IGCT Technology — A Quantum Leap for High-power Converters

Low losses, small size, reliable, modular and cost-effective — uncompromising implementation of IGCT technology creates medium-voltage converters with entirely new characteristics.

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From the very beginning, the development of power semiconductors was nothing more than a search for the ideal switch. The lowest on-state and commutation losses, the highest possible commutation frequency and a simple drive circuit were and still are what is needed in practice. From the transistor and Darlington to the IGBT, low-voltage applications have benefited all the way along while the medium-voltage user could only look on — GTO's and more GTO's, nothing else was in sight. Then at last, the IGBT's grew bigger … would they make the grade?

ABB Switzerland has explored a new avenue of development with the aim of exploiting the advantages of the IGBT for higher powers while retaining the strengths of the GTO as far as possible.

Thus the GCT (gate commutated thyristor) grew from the GTO — at first with an improved drive and a new gate connection and then with a new housing, new-technology wafer, monolithically integrated diodes, hybrid integrated drive, a much simplified power circuit and much more. We now find the potential of the new device to be so large that we are convinced we have found a worthy successor for the GTO.

The secret of the GCT

The key to success was in the GTO itself. More precisely, the only thing wrong with it was an enormous control problem. A typical turn-off response is shown in Fig. 1. Because of the demand for high turn-off amplification, the GTO passes through a region during the transition from the conducting (thyristor) to the non-conducting (transistor) states when both anode voltage and cathode current are impressed (red background). As with a mechanical switch, however, a four-layer device can only assume one of two stable states — on and off. The transition tends to instability and has to be got through as quickly as possible and be supported by snubber

Interdisciplinary development

Know-how from many disciplines is essential to develop high-power converters. This is where low-power electronics for the control circuit, silicone technology for the power semiconductors, metallurgy and ceramics for the hermetically sealed semiconductor housing, power electronics for the main circuit, conductors and cooling and mechanical engineering for the layout and construction all converge. The circuits of GTO converters are complex and a feature of their development is the many interfaces that were necessary.

IGCT megawatt converters of a piece

GCT's have a low-inductance drive circuit and for this reason conduct evenly. Poor compromises are eliminated, development and design become clearer and scalable, the ditches between the disciplines involved are bridged, R&D becomes coordinated — a converter of a piece is created.

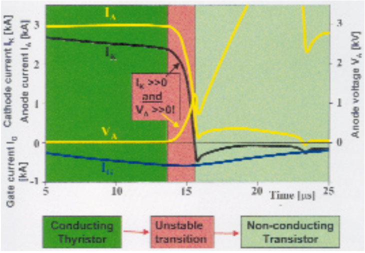

Fig. 1: Typical turn-off characterstic of a 4.5 kV, 3 kA, GTO

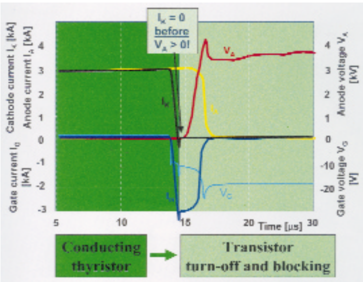

Fig. 2: Typical turn-off characterstic of a 4.5 kV, 3 kA, GTO

circuits. The basic principle of the GCT resolves these problems, because the device now has what is referred to as a hard drive (Fig. 2), i.e. instead of dIG/dt @ 50 A/µs, dIG/dt ≥ 3000 A/µs is applied to the gate. The current is thus switched from the cathode to the gate (hence the name GCT) before any appreciable change in the distribution of the charge between the gate and the anode can be observed. The conductivity and therefore the low anode voltage remain unchanged for as long as this charge (plasma) exists. The device thus changes directly from the thyristor to the transistor mode and turns off as a consequence just as stably, fast and without the help of a snubber circuit as an IGBT (insulated gate bipolar transistor).

1st. step towards an IGCT converter — a low-inductance drive

The rate-of-change of the drive is critical for the operation of the GCT. The cathode current has to be turned off in less than 1 µs, otherwise the device moves into the unstable part of the characteristic. This corresponds to dIG/dt ≥ 3000 A/µs for a 3 kA GCT and proportionally more or less for other types. The voltage needed results for a given inductance of the gate circuit, respectively the inductance for a given gate voltage.

