AN APPLICATION-SPECIFIC ASYMMETRIC IGCT

Bjoern Oedegard, bjoern.oedegard@ch.abb.com, Thomas Stiasny, thomas.stiasny@ch.abb.com,
Eric Carroll, eric.carroll@ch.abb.com, Marco Rossinelli, marco.rossinelli@ch.abb.com,
ABB Semiconductors AG, Fabrikstrasse 3, 5600 Lenzburg, Switzerland
Tel.: +41 62 888 6222, Fax: +41 62 888 6305

Abstract:

The need for higher frequency operation in motor drives and Energy Management Systems, along with the conflicting demands for high average current in, for instance, circuit breakers, is forcing the development of application-specific devices. The Integrated Gate-Commutated Thyristor (IGCT) lends itself well to these adaptations through carrier lifetime engineering on the one hand and the flexible functionality of its standard gate unit on the other. The latest developments of the 91 mm 4.5 kV IGCT have led to three device variants capable of optimally satisfying the needs of such disparate applications as Static Breakers, Traction Drives and high frequency Medium Voltage Drives, all of them using the same standard gate unit.

Introduction

The Integrated Gate-Commutated Thyristor (IGCT) operates on the principle that thyristors are ideal conduction devices whereas transistors are ideal turn-off devices [1]. The IGCT therefore converts a thyristor structure to a transistor structure *prior* to turn-off by fast commutation of the cathode current. This results in a device which dynamically and statically blocks like a transistor (open-base pnp transistor producing the same turn-off losses) but conducts like a thyristor i.e. with about half the on-state voltage compared to an IGBT, due to the greater plasma density produced by its two emitters (pnp & npn transistors). Fig. 1 illustrates the principle of operation and Fig. 2 shows a typical turn-off waveform.

Demands are now being made for application-specific devices which are served by tailoring the same wafer to Power Distribution, Energy Management [2], Traction and Industrial Drive requirements [4].This has been done by lifetime control techniques and an advanced gate-unit design that meets all the requirements of the aforementioned applications. The IGCT is the first power semiconductor to be supplied integrated into its gate-unit with the supplier taking the responsibility for the complete switch function. This is made possible by virtue of the fact that the device is only a *switch*: it makes no attempt to modulate transition speeds neither *on* nor *off*. As a result, the gate-unit is neither *type* nor *voltage* specific which allows a high degree of material and process standardisation in its production.

In this paper device characteristics and functionality are described with emphasis on turn-off losses over a wide voltage and current range and frequency/current limitations of both gate drive and semiconductor of different application-specific types.

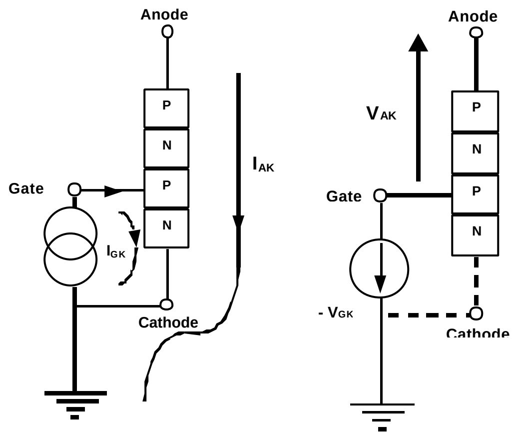

Fig. 1a **Conducting** IGCT (Thyristor).

Fig. 1b **Blocking** IGCT (Transistor).

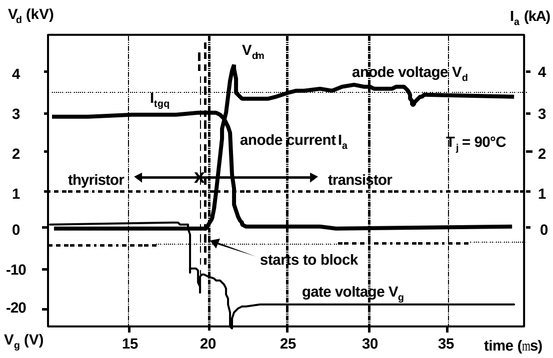

Fig. 2 IGCT turn-off exhibits same waveform and losses (E_{OFF}) as transistor.

