# ABB IGCTs: Benchmark performance with developments on many fronts

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## INTRODUCTION

The Integrated Gate-Commutated Thyristor (IGCT) was introduced about 15 years ago and has established itself as a preferred solution for a number of high power electronics applications. These applications have in common that the rated power level is in the megawatts (MW) and they range from industrial drives and track-side supplies to power quality and high-current breakers. In this article we highlight the features making the IGCT so attractive for high power applications and we discuss the developments that will further strengthen the IGCT's advantages in high power applications.

Figure 1 — The IGCT product family

## IGCT FEATURES

The IGCT design offers a number of outstanding features. Some of the product features, their impact on the equipment design and the resulting customer benefits are discussed in the following.

**Available as asymmetric and reverse conducting (with integrated diode)**

ABB offers two different types of IGCTs: the asymmetric and the reverse conducting (RC).
The asymmetric IGCT offers highest power levels. It is available as standard asymmetric IGCT and as the newer HPT-IGCT with improved turn-off capability. Applying asymmetric IGCTs allows choosing optimized free-wheel diodes as for instances ABBs new IGCT diodes as presented in Bodo's Power Systems, issue May 2012.
The RC-IGCT features a monolithically integrated free-wheel diode and therefore enables very compact stack designs. The RC-IGCT has been designed aiming for good performance in drive applications with moderate regeneration to the grid.

**Voltage ratings 4,500 up to 6,500 V with current ratings of 520 up to 5,000 A of peak turn-off current**

ABB's IGCTs are available with different voltage ratings. The 4,500 V and 5,500 V devices are perfectly well suited for 3-level inverters targeting the standard line voltages 3,300 V and 4,160 V (Table 1). The availability of different IGCT sizes allows drive manufacturers to offer inverter families covering a certain power range just by choosing the corresponding IGCT.

| Nominal line voltage | Nominal DC-link voltage for cosmic ray rating (V) | Preferred repetitive blocking voltage rating (V) |
|---|---|---|
| 2,300 $V_{RMS}$ | 1,900 | 3,300 |
| 3,300 $V_{DC}$ | 2,000 | 3,300 |
| 3,300 $V_{RMS}$ | 2,700 | 4,500 |
| 4,160 $V_{RMS}$ | 3,400 | 5,500 |
| 6,000 $V_{RMS}$ | 4,900 | 8,000 |
| 6,600 $V_{RMS}$ | 5,400 | 8,500 |
| 6,900 $V_{RMS}$ | 5,600 | 9,000 |
| 7,200 $V_{RMS}$ | 5,900 | 9,500 |

Table 1 — Preferred blocking voltage ratings for high power semiconductors used in 3-level voltage source inverters (VSIs).

Inverter output powers of up to 8 MW can be realized with 2-level inverters utilizing the large asymmetric 4.5 kV HPT-IGCT (91 millimeter wafer diameter) as shown in Figure 2. The flattening of the curves for the non-HPT devices towards lower frequencies is due to save operating area (SOA) limitations. 3-level inverters even achieve power levels that are about twice the power of 2-level inverters. Accordingly, converters rated 10 MW and beyond can be realized without the need of paralleling and/or series connection of devices.

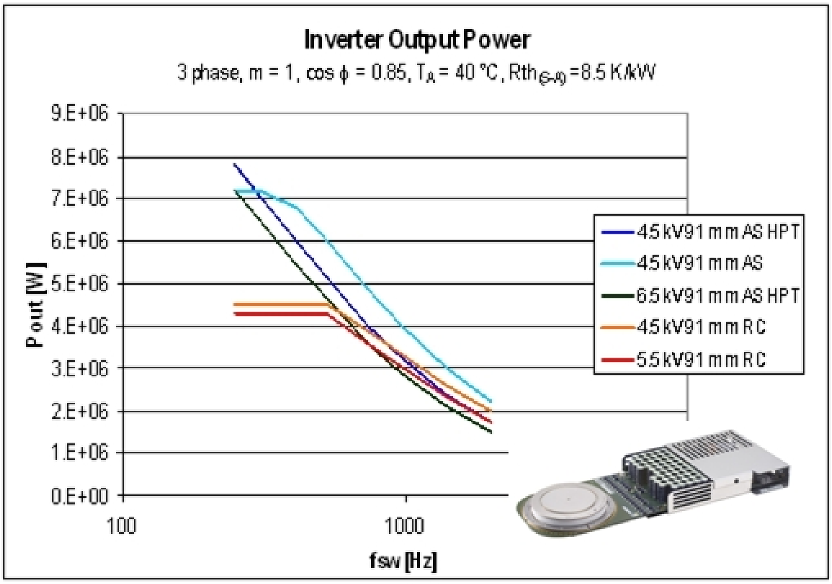


Figure 2 — Achievable output powers of a 2-level inverter using ABB IGCTs

**Integrated gate unit - critical to device performance**

The gate driving circuit, commonly called gate unit, is critical for the device performance and is therefore an integral part of the IGCT. There is no need to externally source a gate unit which even might compromise the device performance. The IGCT only needs a power supply and two optical fibers for the control and can be considered plug-and-play, although it may be a bit unusual to describe a MW-device in this way.

