GvA Leistungselektronik GmbH
Boehringer Strasse 10-12
68307 Mannheim
Germany

Tel: +49 621 789 9212
Fax: +49 621 789 92 99
e-mail: w.bresch@gva-leistungselektronik.de

IGBT vs. IGCT, where does it lead?

The IGBT has become the ultimate power semiconductor switch in a broad spectrum of power ranges and in many applications. With collector current switching capabilities up to 2400 A and blocking voltage of 3300 V it is breaking into applications that were reserved for the GTO until now. New IGBT variations with collector currents up to 650 A and blocking voltages up to 6500 V have been announced for both module and disc cell housings. Is this the end for the GTO?

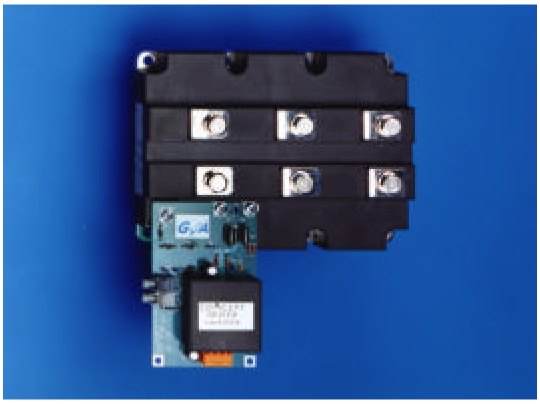
The technological answer, in classic bipolar technology, is the further developed IGCT, which evolved from the GTO. There are now reverse conducting and asymmetric blocking variants available in disc cell housings that have current switching capabilities of up to 4000 A and blocking voltages of up to 5500 V. New variations have been announced that are to have blocking voltages of up to 10 000 V, and that with symmetric blocking characteristics too.

The following article describes a comparison of these two completely different gate turn-off power semiconductor switches in a sample application for the end stage of a 1 MVA PWM inverter. The specific characteristics of both semiconductor switches will be examined, both in respect to their electrical as well as their mechanical aspects.

Comparison Base

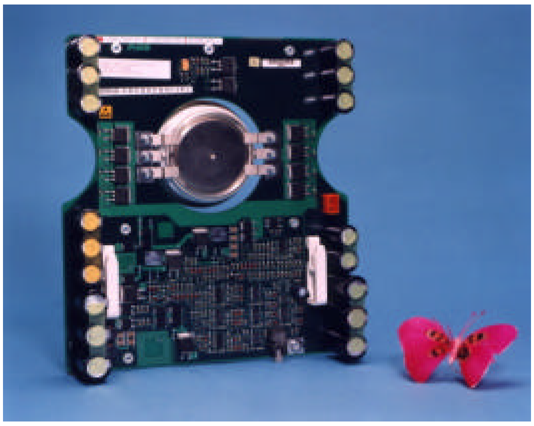
Beginning with the observation that the price for a power semiconductor, aside from wage expenses, housing costs and yield, is primarily dependent on the expanse of silicon surface area that is put to use, the power semiconductors to be compared will be selected on the basis of their thermal contact area. The thermal contact area permits a deduction to be made about the amount of silicon used.

For the IGBT, we will start with a component rated at 1200 A/3300 V that is packaged in module form. This is currently being offered by a number of manufacturers as a standard. The outside dimensions for thermal contact area is about 140 mm by 190 mm. This represents a thermal contact surface area of about 26 600 mm^2. This area is occupied by the silicon for the IGBT as well its anti-parallel freewheeling diode, which are arranged as a parallel configuration of many individual chips. Since these must be spaced away from one another, as well as away from the housing, the effective amount of silicon area used is about 70% of the total area, therefore about 18 500 mm^2.



Large IGBT Module with Driver Board

The comparable asymmetric IGCT is a 4000 A/4500 V component in a disc cell housing. The diameter of the thermal contact area is about 115 mm, the resulting calculated area is about 10 380 mm^2. The respective freewheeling diode is a separate 1000 A/4500 V component which is also in a disc cell housing. Its thermal contact area has a diameter of about 63 mm and the calculated area is then about 3010 mm^2. Therefore the total contact area for these components amounts to a silicon area of about 13 390 mm^2.



IGCT with Driver Board

Result Summary

IGBT active area, including freewheeling diode	IGCT active area, including freewheeling diode
about 18 500 mm^2	about 13 390 mm^2

This comparison also takes into account the system dependent peculiarities of the respective power semiconductors. In the case of the IGBT switch, it should be noted that it has the necessary freewheeling diode as an integrated element, with built-in internal electrical isolation, within its module housing. This means that a number of such modules, ideally all six needed to configure an inverter's end stage, can be mounted on a large-surfaced heat sink. All further observations are based on this assembly style.