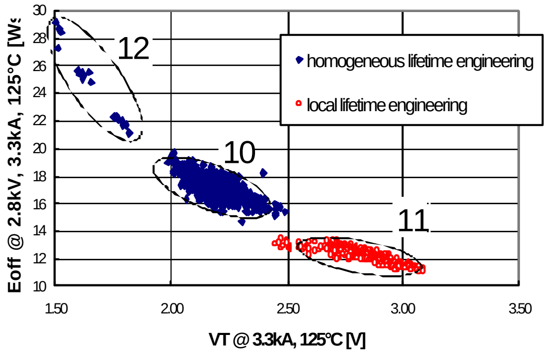

Fig. 3 Technology curves of asymmetric 4kA/4.5kV IGCTs with two different lifetime control technologies (*filled diamonds*: homogeneous lifetime engineering, *open circles*: local lifetime engineering).

With these two lifetime control technologies three application groups with different switch requirements are served with a single wafer:

Type 12: *low on-state losses*
Type 10: *low total losses*
Type 11: *low switching losses*

Application-Specific Charge Carrier Lifetime Engineering

Currently required device trade-offs are: *low on-state losses* (e.g. breakers), *low switching losses* (high pwm frequency motor drives or a *wide temperature range* and low *total losses* (e.g. traction drives). For these different requirements, the original 4 kA/4.5 kV device was tailored by carrier lifetime and "shifted" along its E_{OFF} vs V_T (or "technology") curve allowing 20% turn-off loss reduction for the high frequency device. In Fig. 3 the turn-off losses of the aforementioned IGCT are shown as a function of its on-state losses for two different lifetime control technologies and a wide range of lifetime adjustments. Three different IGCT types with optimised low *on-state losses*, low *total losses* and low *switching losses* (Fig. 2, Types 12, 10, 11, respectively) are presented. See Table 1 for comparison of key parameters.

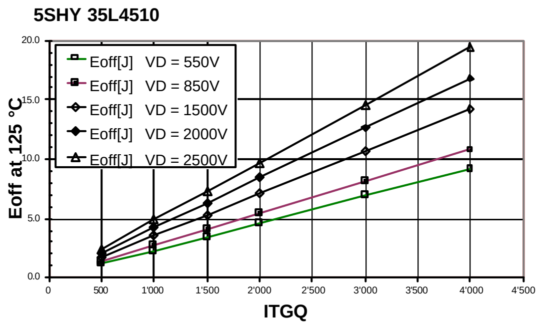

Fig. 4a
Turn-off energy at 125 °C of 5SHY35L4510

Turn-Off Losses

The lifetime control techniques of Fig. 3 result in different turn-off loss curves for the three devices as functions of turn-off current and DC link voltage, shown in Fig. 4

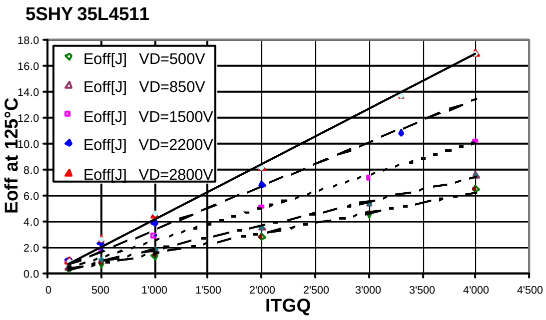

Fig. 4b
Turn-off energy at 125°C ofr 5SHY35L4511

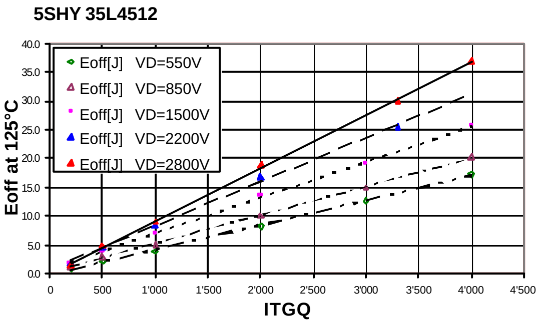

Fig. 4c
Turn-off energy at 125°C for 5SHY35L4512

Turn-Off Capability

IGCTs are used predominantly as snubberless devices in high frequency PWM applications. As can be seen from Table 1 however, Type 12 with its high turn-off loss and low on-state voltage is designed for very low frequency applications in which snubbers do not generally pose a loss problem. In such situations, e.g. for static breakers, snubbers may be used to increase the turn-off capability of IGCTs by as much as 50% and allow constructions with high levels of unclamped inductance. In these conditions, an IGCT can be used as a “super GTO” with high turn-off capability and very low conduction losses (half that of an equivalent GTO.

