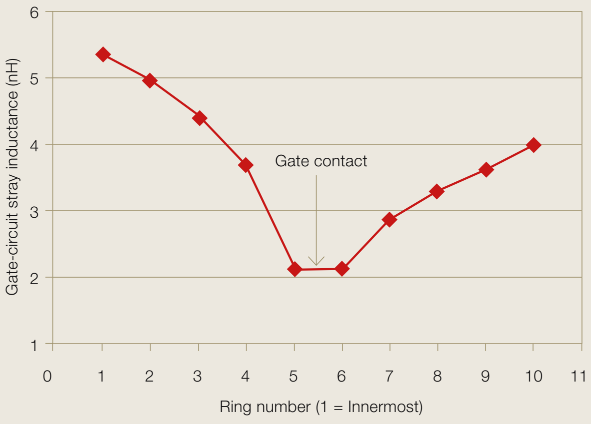
3 A schematic circuit diagram of the IGCT with the gate unit and its outside connections on the left, and the GCT power semiconductor on the right



4 The current dependence of t_{com} and $t_{com}+t_{desat}$ shown for the improved HPT technology (red) and conventional technology (blue)



5 The stray inductance of the individual segment rings on a GCT wafer as a function of their placement



With the HPT IGCT, ABB introduces a new design feature – the corrugated p-base. In 6, the main characteristics of this technology are sketched: In conventional technology, the p-base diffusion is homogeneous over the whole wafer. In HPT technology, the lower p-diffusion layer is masked underneath the cathode fingers. As a result, the p-base has a corrugated appearance. Together with the new gate unit, it has a substantial impact on RBSOA. It is breathtaking that such a tiny spot with reduced doping can in fact make this tremendous change.

The new capability…

The HPT technology is available in 4.5 kV and 6.5 kV asymmetric IGCT versions. 7 shows the new ABB design of an IGCT with HPT.

With HPT technology, the destruction limit of the IGCT has increased by 50 percent at 125 °C and by 80 percent at room temperature. The IGCT demonstrates a negative temperature coefficient of maximum controllable current, illustrating that the device is now limited in the same way as IGBTs 8.

With its new robustness, the HPT IGCT is also able to withstand switching self-clamping mode (SSCM), which is a harsh benchmark of ruggedness extensively described in connection with IGBTs over the last few years.

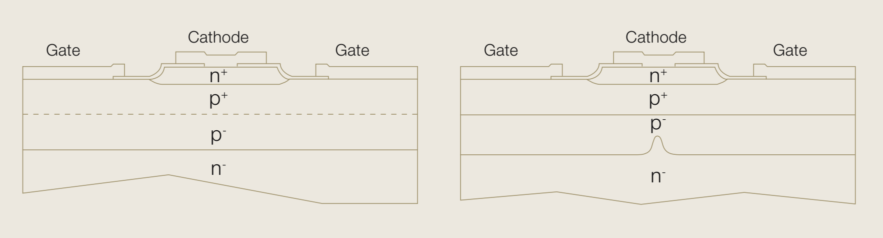
> The robust High-Power Technology IGCT is able to withstand switching self-clamping mode (SSCM), which is a harsh benchmark of ruggedness.

… and its future development

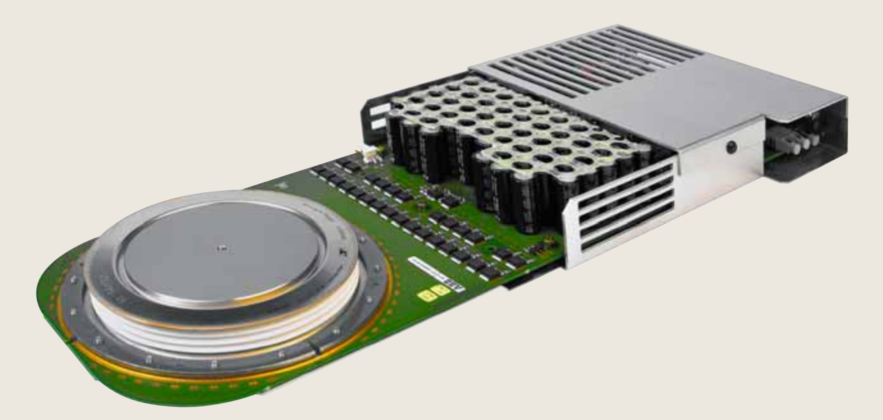
Apart from the immediate benefits mentioned above, this novel technology allows future expansions of the IGCT range:

- 10 kV IGCTs will have competitive turn-off current ratings comparable with today's ratings of 6 kV devices.
- In principle, HPT will allow for better homogeneity of the turn-off process over the diameter of the wafer.
- A further increase of the wafer diameter appears feasible.

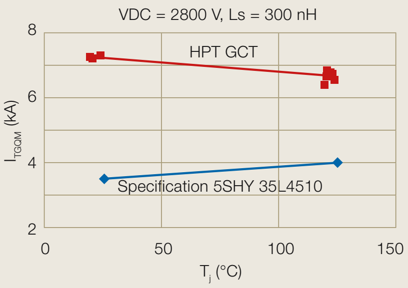
6 The structure and doping design of a conventional GCT cell (left), and the HPT technology with the corrugated p-base (right)



7 The new HPT IGCT from ABB, available in 4.5kV and 6.5kV variants



8 The maximum turn-off current of the HPT compared with the conventional IGCT specification



As only a conventional reference exists for 4.5 kV, these results are shown here.

Combining these advantages, it is highly possible that in the near future, larger IGCTs will be capable of switching more than 4 kA against DC voltages of more than 6 kV, enabling three-level 20 MW medium-voltage drives for 6 kV AC motors without any need for series or parallel connection.

At the other end of the application range, due to the enormous turn-off capability in combination with a potentially thyristor-like on-state voltage drop, additional possibilities arise for the use of IGCTs as wear-resistant static circuit breakers.

For more on ABB's IGCT and IGBT product offerings, see "Conducting business" on page 6 of this issue of *ABB Review*.

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