**Low on-state losses**

Due to its design the unirradiated IGCT has a very low on-state voltage drop and therefore very low on-state losses. This makes the IGCT very well suited for a number of static and hybrid breaker applications as well as an interesting alternative for high power multi-level converters. Traditional applications, however, require a trade-off between on-state losses and turn-off losses. The relationship between on-state and turn-off losses is determined by irradiation of the GCT wafer. ABB offers IGCTs with low on-state losses, with low turn-off losses as well as with a good trade-off between the two.

**Press-pack design for efficient double sided cooling**

The press-pack design of the IGCT has the advantage that the device can be mounted directly between two heat-sinks and therefore be efficiently cooled from both sides simultaneously. Further, there is no need for thick layers of thermal compounds thus allowing for very low thermal resistances in the cooling system. This directly translates into very high power densities for the assembly and reduces the space required for a converter of a given rating when compared with assemblies using isolated power components.

**Press-pack design for high load cycling capability**

The hermetically sealed press-pack design of the IGCT has proven its extraordinary load cycling capability and reliability in numerous applications for years in the field. Consisting of only a few layers of well-designed materials there are no issues with solder voids or bond lift-offs as apparent in other packaging technologies. Proper coatings and the used materials themselves assure that the mechanical wear of the device due to temperature excursions when operating at intermittent load are kept within reasonable limits. This makes the IGCT well suited also in applications with severe conditions as experienced in steel mills, mine hoists, marine drives and others.

# TECHNOLOGY OUTLOOK

To improve the IGCT performance in existing applications and to bring about further opportunities a number of developments are in progress. We will take a closer look at some of these development activities and see what the benefits of these new developments will be.

## Increased junction temperature

A possible way to increase the output power of an existing converter design is to increase the temperature rating of the used power semiconductors. For continuous operation the cooling system may set a limit for the additional losses that result from the increased temperature. For intermittent operation though, the temperature increase is a valid option. This since the increase in average power, and through that the requirements on the cooling system, is limited. Important is that the semiconductor can handle a high load for a limited amount of time and by this avoids to step up in converter size.
To achieve such a high load capability, a number of improvements to the HPT-IGCT are being implemented with a targeted operating temperature increase from 125 °C to 140 °C. In the silicon the corrugated p-base doping profiles introduced in the HPT-IGCT have been optimized to allow for full SOA exploitation over the whole temperature range from 0 °C to 140 °C. Further, also internal interfaces like the metallization on the wafer have been improved to achieve a higher thermo-mechanical wear resistance. These measures allow for the higher temperature excursions of the device under intermittent operation at 140 °C. The verification of these improvements has started and the first results look very promising.

## The reverse blocking IGCT

Certain AC applications and current source inverters (CSIs) require a switching device that is symmetrically blocking. Although this could be realized by using an asymmetric IGCT connected in series with a fast diode, the preferred solution is a symmetric IGCT. Since the performance requirements and some modes of operation of symmetric IGCTs considerably differ from asymmetric IGCTs, there is quite much learning needed for their realization. ABB has taken the challenge and realized the first symmetric IGCTs that are undergoing extensive testing. A new product lineup is planned with a voltage rating of 6,500 V, ideally suited for a 2,300 V line voltage as per table 2.

| Nominal line voltage | Nominal AC peak voltage for cosmic ray rating (V) | Preferred repetitive blocking voltage rating (V) |
|---|---|---|
| 2,300 $V_{RMS}$ | 3,700 | 6,500 |
| 3,300 $V_{RMS}$ | 5,400 | 9,000 |

Table 2 — Preferred blocking voltage ratings for high power semiconductors used in current source inverters (CSIs)

## The 150 mm IGCT

The quest for ever-growing power ratings makes the option of expanding into larger silicon diameters viable. The ABB HPT-technology's improved scalability combined with the advances in BiPolar technology towards larger silicon wafer sizes enables the design of devices beyond the standard 91 mm wafer sizes. Phase control thyristors with a wafer size of 150 millimeters have been around for some time and based on their manufacturing capabilities first 150 mm reverse conducting 4,500 V HPT-IGCT prototypes have recently been manufactured and a prototype with gate unit is shown in figure 3.

