Applying IGCT Gate Units

ABB

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1. Introduction

A novelty in the high power semiconductor business is that a semiconductor manufacturer takes technical and commercial responsibility for both the power semiconductor *and* its gate drive. Semiconductor control parameters like turn-on and turn-off pulse amplitude, pulse width and rate of rise, gate circuit inductance, back-porch current and other parameters are standardised and taken care of by the semiconductor manufacturer. The result is the IGCT with a standard gate unit suitable for widespread used converter topologies namely Voltage Source Inverters, Current Source Inverters, Resonance Converters, Static Breakers and many others. Now the control interface discussion between converter design engineer and power semiconductor manufacturer can be reduced to the specification of power supply, control signal transfer and mechanical assembly. A reduction of development costs and time is the result, and the power semiconductor technology can be made available to a broader group of users.

Basic design rules and handling / application recommendations for IGCT gate units regarding power supply, isolation and optical control interface, control-, diagnostics- and protection parameters as well as environmental aspects are described in Chapter 3.

In Chapter 4 basic IGCT driving functionality is explained.

2. Table of contents

3. Users Guide

The most important user aspects of gate drive power supply, isolation interface, optical interface, control and diagnostic functionality during normal and faulty operation are explained. Also environmental issues like electromagnetic immunity, thermal management and pollution are briefly covered. As an appetiser an example of a functional block diagram of an IGCT gate drive is given in Fig. 1:
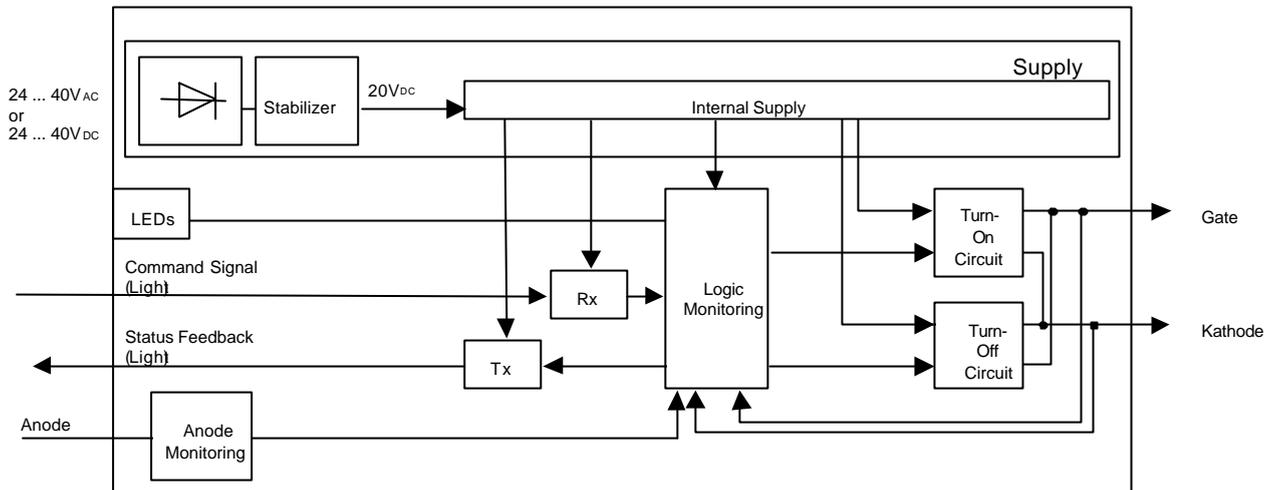

Fig. 1:   Block diagram of an AC input asymmetric IGCT.

3.1 Power Supply Interface

Isolation

The isolation requirement in the IGCT environment is a function of the maximum applied nominal voltage of the converter application itself. This voltage varies from a few thousand volts to several tens of thousands of volts over the IGCT application range. Hence, the requirements on isolation strength and distances can be very different. Furthermore, the power consumption which needs to be transferred across the isolation interface is also strongly application dependent, and users are likely to require quite different isolation interfaces in terms of both power handling capability and isolation strength.

As this also applies to the costs of the interface, standardisation of the isolation interface is difficult.

This is why the IGCT gate drive does not provide an on-board potential separation and the gate unit power supply output as well as the supply cable must withstand the high voltage potential of the power semiconductor switch against all other relevant potentials in the converter.

Gate Unit Power Connector

The connector X1 is specified in the corresponding IGCT data sheet. The information about the corresponding power cable connector can be found on the connector supplier's web site, which is also mentioned in the data sheet.