On the other hand, a simple, reliable and cost-effective drive unit is only possible at low voltages. An ideal voltage is –20 V, because the gate can withstand this voltage after turn-off. The permissible leakage inductance for interrupting 3 kA is 6 nH or less which is only 1/50 of the usual value for a GTO. It was possible to achieve this value by adopting a coaxial configuration of the device connection and a multi-layer connection to the power output of the drive (Fig. 3).

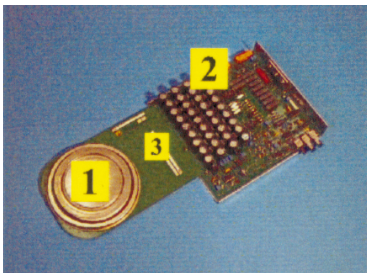

Fig. 3: 4.5 kV, 3 kA, IGCT (integrated gate commutated thyristor).
The GCT (1) and the gate unit (2) form a single part. The PCB (3) connects the GCT and the drive.

2nd. step towards an IGCT converter — optimum silicone technology

The so-called hard drive solves the GTO's drive problem. This actually also improves a standard GTO wafer and the GCT manufacturer no longer has to compromise when designing the wafer in order to obtain the desired switching characteristic. The GCT wafer can be much thinner than GTO wafer and this smoothes the way to the utilisation of plasma engineering techniques. GCT's generate for this reason much lower losses than GTO's (Fig. 4).

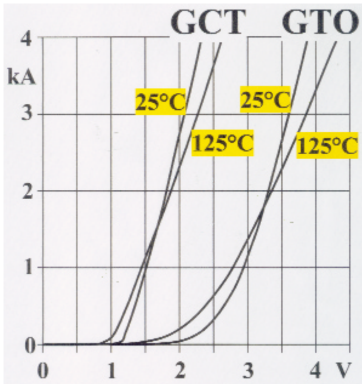

Fig. 4: A comparison between GTO 5SGA 40L4501 and GCT 5SGY 35L4502. The commutation losses of both devices are approximately the same.

3rd. step towards an IGCT converter — higher converter integration and linear sizing with current

IGCT technology applies two levels of integration: monolithic on the wafer and hybrid for the periphery of the GCT.

In many cases, the anti-parallel diodes can be integrated monolithically (Fig. 5). This eliminates the diode stack and associated heavy current connections.

Fig. 5: GCT (1) and diode (2) on the same wafer. The gate has its contact at the centre (3) on the 51 mm disc (6 kV, 520 A).

Integration of this kind only becomes impractical at the highest currents and the GCT and the diode have to remain separate.

Hybrid integration achieves a closer blending of GCT, drive unit and cooler (Fig. 6). The synergies of the mechanical construction produce advantages with respect to reduced size, greater stability and lower cost. The hard unambiguous drive achieves an overall even, smoother operation. Every segment of the wafer, of which a 3 kA unit has more than 2000, ”knows” when it has to switch and executes the corresponding command independently of the others. Since all the segments respond exactly the same, optimum parallel operation is achieved and the switching capacity varies in proportion to wafer area. It is therefore relatively simple to develop an appropriately graded family of GCT devices (Fig. 7).

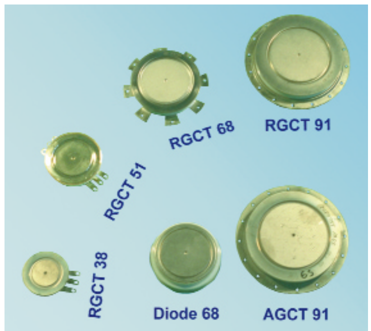

Fig. 7: Reverse conducting GCT with wafer diameters of 38 mm, 51 mm, 68 mm and 91 mm and a 91 mm GCT

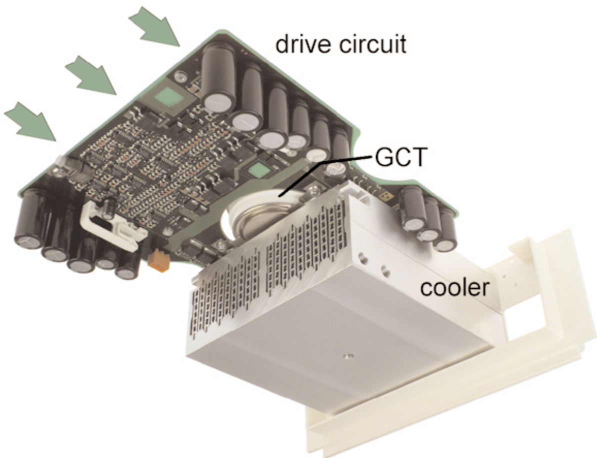

Fig. 6: GCT and drive circuit slide onto the cooler to form a single unit both electrically and mechanically.