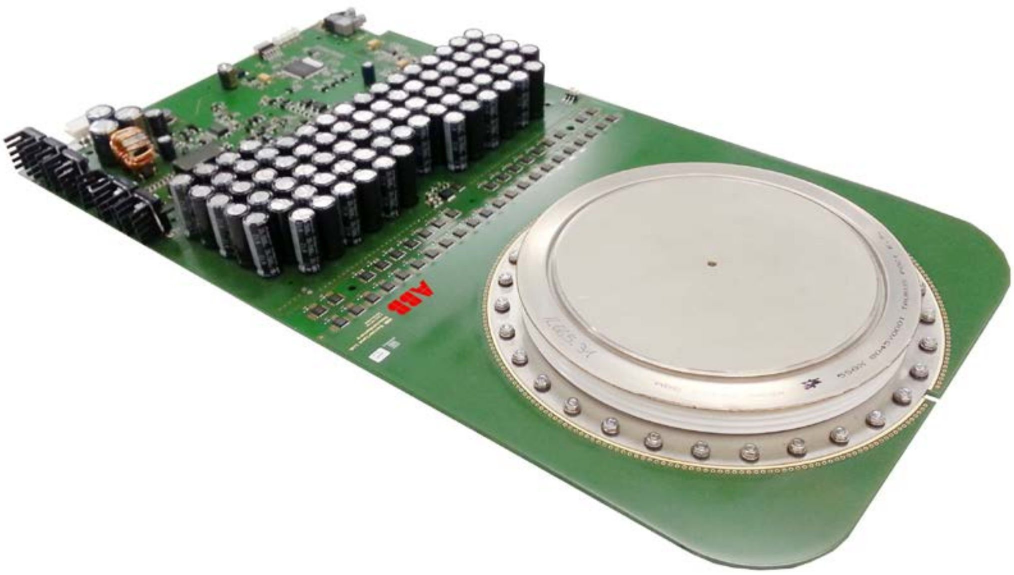


Figure 3 — 150mm 4,500 V RC-IGCT (Prototype)

First 4,500 V samples have been tested and show good turn-off capabilities (Figure 4) which gives a strong indication that the wafer, housing and gate unit have the targeted performance in respect to uniformity and absolute inductance.

