High Power IGCT Switches - State-Of-The-Art and Future

Today, ABB's IGCTs (Integrated Gate-Commutated Thyristors) present the best option for medium voltage drives operating at the highest power levels. Combined with optimum switch-off conditions during operation, the switch offers excellent reliability in demanding conditions. Here, we introduce ABB's latest generation of IGCT technology and provide an outlook into product development of IGCTs of the future.

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In Figure 1 the maximum average on-state current rating per device vs. blocking voltage for various ABB high power semiconductor devices is shown. Phase controlled thyristors (PCTs) have the highest power rating of any device, making them an excellent choice for power electronics for large LCI drives or large HVDC transmission valves. The PCTs are available in sizes up to 6", thereby supporting much higher current levels. Industry standard large IGBT modules have slightly lower ratings than press-pack Bipolar IGCTs. This is basically because of two things. First, they have IGBT chips of a maximum size of 14mm x 14mm parallel coupled to achieve the highest possible current rating. Secondly, the switch has integrated free-wheeling diodes in the package making it a complete switch. The largest switch for a 4.5kV IGBT module is 2kA in a special press-pack design (StakPak™). Usually, IGBT HiPak™ modules are the preferred choice for traction converters, and when paralleling the HiPak™ modules it is possible to make power electronics based on IGBT modules for controlling also large AC motor drives for industrial applications.

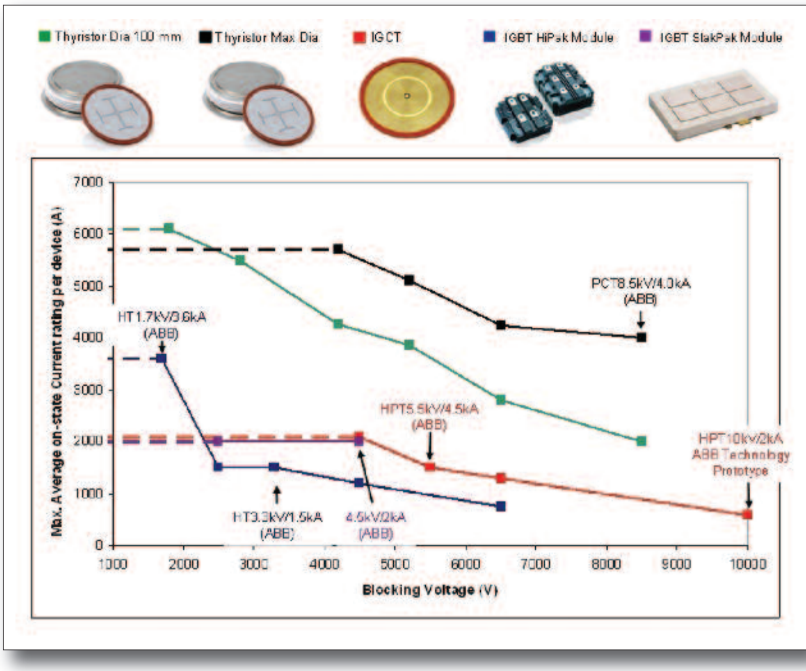

Figure 1: Maximum average on-state current for different device technologies as function of the voltage rating

IGCTs in application

The IGCT is an invention that has made compact and reliable medium voltage drives for the heavy industry possible. Applications range from steel mills and marine drives to trackside power supply systems for traction. For upcoming markets utilizing renewable energy and the need, for instance, to connect generated wind power into the power grid, ABB has developed a flexible medium voltage converter platform called PCS 6000 Wind.

The PCS 6000 Wind, see Figure 2, is designed for wind turbines with conversion of the full generator power, thus decoupling the generator side from the grid side through an intermediate DC link which gives an independent control of the grid side to enable compliance with existing and expected grid codes. The converter consists of two identical 3-level inverter units equipped with large-area asymmetric IGCTs. The selected topology and power semiconductors in the system allow for a power rating of 9MVA without the need of series and/or parallel connection of power semiconductor devices keeping the part count to a minimum. The low part count exhibits a lower estimated failure rate compared with other solutions at this power level. The

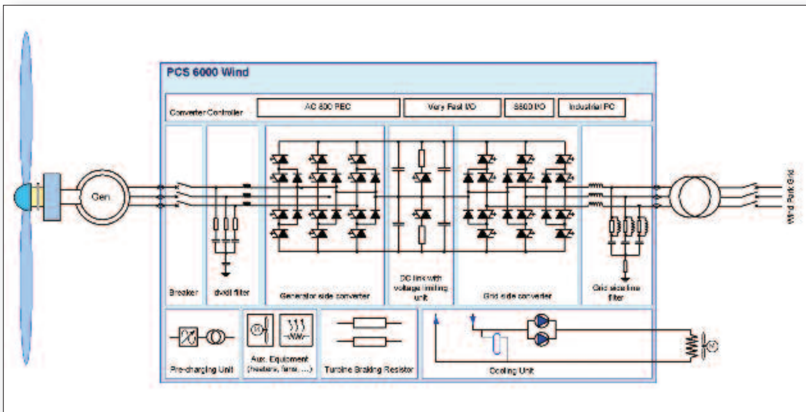

Figure 2: Block diagram for PCS6009 wind, a 3-level converter for wind applications using IGCTs