Series of ratings through modular design

Because of the varying requirements from one application to another and the small quantity needed, there is a confusing number of types of high-power converters — almost an individual version for every application. A modular system of components is therefore the only sensible solution.

IGBT modules have been able to satisfy this demand in the medium-power range, i.e. a wide range of currents by connecting chips in parallel in the modules, converters for a wide range of ratings by connecting modules in parallel and a drive system that almost fits into a single IC. The success of the IGBT is assured.

Pressure contacts for high powers

Because of the stress on the insulation, the gauges of conductors needed and the unhandy size of the converter units, conventional module technology can only handle high voltages and currents with difficulty. It therefore has to be possible to easily dismantle high-power converters into their component parts.

IGCT technology employs conventional pressure contacts, but adopts a new approach. Drive unit, power semiconductors and cooler are integrated in a single functional unit and optimised wafers in standard housings have taken the place of the array of chips in expensive parallel configurations. Engineering and manufacture take less time and less money and the units are easier to handle. As a consequence, the range of application can be extended down to 250 kW and by connecting units in series up to 100 MW.

4th. step towards an IGCT converter — reducing circuit complexity

GCT's turn off in the same way as transistors. In contrast to a GTO, a GCT converter does not therefore need snubber condensers, diodes and resistors. It is still necessary, however, to limit the current rise time (dI/dt) when turning a GCT on, because the speed of the high-voltage silicone diodes is nothing like that of the low-voltage diodes used in IGBT applications. A new heavy current circuit, on the other hand, enables all the phases of an inverter to be connected to the same DC bus (Fig. 8). This brings the overall cost of an IGCT converter down to about the same level as for a conventional IGBT converter.

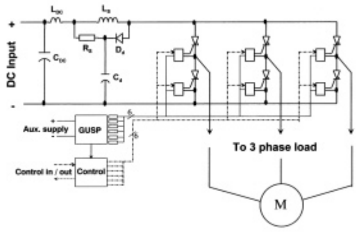

Fig. 8: Typical circuit of a three-phase IGCT converter. A common supervision unit continuously checks swich

Fig. 9: 100 MW "Bremen" railway system inter-tie

IGCT converters in operation

The first IGCT's were installed in plants built by ABB. The most prominent representative of these is most certainly the 100 MW "Bremen" railway system inter-tie (Fig. 9). 288 GCT's have operated without failure in this installation since 1996. It is an example both for the superior reliability of these devices and the ease with which they can be connected in series.

IGCT's are capable of high commutation frequencies at high power ratings. They are also ideal for highly dynamic applications such as NBPS (no-break power supplies) (Fig. 10). A dynamic response is also expected of traction inverters: the direct torque control (DTC) system launched by ABB for low-voltage drives in 1995, commutates the IGBT's in the two-point inverter in the ACS600 for limited periods at up to more than 20 kHz. As early as the end of 1997, after a development period of just two years, ABB presented the first of a series of medium-voltage converters, i.e. the ACS1000 with DTC, three-point IGCT converter and sinusoidal output filter (Fig. 11). The most important features of this series of drives are:

- A mean commutating frequency of 500 Hz for a three-point converter corresponding to about 2 kHz for a two-point circuit
- Highly dynamic commutating frequency intermintently up to 7 kHz
- Sinusoidal output with low harmonic content
- DTC with all its well-known advantages

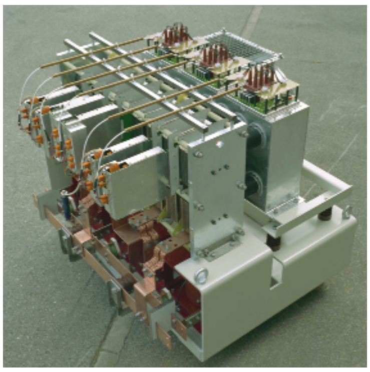

Fig. 10: Air-cooled three-phase 1.5 MW phase module for a commutating frequency of 1050 Hz