The IGCT and its freewheeling diode are contained in two discretely separate disc cell housings. This permits each of these components to be fitted with two heat sinks. Since these components do not have any internal isolation (as was the case with the modules), the heat sinks must be electrically isolated from one another as well as isolated from ground. Here too, the remaining observations will be based on this style of assembly.

Establishing the Inverter's End Stage Performance

The electrical and thermal dimensioning is produced on the assumption of the following constraints:

inverter output power:	1000 kVA
inverter output current:	485 Aeff
inverter output voltage:	1200 Veff
inverter intermediate voltage:	1700 Vdc (limited by IGBT blocking voltage)
output frequency:	50 Hz
PWM frequency:	1000 Hz
ambient temperature:	35 °C
cooling:	forced air

Starting conditions and overload conditions will not be taken into consideration in the remaining observations. The inverter end stage is to be capable of 100% energy recovery.

Determining Dissipation Losses

Dissipation losses are determined on the basis of the conducting-state voltage drop as well as the on and off switch transition losses invoked by the respective power semiconductors employed.

The relative parameters are as follows:

IGBT		**IGBT freewheeling diode**	
Vcesat:	< 4.3 V at Ic=1200 A Tj=125 °C	Vf:	2.8 V at If=1200 A Tj=125 °C
Eon:	<2.88 Ws at Ic =1200 A Vcc=1800 V, Tj=125 °C		
Eoff:	<1.53 Ws at Ic=1200 A Vcc=1800 V, Tj=125 °C	Eoff:	1.5 Ws at If=1200 A Vr=1800 V, Tj=125 °C

All values are typical for the recommended gate resistance.

IGCT		**IGCT freewheeling diode**	
Vt:	< 2.7 V at It=4000 A Tj=115 °C	Vf:	4.2 V at If=3300 A Tj=125 °C
Eon:	<1 Ws at It =4000 A Vd=2800 V, Tj=115 °C		
Eoff:	<16 Ws at It=3500 A Vd=2800 V, Tj=115 °C	Eoff:	6 Ws at If=3300 A Vr=2800 V, Tj=125 °C

All values are limit values, an additional RCD snubber is necessary in the intermediate DC circuit.

Using the values given above, the following power losses result:

	IGBT	**IGBT-Diode**	**IGBT Switch**
Pt	767 W	350 W	1117 W

	IGCT	**IGCT-Diode**	**IGCT Switch**
Pt	330 W	301 W	631 W

Heat Sinks, Stray Inductance, Control, Circuitry

The figure for thermal transfer resistance, R_{thKA}, that is usually specified by heat sink manufacturers, assumes that the transfer of dissipated heat proceeds homogeneously across the entire contact surface between the heat source and the heat sink. However, IGBT modules that are mounted on a heat sink as proposed above, which has a width of 600 mm and a length of 800 mm (height 84 mm), represent heat sources that have spotty concentrations. Therefore, the IGBT modules must be spaced out across the large surfaced heat sink such that the lateral spread of the heat sink surface is optimally used in order to come as close as possible to the "ideal condition" for the homogeneous transfer of heat to be dissipated. But even so, the thermal transfer resistance specified for this heat sink R_{thKA} <0.01 K/W is extremely optimistic despite forced air cooling with an air speed of 6 m/s. Nevertheless, this optimistic value will be used in the following observations to assess IGBT junction temperatures.

The necessity to spread out the IGBT modules to achieve acceptable heat sink efficiency runs contrary to the need to keep stray inductances between "high and low side" IGBTs as small as possible. This aspect is improved by keeping the space between IGBT modules as small as possible so that turn-off voltage surges in normal and overload operation, but also for short-circuit current cutoff, are held within limits. This means that the mechanical layout can at best only represent a compromise between "heat sink efficiency" and "inherent stray inductance". In turn, this may mean increased overhead for driver circuitry which, in some circumstances, could result in the need for implementing two stage cutoff driver circuits or drivers with an "active clamp". The driver circuitry is not an integral part of the IGBT module and must therefore be developed by the user himself. The IGBT can be operated without individual RC(D) protective circuits.

IGBT Inverter 1,2MVA

The IGCT and its discrete IGCT diode are cooled on both sides with relatively small heat sinks. The heat transfer resistance figures applicable to these points, R_{thKA}, are based on the power dissipating transfer surface area which results from the dimensions of the disc cells. This is 0.027 K/W per heat sink half when a forced air speed of 2 m/s is used.

In contrast to the IGBT, the mechanical layout of an IGCT inverter end stage need not be designed for extreme minimization of stray inductances. A laminated multi-layer , that is imperative for the IGBT, is not necessary for the IGCT. However, the IGCT does need a di/dt limiting choke with an RCD clamp circuit in its intermediate DC circuit. The required minimum values for this can be obtained from the data sheets. The driver circuitry is integrated into the IGCT so a design effort is unnecessary for this aspect. Individual RCD protective circuits are also not necessary here.