Product	Connector X1	Remark
5SHX xx**D**xx**0**x 5SHX xx**F**xx**0**x 5SHX xx**H**xx**0**x 5SHZ xx**F**xx**0**x 5SHZ xx**H**xx**0**x	2 pin DC input	Polarity shown on gate drive board Positive pin is cathode potential
5SHY xx**L**xx**1**x	5 pin AC input	Center pin is cathode potential for possible shield connection. See Fig. 2
5SHX xx**L**xx**0**x 5SHY xx**L**xx**0**x	4 pin DC input	As 5 pin connector shown in Fig. 2, but without center pin Polarity shown on gate drive board Positive pins are cathode potential

Table 1:   Power connector main data by product group.
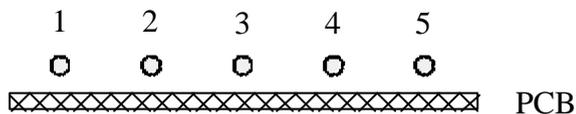
1 - $V_{IN,\ positiv}$

2 - $V_{IN,positiv}$

3 - transformer shield, cathode

4 - $V_{IN,return}$

5 - $V_{IN,return}$

Fig. 2:   Pinout of power input connector of 5SHY … gate drive (looking into the connector from the outside)

Regulated DC Input Voltage

The hard drive principle of the IGCT requires a regulated internal DC supply voltage:

$$V_{GINT} = 20 \pm 0.5 \ \text{V}$$

For some IGCT products (see data sheet and Table 1) this is also the requirement on the gate drive supply voltage V_{GDC}. When using IGCT products of this type, an interface board with a rectifier and a regulator has to be provided between the IGCT and the isolation transformer. This board needs to be mounted on high voltage potential.

AC Input Voltage

Other IGCT products (see data sheet and Table 1) have built-in rectifier and voltage regulator. Hence the isolation transformer output can be connected directly to the gate drive power supply input. The power supply voltage V_{GAC}, specification yields:

$$V_{GAC} = 24 ... 40 \ \text{V}$$
$$\text{square wave amplitude}$$

or equivalently

$V_{GAC} = 48 ... 80$ V
square wave peak-to-peak voltage

Recommended frequency range of the ac square wave voltage is

$f_{in} = 15 ... 100$ kHz

Inrush Current Limitation

The AC input gate drive has an internal voltage regulator and a current limitation, which also limits the inrush current at power up. See Fig. 14, page 13.

DC input gate drives do not have this feature.

Power Consumption

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

One big part is transferred from the turn-off capacitors to the load during turn-off. A charge equal to the gate turn-off charge Q_{GQ}, is necessary to recharge the capacitors to the reference voltage, V_{GINT} after each turn-off event. Thus the transferred power can be expressed as

$$P_{transfer} = V_{GINT*} Q_{GQ}(I_{TGQ})_*f_S$$

f_S being the device switching frequency and I_{TGQ} the anode turn-off current.

The gate charge Q_{GQ}, is a function of the turn-off current I_{TGQ}, and the device design itself. Gate charge characteristics and transferred power as a function of switching frequency, turn-off current at a duty cycle of 50% of the device 5SHY 35L4510 are shown in Fig. 3 and 4.
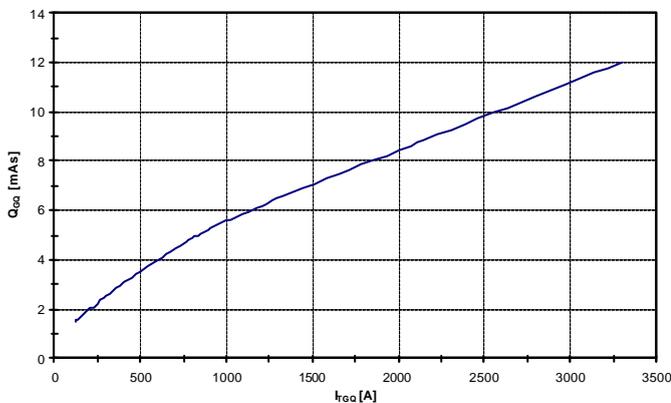
Fig. 3:   Gate charge characteristics of 5SHY 35L4510