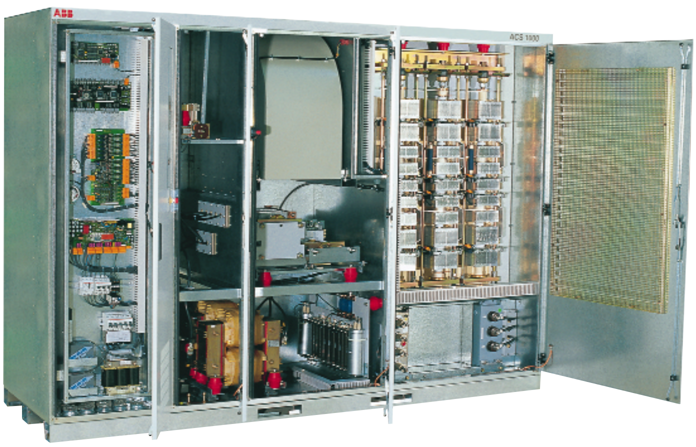

Fig. 11: Air-cooled drive converter of the ACS1000 series (4.16 kV, 1.2 MW sinusoidal output)

- Small size
- Low number of power semiconductors (total of 12 in a three-point converter)
- High reliability (MTBF > 6 years)
- High overall efficiency > 98 %
- Wide range of types from 2.3 kV to 4.16 kV and from 315 kW to 5 kW
- Simple as the ACS600 to commission
- Supply for existing, previously unregulated motors (retrofit)

Summary and outlook

In the few years since its inception, IGCT technology has been able to establish itself firmly in the medium-voltage range of applications. Its close relationship with the GTO and IGBT facilitated a development in finite calculable steps (Fig. 12). It unifies the advantages of its predecessors and overcomes their disadvantages.

The main features and advantages of IGCT technology

Excellent component characteristics

- High rated voltage
- Low turn-on and commutation losses
- High commutation frequency and absolute peak limit frequency
- Good utilisation of the silicone area
- Even current distribution in the silicone
- Linear relationship between the active wafer area and current rating
- Relatively easy to model

Optimum circuit design

- All three phases supplied from a common DC bus
- Central dI/dt limiter with integrated clamp
- Uncritical connection of the intermediate circuit
- Absolute safety even under worst case conditions
- Simple drive circuit
- Directly coupled gate signal (on / off)
- No regulator circuit (dV/dt, dI/dt)
- Two-wire low-power supply

Superior performance

- Only few components, none of them special
- Modular mechanical construction
- Monolithic integration up to the highest ratings
- Ideally matched power semiconductors, control system and cooler
- Robust pressure contact technique with simple centring
- Modular design
- Simple to service
- High overall efficiency
- Highest possible reliability
- Small size and low weight
- Well-defined manageable interfaces to the intermediate circuit, load and control system

Highest powers manageable

- Reliable series operation
- Further enhanced reliability due to redundant stages when connected in series

With these characteristics and its other potential strengths, the IGCT is the ideal successor to the GTO.

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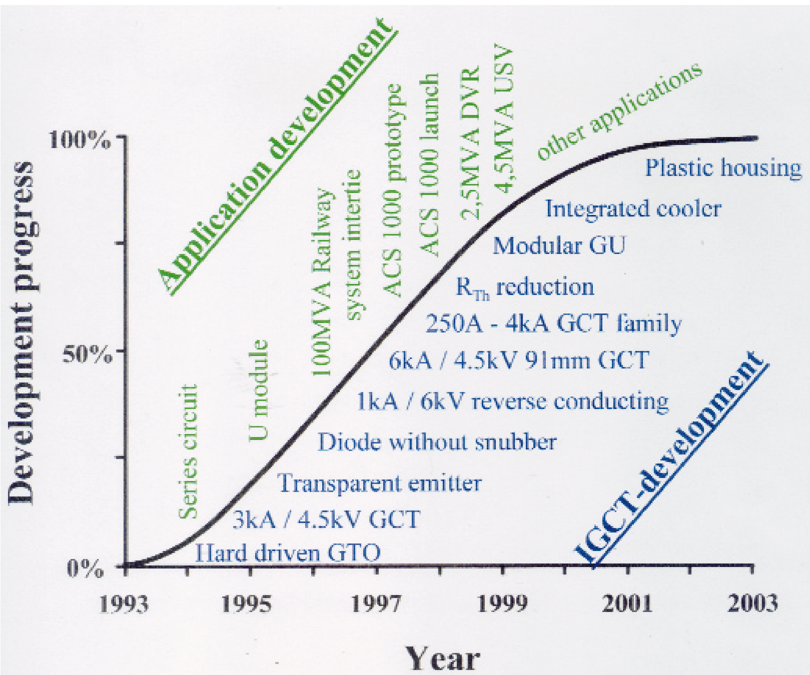

Fig. 12: The development of IGCT components and their application