IGCT Inverter 1MVA

Power Dissipation, Cooling, Chip Temperatures

Under the described circumstances, the following chip temperatures result for the IGBT module.

dissipation, IGBT:	767 W
dissipation, diode:	350 W
dissipation, module:	1117 W
dissipation on heat sink:	6702 W

R_{thjc} IGBT:	0.0085 K/W
R_{thjc} diode:	0.017 K/W
R_{thck} module:	0.004 K/W
R_{thKA} heat sink:	0.01 K/W at 6 m/s

	IGBT	IGBT diode
ambient temperature:	35 °C	35 °C
temperature rise, housing/heat sink:	4 °C	4 °C
temperature rise, chip/housing:	7 °C	6 °C
temperature rise, heat sink:	67 °C	67 °C
chip temperature:	113 °C	112 °C

Under the described circumstances, the following chip temperatures result for the IGCT and its discrete IGCT diode.

dissipation, IGCT:	330 W
dissipation, diode:	301 W
dissipation on heat sink for IGCT:	330 W
dissipation on heat sink for diode:	301 W

R_{thjc} IGCT:	0.012 K/W for double sided cooling
R_{thjc} diode:	0.012 K/W for double sided cooling
R_{thck} IGCT:	0.03 K/W for double sided cooling
R_{thck} diode:	0.02 K/W for double sided cooling
R_{thKA} heat sink:	0.0135 K/W for double sided cooling

	IGCT	IGCT diode
ambient temperature:	35 °C	35 °C
temperature rise, housing/heat sink:	4 °C	4 °C
temperature rise, chip/housing:	1 °C	1 °C
temperature rise, heat sink:	4 °C	4 °C
chip temperature:	44 °C	43 °C

The results show that an IGBT inverter end stage with an output power of 1 MVA, along with the other aforementioned conditions, is pretty well extended to its limits. The junction temperatures reached are 113 °C for the IGBT and 112 °C for its freewheeling diode. The maximum rated temperature listed for the component in its data sheets is 125 °C.

Under the same application conditions, the IGCT reaches a junction temperature of only 44 °C and its freewheeling diode just 43 °C. The maximum rated temperature listed in the data sheet for this component is 115 °C.

Cost Comparison

The following cost comparison is based on quotes for single units. No attempt was made to bargain for lower prices. Therefore this comparison can only be viewed as a rough estimate.

1 MVA IGBT Inverter End Stage Costs

Component	**Quantity**	**% of Total Cost**
IGBT	6	43
DC multi-layer	1	6
DC capacitors	1	23
large area heat sink, 600 mm by 800 mm	1	5
drivers, 6 each	1	3
power supply for the 6 drivers	1	3
fan	1	3
sheet metal set	1	3

small parts	1	3
assembly	1	8
expenses		100%

1 MVA IGCT Inverter End Stage Costs

Component	**Quantity**	**% of Total Cost**
IGCT	6	55
freewheeling diodes	6	13
DC capacitors	1	23
heat sinks	24	12
fan	1	7
brackets	12	5
clamping diode	1	1
heat sink for clamping diode	2	1
bracket for clamping diode	1	1
power supply for 6 drivers	1	6
clamp resistor	1	2
clamp capacitor	1	4
inductor	1	4
aluminum rack	1	13
small parts	1	7
wages	1	18
approximate expenses		172%

The IGCT inverter end stage is about 72% more expensive than the IGBT version in a comparison of the specific component configurations illustrated.

Extended Observations

The initially selected IGCT devices and their freewheeling diodes are substantially over dimensioned (from a thermal point of view) for an IGCT inverter end stage with an output rating of 1 MVA. If the IGCT and its respective freewheeling diodes are loaded such that their power capabilities are used to almost full capacity, based on a junction temperature of 95 °C (the maximum permissible junction temperature is 115 °C), then the IGCT inverter end stage could produce 4.7 MVA of output power. If one were to implement a 4.7 MVA inverter end stage with the components described for the 1 MVA IGBT variation, then one would need five such end stages and these would have to be interconnected in parallel. The cost for this (without output chokes) would increase by a factor of 5 to a total of 500%. The IGBT solution for inverter end stages, when compared to a 4.7 MVA IGCT unit, is about 2.9 times more expensive.

The inverse observation is that IGCT components that are better suited to the desired output rating of 1 MVA could be selected. For example, a reverse conducting type of IGCT rated for 1100 A/4500 V. This IGCT already has the necessary freewheeling diode integrated into it. The calculated junction temperature for an output power of 1 MVA would be about 93 °C.