TABLE 1 - Overview of the three different types of 4.5kV asymmetric IGCTs and their typical applications

Type	low on-state losses (Type 12)	low total losses (Type 10)	low switching losses (Type 11)
Part N°	5SHY 35L45**12**	5SHY 35L45**10**	5SHY 35L45**11**
Junction temp. range	-40°C – 125°C	-40°C – 125°C	10°C – 125°C
V_{TM} @ 4 kA, 125°C	2V	2.7 V	3.5 V
E_{OFF} @ 4 kA, 2.8 kV, 125°C	37 Ws	22 Ws	17 Ws
Typical application	AC/DC breakers (SSB)	Traction, Energy Management	high frequency MVDs

Gate-Unit

This new generation of IGCTs is comprised of a gate driver whose functionality is suitable for symmetric, asymmetric and reverse conducting GCTs of any voltage class and application up to 1000 Hz. The allowed ambient temperature range is extended to –40 °C and +60 °C. A single AC power supply allows direct supply from an isolation transformer. Furthermore, these new devices are vibration tested to IEC 61373 (Cat. 1, Class B for Traction) and EMI tested to severe electromagnetic, electrostatic and common mode stress conditions derived from demanding applications. The particular gate-unit used with the new 3-device group of tailored IGCTs described in this paper is shown as a complete IGCT in Fig. 5

Fig. 5 New IGCT types 5SHY 35L4510/11/12 showing versatile gate-unit for VSI and CSI applications down to –40°C (5SHY 35L4510) and PWM frequencies of 1000 Hz (5SHY 35L4511 & 12).
All three types have a single AC power supply, fibre-optic gate-status feedback, visible LED status indication, are suitable for series connection and meet IEC 61373 vibration requirements.

Control Power Consumption

The power supplied to the gate-unit falls into two parts:

a) a thermal dissipation in the gate circuit, shown in Fig. 6 (which includes gate-cathode junction). It is dependent on the switching frequency (for turn-on pulse generation, I_{GM}), the duty cycle (for "back-porch" generation, I_G), and ambient temperature. At higher ambient temperatures the "back-porch" current is reduced in order to achieve better thermal behaviour of the gate drive without compromising the GCTs need for a high level of "back-porch" current at low temperatures. The no-load power dissipation is typically less than 5 W.

b) a part which is transferred to the load during turn-off (see Fig. 1b) and must be replaced after turn-off.

The sum of a) and b) above is shown in Fig. 7 for all 3 types. It is strongly dependent on switching frequency and I_{TGQ}.

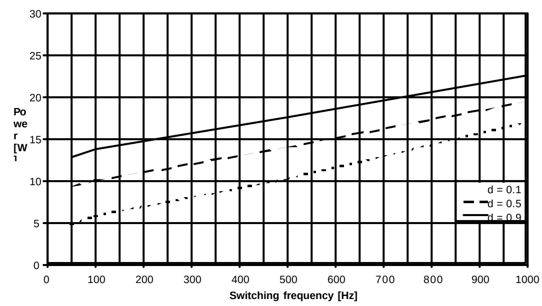

Fig. 6 Power *dissipation* in the gate-circuit *and* in the gate-cathode junction of the GCT for duty cycles of 0.1, 0.5 and 0.9. The ambient temperature for the shown charakteristics is 25 °C.

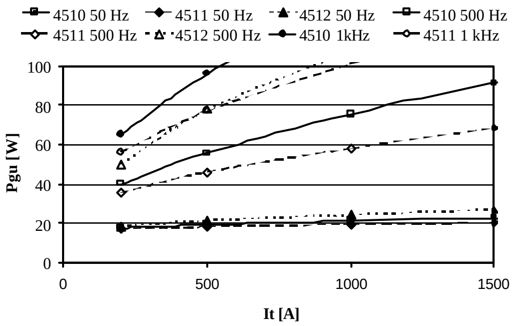

Fig. 7 Total control power *consumption* (dissipated *plus* transferred power) as a function of turn-off current, I_{TGQ} and switching frequency, f_s of device types 5SHY 35L4510/11/12. Duty cycle = 0.5, T_J = 125°C

Power Supply Input

In order to simplify the control interface and to reduce system costs, a rectifier and voltage regulator are integrated in the gate-drive board. This allows direct connection to an isolation transformer with an AC square-wave output-voltage range of 24 to 40 V. The device is however optionally available for a regulated input voltage of 20 V_{DC} +/- 0.5 V making it reverse compatible with earlier IGCTs. This further allows operation at frequencies of up to 1500 Hz continuous since the added dissipation of the built in regulator is then eliminated.