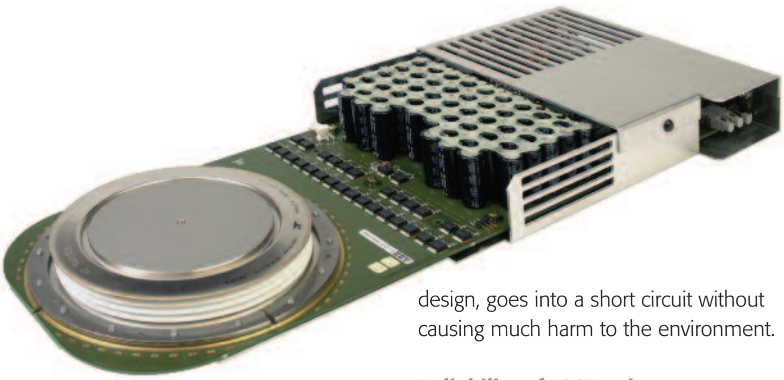

Figure 3: IGCT 5SHY 55L4500 rated 5000A/4500V

development in the IGCT technology will, in the coming years, allow a further increase in the converter power rating well beyond 10MVA without the need for changed converter footprint. Increased IGCT voltage ratings will also allow an increase in the operating voltage without changes in the basic topology of the converter. The platform has been in operation since the end of 2009 in wind turbines in the offshore test field Alpha-Ventus and additional wind turbines equipped with PCS 6000 Wind will be put into operation in 2011 [1].

Due to the integration of a low inductive gate unit, see Figure 3, the IGCT conducts like a thyristor (i.e. low on-state losses) and turns off like a transistor (i.e. hard switching) which means that it can, as an IGBT (Insulated Gate Bipolar Transistor), operate without a snubber making the circuitry very simple. The IGCT is available with turn-off current ratings between 520 and 5000A and with blocking voltage capabilities of 4500, 5500 and 6500V, all as asymmetric and reverse conducting devices where the latter has a free-wheel diode already integrated on the silicon wafer.

The press pack design of the IGCT, where the wafer is pressed between molybdenum plates, has an advantage in power cycling compared with devices with internal bonding and soldering, which also may impact of the overall reliability of the converter given any mission profile for the application. The field experience we have gathered shows that during a device failure, the IGCT, due to its press pack design, goes into a short circuit without causing much harm to the environment.

Reliability of IGCT units

A concern when comparing ICGTs with IGBTs is the reliability of the fairly large IGCT gate unit. Actually, the circuitry is simple but requires a certain amount of capacitor energy to clear the gate. Especially the electrolytic capacitors on the IGCT gate unit have been designed for reliability and have been selected carefully with considerations made regarding aging. Our experience shows that the gate unit reliability is well within an acceptable range. How competitive this reliability is towards the IGBT gate units is difficult to say, due to the absence of published field data for gate units for devices in a power range close to the IGCT.

When comparing power semiconductor devices such as IGCTs and IGBTs, it must be considered that the IGCT has an integrated gate unit compared with high power IGBT modules that work with a separate gate unit. On the other hand, certain IGCTs need a separate free-wheel diode that most IGBT modules have integrated within the same package. Consequently, to make a good comparison the IGCT with a free-wheel diode must be compared with an IGBT module with its gate drive.

The reliability of a power semiconductor device is determined largely during the design phase of both the device as well as the equipment where it is to be used. Three of the major failure causes are well documented and are considered in the converter design. These concern the selection of the device voltage rating for a given output voltage and the connected stray inductance to ensure that the over-voltage peak during turn-off is within the device capability. Thirdly, the failure rates due to cosmic rays are documented and considered. Most crucial is the thermal design since both the maximum allowed junction temperature of the device must be considered as well as the thermal fatigue through load cycling that can lead to a low life time if not considered in the design. Other failures result from field operation, mainly of transient character, and therefore the estimated field failure rate will be the sum of the probability of the different failure effects at the expected operation conditions.

Despite the uncertainty concerning the above mentioned failures, an estimation of the reliability of a well-designed 8MVA inverter unit can be made according to the selection of the different high power semiconductor devices that come into question for a wind turbine converter and the result is presented in Table 1. For comparison, the 3-level inverter topology such as PCS 6000 Wind is used and compared with a GTO as well as an IGBT solution using standard high power modules with base plate 190*140 mm by ABB referred to as HiPak. The estimation is based on ABB's experience as manufacturer of all three device types, although much of this experience has been gained from applications other than wind turbines.