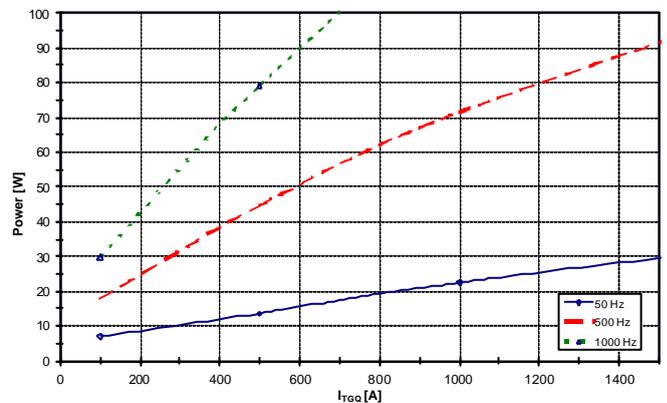Fig. 4:   Transferred power of 5SHY 35L4510

The second part of the power is dissipated in the gate circuit (including gate-cathode junction). It comprises standby power, generation of turn-on pulse and back-porch current, dissipation in the gate drive turn-off circuit and input rectifier.

Fig. 5 shows the dissipation in the gate circuit as a function of the device switching frequency at zero anode current.
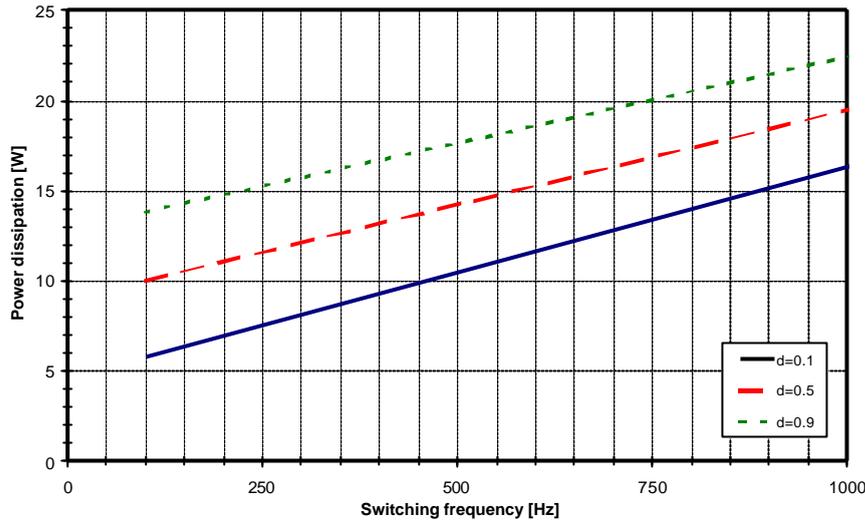
Fig. 5: *Power dissipation in the gate-circuit and in the gate-cathode junction of the GCT for duty cycles of 0.1, 0.5 and 1.0 at room temperature*
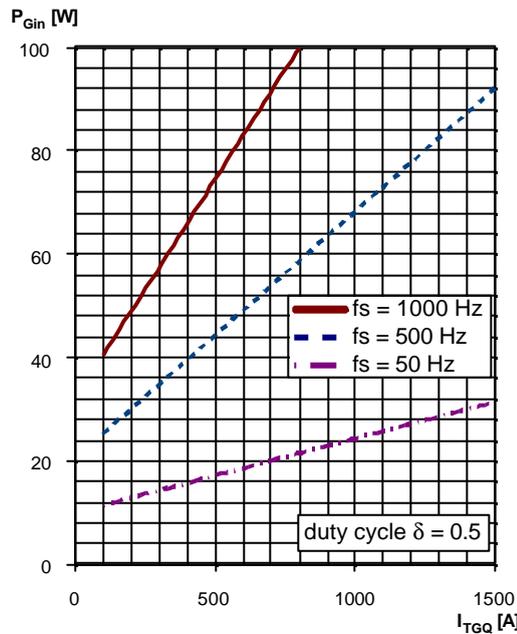
Fig. 6: *Maximum gate unit input power (dissipated plus transferred) in chopper mode of device type 5SHY 35L4510*

The total power consumption of the IGCT gate drive appears to be strongly load dependent as can be observed in Fig. 6. Both turn-off current I_{TGQ}, switching frequency f_S and device technology (gate charge Q_{GQ}) have a major influence on the power consumption. The bulk of the power is transferred to the load, the smaller part of it is dissipated in the gate circuit itself. Nevertheless gate drive limitations must be checked before the operating range in a specific application is determined. For the thermal limitations see Fig. 15, page 15.

The no-load dissipation is smaller than 5 W.