Propagation Delay Tuning

In applications with series connection (which require snubbers for voltage sharing) [4], banding of devices with similar turn-off delay times is used to minimise snubber requirements. In this new gate-drive design, “post production tuning” of propagation delay times can be implemented achieving a single group of 100 ns spread which allows a snubber capacitor of below 1µF for a 4 kA device switching 12 MW.

Status Feedback

The optical status feedback provides supervision of:

– the regulated internal supply voltage
– the state of the gate-to-cathode output
– the optical signal transmission of both command and the feedback itself.

Errors in the above will result in fault status feedback (without detailing *which* fault occurred). An additional detection input can be made available (e.g. for anode over-voltage detection in series connection) with the errors announced via the same optical feedback connector.

Versatile Protection Concept

Because the gate-drive behaves as a slave, the protection sequence can in most cases be controlled via the command input. Even in the case of power supply failure the hold up time is normally sufficient to carry out a controlled shut down of the inverter before gate control is lost. This concept works for both VSI and CSI [5] applications.

IGCT Chopper Operation Diagram

The advantages of the different types of IGCTs (Type 10, 11, 12) with respect to their applications are shown in Fig. 8 by comparing the thermal limitation of the GCT with that of the gate-unit in a simple chopper application. Here the maximum allowable continuous switching frequencies for both the GCT and gate-unit are compared as a function of the turn-off current.

Dynamically, the IGCT has a burst capability of 25 kHz for 10 pulses as shown in Fig. 9. In this test, the device starts at T_J = 25 °C and with a DC voltage of 3500 V. The peak switching transient is initially 4.5 kV and decreases as the DC link discharges. The test is stopped when the anode current reaches 4 kA on the 10^{th} pulse.

Improvements both in allowable junction temperature and thermal resistance since the device’s introduction in 1997 have increased the standard devices' current rating by almost 75% (present type 5SHY 35L4510 vs original type

5SHY 35L4502) as shown in Table 2. The present introduction of the low on-state type 5SHY 35L4512 has effectively doubled the rating.

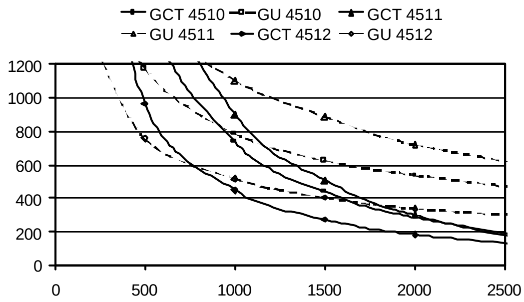

Fig. 8 5SHY 35L4510/11/12 max steady-state frequency vs turn-off current in snubberless chopper mode.

Conditions:

- $T_J = 125°C$
- $T_C = 85°C$
- Duty Cycle = 0.5
- $V_{DC} = 2800$ V

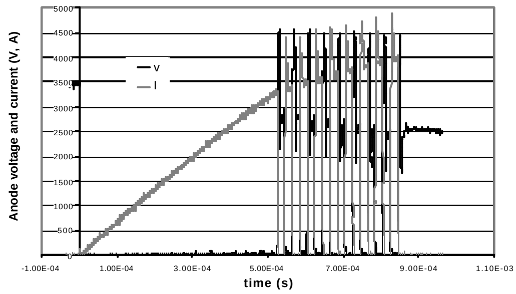

Fig. 9 25 kHz 10-pulse burst operation of IGCT type 5SHY 35L4510

$V_{DC\ start} = 3500$ V

$T_{J\ start} = 25$ °C

$V_{DM\ peak} = 4500$ V

$I_{TGQ\ peak} = 4000$ A

Duty cycle = 0.5

Table 2. Irms rating improvements of IGCT Type 10

	1997	1998	1999	2000	2001	2002	2003	2004
Junction Temp (°C)	115	115	125	125	125	125	140	140
$R_{TH\ J\text{-}S}$ (K/kW)	15.0	14.0	14.0	14.0	11.5	11.5	11.5	10.5
Increase in I_{RMS} w.r.t. 1997 for T_C = 85°C	0%	7%	43%	43%	74%	74%	139	162%

Shaded area are targeted values

Reliability

The field reliability established to-date (since 1996) is less than 200 FIT (Failures-In-Time in failures per billion device-hours) which compares favourably with a predicted rate of 250 FIT for the IGCT of which 50 FIT can be ascribed to the GCT (the power semiconductor part). A detailed reliability analysis of IGCT gate units is outside the scope of this paper, but the most frequently mentioned reliability concern of todays customers will be adressed, namely the reliability and the lifetime of the gate driver's on-board capacitors which are of the "high ripple current, long life, 105°C" type. Due to the built in redundancy of the capacitor bank, and the modest voltage stress (20 Volt operating versus 35 V rated voltage), the failure rate of the capacitor bank is a tiny portion of the overall IGCT FIT-rate. This statement is also supported by the field experience made not only with IGCT gate units, but also with GTO gate units.