The cost structure would then be more in line with that shown below:

1 MVA IGCT Inverter End Stage Costs

Component	**Quantity**	**% of Total Cost**
IGCT, reverse conducting	6	31
DC capacitors	1	23
heat sinks	12	6
fan	1	3
brackets	6	3
clamping diode	1	2
heat sink for clamping diode	2	1
bracket for clamping diode	1	1
power supply for 6 drivers	1	6
clamp resistor	1	2
clamp capacitor	1	4
inductor	1	4
aluminum rack	1	3
small parts	1	3
wages	1	7
expenses		99

With this set of components, the price difference between IGBT and IGCT solutions for an inverter end stage are practically nil.

Load Cycle Ruggedness

An IGBT module is a multi-layer structure consisting of a copper base, metalized isolation ceramic and the chip. These are mechanically connected with one another by solder layers. The chips are electrically interconnected with wire bonds. Such a construction has a naturally limited lifetime with respect to load changes. The anticipated life expectancy is heavily dependent on the extent of temperature variations and their cycle times. More detailed information about this is available from the manufacturer.

The IGCT is a pressure contacted component in a metal/ceramic housing. The individual elements used internally are thermally and electrically connected by pressure applied by an external clamping system. Cyclic warming, which is typical for fluctuating loads, causes the differing materials to glide on one another. Components which are constructed in this manner exhibit a significantly improved ability to cope with changing loads. More detailed information about this can also be provided by the manufacturer.

Housing Explosion

Fault currents which can no longer be handled by an IGBT module generally cause the wire bonds to detach from the chip metalization. A plasma formation builds up within the module. The module's housing then breaks due to the internal pressure. The plasma then escapes into the equipment in an explosion-like event.

The IGCT is mounted in a hermetically sealed metal/ceramic housing. Between the pressure contacts of individual elements, there is no opportunity for plasma to form during fault conditions. Therefore housing breaks do not occur in inverter circuits.

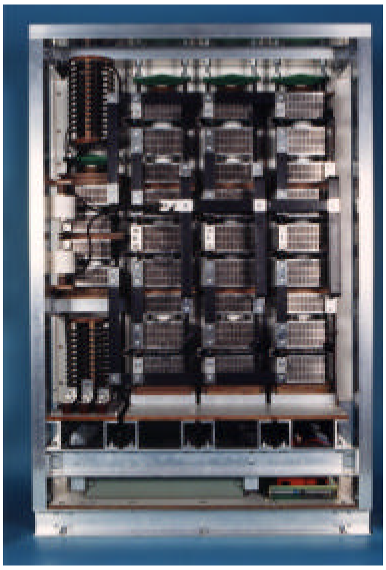
Dielectric Strength

IGBT modules exhibit an electrical isolation between chip and base plate. The dielectric test voltage is listed in the device's data sheet and, in the case of the 3300 V IGBT module, is stated as 6 kVeff. However, the values important for long-term reliability with regard to partial-discharge resistance are not provided. In particular, these include the partial-discharge inception voltage and the partial-discharge extinction voltage. In the case of the 3300 V IGBT module, the value for partial-discharge extinction voltage is about 2800 Veff. For 3-level inverter applications, this may be too low. In some cases then the modules must be mounted on individually isolated heat sinks. The primary advantage of these components, their internal module isolation, is thereby lost. The assemblies become more voluminous and this in turn leads to increased parasitic stray inductances with the effects that were described earlier.

The IGCT, in its disc cell housing, exhibits no internal isolation at all. The complete system must be externally isolated, along with its respective heat sinks. The dielectric strength, partial-discharge inception voltage, and partial-discharge extinction voltage, are all a function of the insulating materials used, the air gaps provided, and the leakage paths involved.

Summary

Economical inverter end stage designs based on the IGBT with forced air cooling can be economically realized up to about 1 MVA, with liquid cooling up to about 1.4MVA. For higher ratings, the IGBT must be arranged directly in parallel or entire inverter end stages must be wired in parallel. However, the design criteria for such solutions quickly run into expensive techniques, especially then when the operating voltages to be handled are also higher, as is typically the case for 3-level converters. Nonetheless, the IGBT is the more economical choice for standard applications of up to about 1 MVA.



IGCT 3 Level Inverter

Applications which require greater stability under fluctuating load conditions, or more intermediate circuit voltage than can be realized with the 3.3 kV IGBT, are ripe for an IGCT solution when the power requirement exceeds 500 kVA. This is true on a price comparison basis as well as on an engineering basis. The IGCT permits the construction of air-cooled solutions for 2-level inverter end stages up to about 5 MVA and 3-level inverter end stages up to about 10 MVA without a need to make parallel circuits. These performance ratings can be doubled when liquid cooling is used. Applying IGCTs to power ranges over about 1 MVA, or where there is a requirement for improved resistance to fluctuating loads, will result in more economical solutions.