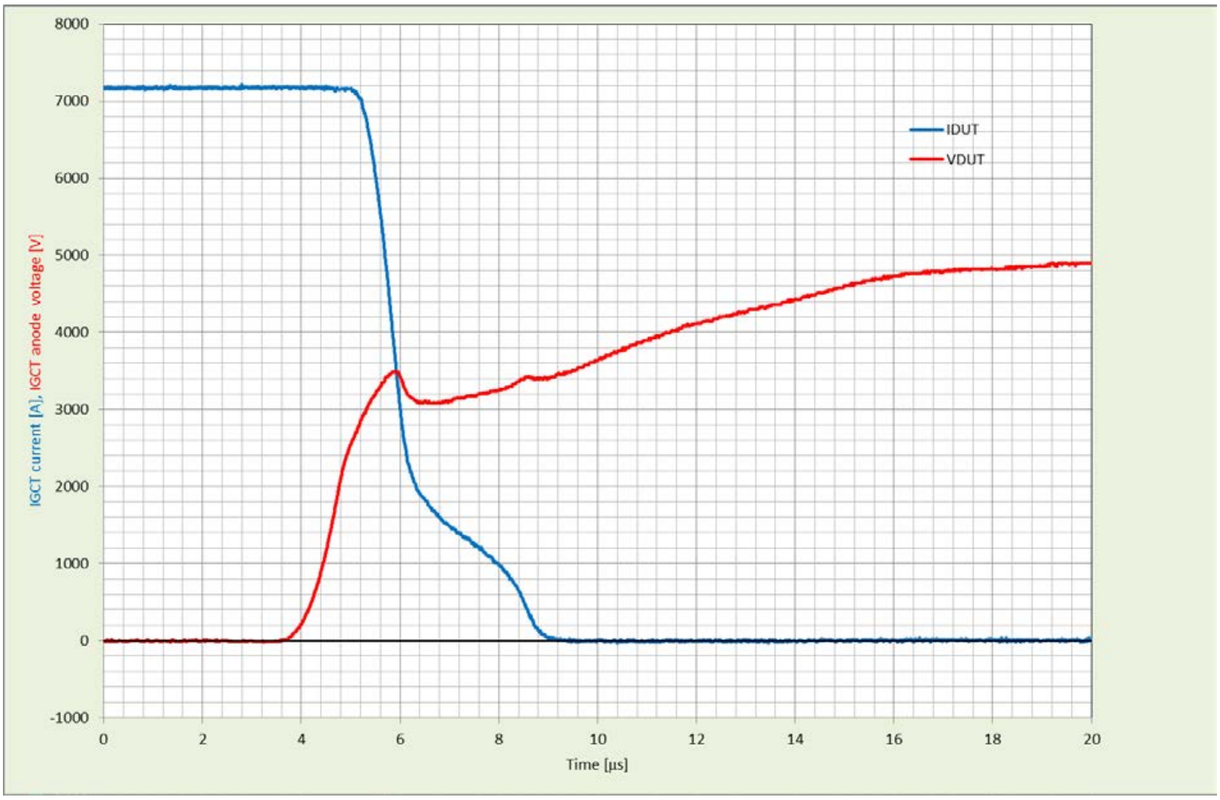


Figure 4 — Turn-off wave form for the 150 mm 4.5kV RC-IGCT at $I_T$ = 7.2 kA and $V_{DC}$ = 2.8 kV

With this RC-IGCT, it will be possible to realize 3-level inverters of up to about 20 MW without the need for series or parallel connection of power semiconductors. There is though still some work to be done before the device will be released. The final package design and the gate unit are still to be finished and the best IGCT versus diode area ratio to be determined. And finally, prior to sampling, extensive electrical and environmental qualifications lie ahead.

## The 1 V initiative

Today, there is a clear trend towards multi-level topologies in many power electronics applications. Multi-level converters are operating at fairly low switching frequencies but at the same time they require high current carrying capabilities and/or high efficiency. Due to the IGCT's inherent low conduction loss thyristor properties and the hard switched functionality the IGCT is predestined for such applications. Figure 5 shows how a 4,500 V, 91 mm IGCT can be tuned to different application requirements and compares with a corresponding state-of-the-art IGBT press-pack module.

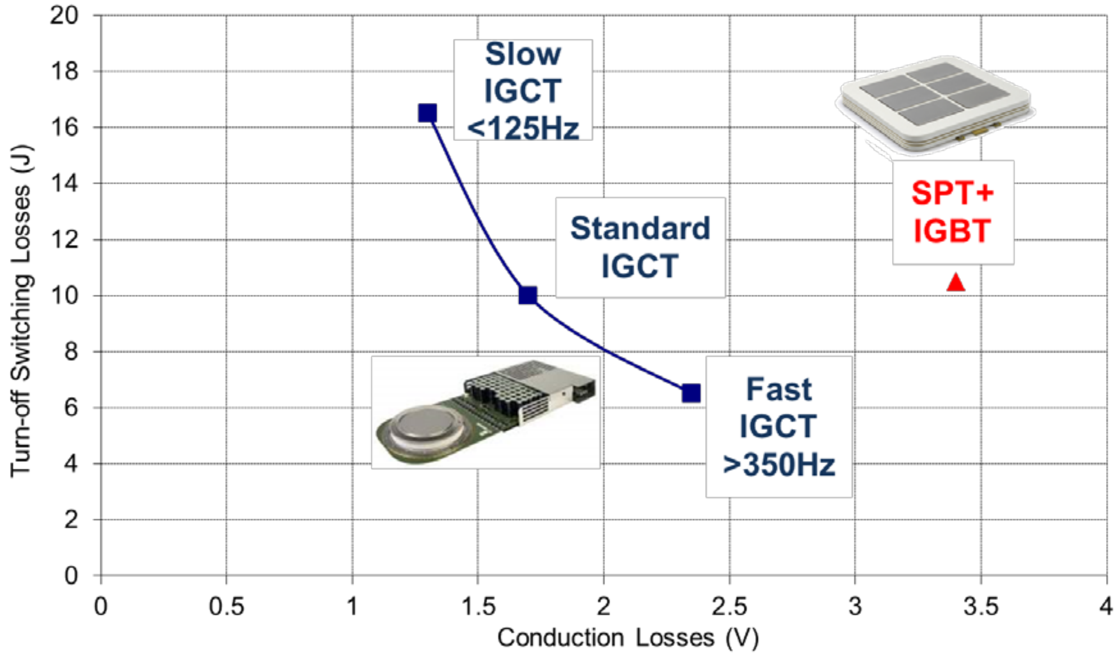


Figure 5 — Trade-off between conduction losses and turn-off losses for differently tuned 91 mm IGCTs compared with a press-pack IGBT module at $I_T$ = 2 kA, $V_{DC}$ = 2.8 kV, $T_j$ = 125 °C.