Fig. 10 shows the rated lifetime of the capacitor bank as a function of ambient temperature.

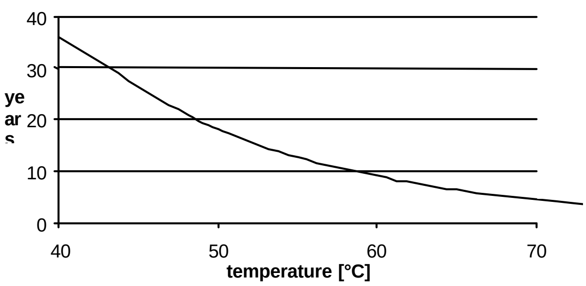

Fig. 10

Lifetime of the on-board gate-unit capacitor bank as a function of gate unit ambient temperature.

Standardisation

The key to cost-effective and reliable Power Electronics (PE) lies in simplicity and standardisation of components. This mantra has been the *Leitmotiv* of IGCT development from the outset and results in a growing family (14 devices at present) of 4.5 and 6 kV symmetric [6], asymmetric and reverse conducting devices all based on the same manufacturing and encapsulation processes. The new gate unit for the described devices is based on a standard but versatile platform which allows all the aforementioned device types to operate in all PE applications:

- Current or voltage source inverters
- AC or DC breakers
- Traction, industrial and T&D environments
- Hi-Rel applications such as sub-sea installations
- Resonant series or parallel inverters
- Snubbered or un-snubbered circuits
- Series connection
- High current or high frequency applications
- Systems with AC or DC gate power supplies.

The simple construction of a 91 mm reverse conducting GCT device is shown in Fig. 11.

Fig. 11

Open 6 kV reverse conducting IGCT rated 1800 A turn-off current showing wafer and housing parts.

For the 4.5 kV/4kA devices described in this paper, only the wafer is different – all housing parts, as well as the gate unit are the same.

Conclusions

After five years of service and after only four years of market introduction, the IGCT has established itself as a polyvalent power switch for Energy Management (Power Quality), Traction and Industrial Drives in both VSI and CSI topologies and is finding new applications in Power Generation and Industrial Processes such as high current rectifiers and induction furnaces.
The need for both component and *platform* standardisation is met by using standard wafers tailored only by lifetime engineering technologies („back-end" processes). Together with standard gate-units and housings, IGCTs allow *flexibility* and *standardisation* for both equipment and semiconductor manufacturers. Both these aspects are essential requirements for the realisation of reliable and cost-effective designs in high power electronics. With only four standard housings/gate-units and ease of series connection, IGCT equipments today cover a power range from 0.3 to 300 MW.

Acknowledgements

The authors are indebted to Ambros Imboden, Mark Frecker, Hans Vetsch from ABB Semiconductors for device measurements and Philippe Maibach of ABB Industrie for gate unit design support.

References

[1] *"High-Power Hard-Driven GTO Module for 4.5kV/3kA Snubberless Operation"*, H.Grüning, B.Oedegard, *A.Weber*, E.Carroll, S.Eicher, PCIM, Nuremberg 1996

[2] *"Customer Reliability Improvement with a DVR or a DUPS"*, W.Raithmayr *et al.*, PowerWorld98, Santa Clara 1998

[3] *"Design, simulation and realization of high power NPC converters equipped with IGCTs"*, A. Zuckerberger, E. Suter, Ch. Schaub, A. Klett, P. Steimer (ABB), IEEE-IAS, St Louis, 1998

[4] "Innovation IGCT Main Drives", J.P.Lyons, V.Vlatkovic, P.M.Espelage, F.H.Boettner, E.Larsen, IEEE IAS, 1999

[5] *"A New Current Source Converter Using A Symmetric Gate Commutated Thyristor (SGCT)"*,N.Zargari, S.Rizzo, Y.Xiao, H.Iwamoto, K.Sato, J.Donlon, IEEE IAS, Rome 2000

[6] *"Reverse Blocking IGCTs for Current Source Inverters"*, A.Weber, T.Dalibor, P.Kern, B.Oedegard, J.Waldmeyer, E.Carroll, PCIM, Nürnberg 2000