In calculation, the common reliability term FIT = Failure In Time is used where one FIT corresponds to one failure in 109 hours of operation. This term is only applicable for the steady state failure rate excluding early failures, often referred to as infant mortality failures. To evaluate fatigue failures due to load cycling, detailed knowledge of the load profiles is needed. Since not much data concerning load and mission profiles for wind turbines exists, experience from applications such as rolling stock (traction) and large steel mill drives must be considered, especially because they often have more severe load-cycling stress.

The difference between the IGCT and IGBT mainly comes from the power levels of available high power semiconductors. To reach the same power levels as with IGCTs, the IGBT modules need to be parallel connected, thus increasing the number of devices by a factor of 2. For the same topology with the same number of devices, the difference in expected long-

8 MVA Inverter Type	Switch	FW Diode	Gate Driver	N° of Parallel Devices	Equivalent NPC Diode per position	Equivalent Clamp per position	Inverter Total (12 positions)	FIT Ratio to IGCT
	FIT	FIT	FIT		FIT	FIT	FIT	
IGCT	100	20	200	1	10	50	4'560	1
GTO	100	20	200	1	10	200	6'360	1.4
IGBT	250		150	2	50	0	10'800	2.4

Table 1: Expected long term reliability for an 8MVA, 3-level converter equipped with different device technologies

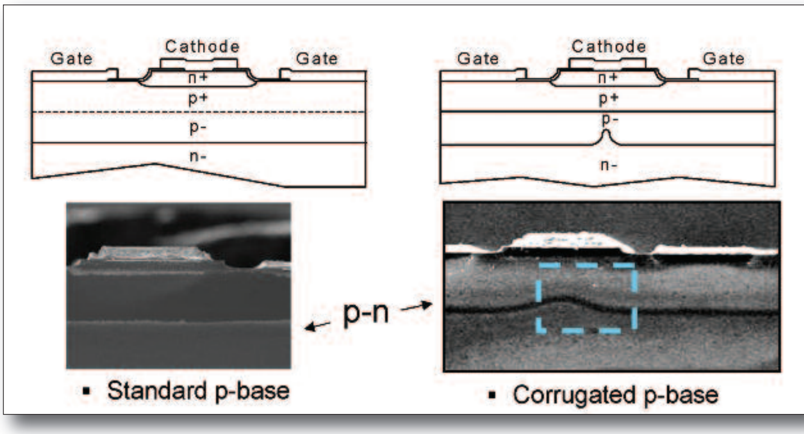

Figure 4: **Comparison standard p-base and corrugated p-base**

term reliability is, within the accuracy of the estimation, negligible. With no need for parallel or series connected semiconductors as required in some multilevel topologies. the part count of an IGCT converter is very low. The converter power can be increased by using larger IGCT modules, larger reactors and capacitors. The benefit being that the overall number of converter components and its FIT rates remains at the same low level.

Outlook into new IGCT products

Development programs within ABB are on-going to further improve the performance of the IGCT products to enable higher voltages for the common 3-level topology as well as to increase the power rating of existing voltage ratings. Introduction to the market in 2009 of IGCT products with the corrugated p-base technology, see Figure 4, has allowed for a 30% increase of the turn-off current without any mechanical changes to the power semiconductor housing. The corrugated base of the IGCT has been referred to as “High Power Technology” (HPT). ABB has developed a full IGCT range based on this technology for voltage classes between 4.5 kV and 10 kV.

ABB is now ready to introduce the next generation of IGCT with HPT technology. Called HPT+, the IGCTs have been further optimized towards higher SOAs at junction temperatures up to 140°C. In addition to the increased SOA, the turn-off losses have been further reduced and the maximum junction temperature has been increased from 125°C to 140°C. The highlights of the new HPT+ technology will be presented at PCIM [2]. The results of this new product development project give confidence that the rating of the PCS 6000 Wind converter, for instance, can be increased above 10 MVA by utilizing HPT+-IGCT devices without touching the converter footprint.