Since there is a certain amount of freedom in selecting the device voltage for a multilevel system a number of simulations and experiments have been performed to see what performance can be achieved with the goal of approaching an on-state voltage drop of 1 V. The results are summarized in figure 6 and show designers how multi-level converters can be optimized with respect to minimum total inverter losses for a given topology, system voltage and current level.

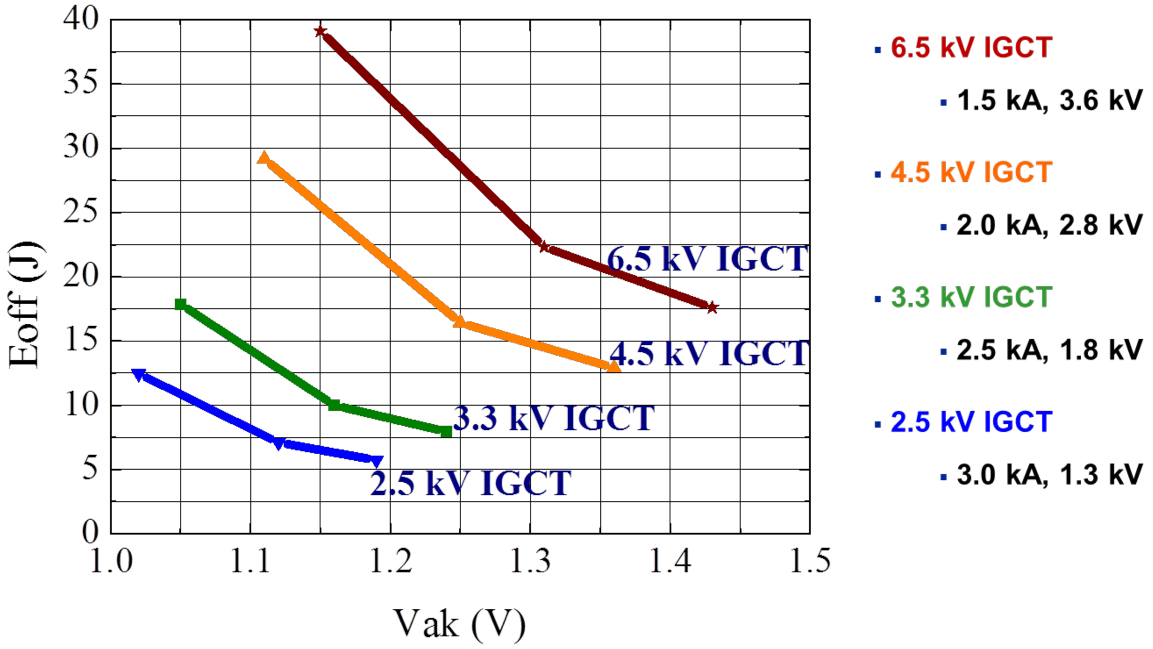

Figure 6 — Simulated technology curves for different IGCT voltage ratings approaching the 1 V on-state voltage drop goal.

## Increased voltage ratings

From table 1 it can be seen that 3-level inverters for line voltages of 6 to 7.2 kV without series connected IGCTs would be possible if IGCT voltage ratings of up to 10 kV were available.

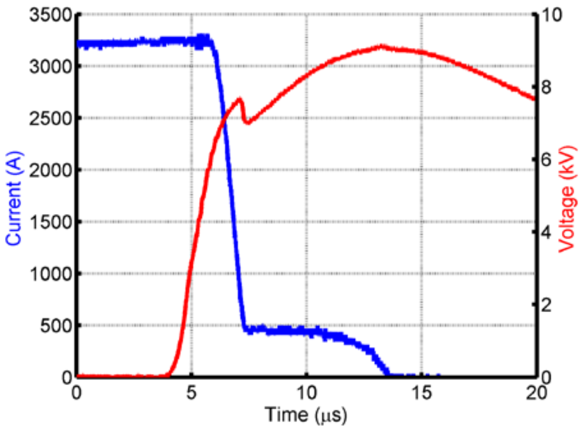

Figure 7 — Turn-off wave form of a 91 mm 10 kV asymmetric IGCT at $I_T$ = 3.3 kA and $V_{DC}$ = 6 kV.

A 10 kV IGCT prototype has been produced to prove that IGCTs with higher voltage ratings are possible and its turn-off wave form is shown in figure 7. Since the high blocking voltage requires quite thick silicon which translates into fairly high switching and conduction losses, these devices target applications as drives for machines with moderate speeds.