For future converters rated at 6kV using the basic 3-level topology and without any series connection, a new IGCT has been developed [3]. It uses the HPT technology and will only differ in the height of the ceramic housing, which needs to be higher than for the 4500V version due to creepage and clearance distances. The turn-off switching results show a robust device that can handle turn-off power peaks above 20MW, see Figure 5. The 10 kV IGCT is now in the ABB new product

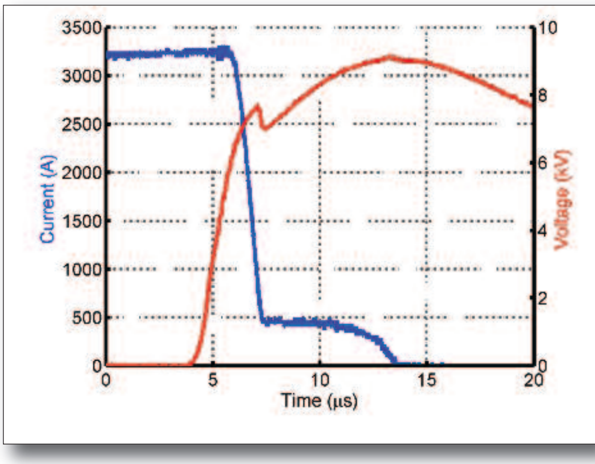

Figure 5: **Turn-off waveform for a 91mm 10kV HPT IGCT at V_{DC} = 6 kV, I_T = 3.2kA resulting in a peak power of 20.7MW**

Figure 6: Large area fast recovery diode with 85 mm pole piece

process phase and results are encouraging. The market echo supports the need for this particular device in new IGCT based converters.

High SOA IGCTs for state-of-the-art voltage source inverters have increased their current handling capability from around 3.5kA to over 5 kA at a 2.8kV DC link voltage with the introduction of the HPT/HPT+ technology. Since the HPT+ IGCTs have the potential to operate above 125°C, the complementary freewheeling and neutral point clamping diodes have to follow this trend, if placed into a common stack. This requires higher turn-off currents at the same di/dt and DC link voltage, and at higher temperatures. The placement of a diode into the common stack with IGCTs requires the same package size with an 85mm pole piece. The size of the accompanying diodes can be then close to 4" (>50 cm_) and the fast recovery diode (FRD) design has to cope with very large area scaling, see Figure 6.

ABB is introducing a new set of fast recovery diodes to the market. Available sizes cover the full range of needs to complement 3-level converter design in a large power range. The large sized diode has been tested at extreme conditions and shows very high RBSOA at elevated temperatures. As an example, rectangular RBSOA up to 7kA and 3.2kV at 140°C have been demonstrated for di/dt values in the range of 0.5 to 1.5kA/_s. The diode also shows sufficiently controlled switching (i.e. softness) for very high di/dt's up to 10kA/_s at a rectangular RBSOA up to 1.5 kA and 3.0 kV at 125°C [4].

The development of a new and proprietary switching element like the 10kV HPT IGCT is of little use if there are no accompanying fast recovery diodes which enable the utilization of the increased switching performance in the converter. In recent years, this has sometimes proven to be a more difficult task than increasing the capability of the switching element itself. A number of requirements, whose standard solution would require contradicting silicon design requirements, are set on the performance on the diode, as low losses and controlled, soft switching without snappiness. New solutions to some of these issues have been recently developed, which do not compromise other features, and they are being implemented into the design of an accompanying 10 kV fast recovery diode. For the earlier mentioned 10kV IGCT, a corresponding 10kV fast recovery diode for dual use as freeheel diode as well as NPC diode (Neutral Point Clamped) in the 3-level converter design is currently in development. A typical switching waveform for this diode can be seen in Figure 7.

Conclusion

ABB is committed to continuously improving and developing their IGCT switching platform. This is in support of existing and new applications featuring energy efficient solutions for industry and applications supporting power quality solutions. High industrial voltages levels up to 6 kV are supported by single switch IGCT solutions, while still being able to switch off large currents in a controllable way under low loss conditions in a single device.

ABB is also committed to improving and developing the fast recovery diodes needed to complement the converter design. The new generation of free recovery diodes will have low losses, high temperature operation and soft switching behaviour so that excessive voltage and current peaks in the device can be avoided during the switching periods of high MVA power.

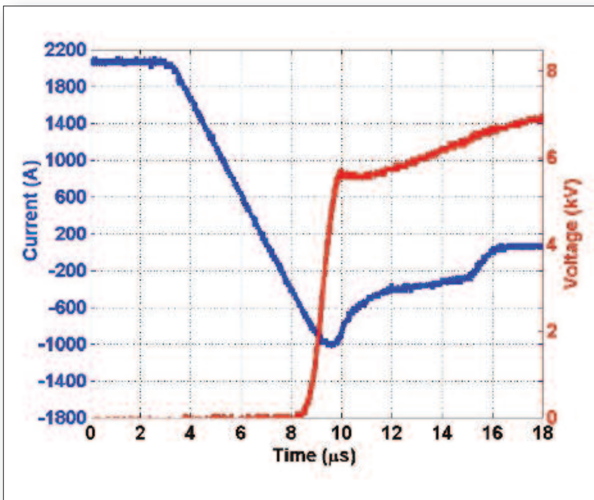

Figure 7 Soft reverse recovery waveforms for 91 mm FCE 10kV diode in nominal conditions (V_{DC} = 5.5kV, di/dt = 500A/µs, T_j = 125°C)

Literature

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