3.2. Optical Interface

The optical control interface uses standard components, which enjoy a widespread use throughout the industry. It is built up around the HFBR Series of Agilent Technologies[1]. The recommended standard type optical fibre is 1 mm POF (Plastic Optical Fibre), which gives a cost-effective and easy-to-use solution. For long distances (> 15 m) the 200 μm HCS type (Hard Clad Silica) type is recommended.

With an appropriate driving circuit for the command input transmitter on the customer side, this interface is suitable for serial and parallel connection of IGCTs.

The specific optical data are given in the data sheets of the IGCT products and on the supplier's web site.

3.3. Control aspects

Signalling

The IGCT requires a command signal from the converter control part and transmits in return a status signal. For some IGCT products the transmitter for optical feedback is not available.

In normal operation, the command signal is translated by the gate drive as follows:

Light   = IGCT ON

No light   = IGCT OFF

Power-up of gate drive power supply

Any attempt to turn-on the IGCT before the power-up sequence is completed might cause a power-up failure or even destruction of the gate drive.

After application of supply voltage it takes up to 5 seconds before the gate unit is ready for operation. The capacitor charging time, however, is less than 0.5 seconds. Application of anode voltage prior to this is definitely not recommended.

Only gate drives with ac input provide an inrush current limitation during power-up.

Furthermore, power-up and power down of the customer control system power supply *while sending light* can be destructive for the gate unit, if the transmitted light intensity is proportional to the supply voltage ramp as shown in Fig. 7.
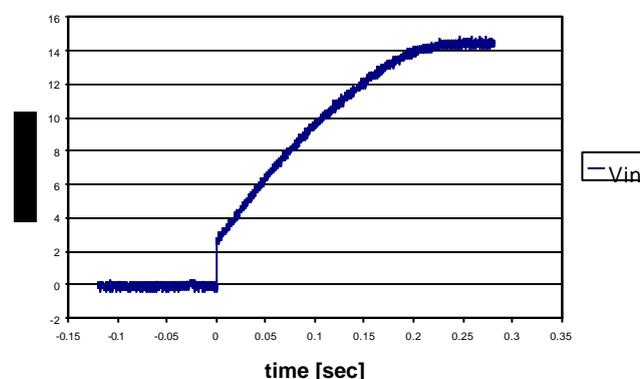

time [sec]

Fig. 7:   Power supply voltage, V_{IN}, of control board during power-up. This behaviour can cause problems shown figure 8 and 9.

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[1] http://www.semiconductor.agilent.com/

In Fig. 8 and 9 is shown how arbitrary and unlimited switching frequencies are generated under these conditions when the light intensity is moving slowly through the region where the optical receiver in the gate drive doesn't know whether it is supposed to be ON or OFF. Overstress of gate drive components is the consequence.
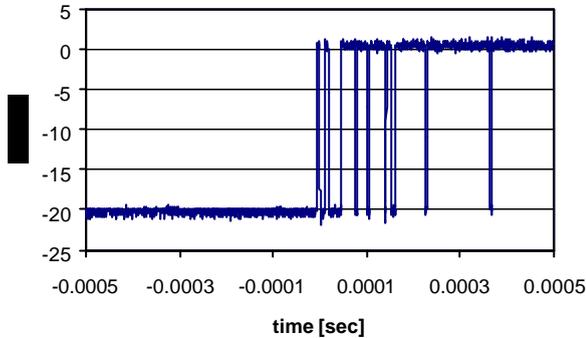
Fig. 8: Gate-to-cathode voltage during power up of control board.
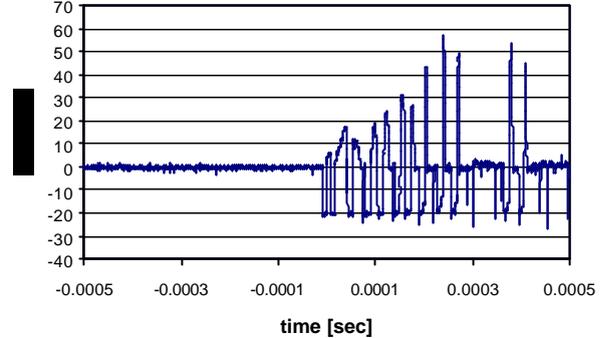
Fig. 9: Drain voltage of FET in back-porch circuit during power up. The component voltage rating is 55 V. The y-scale is offset by -20 V.

Glitch filter

A glitch filter suppresses noise spikes appearing on the optical input. All pulses with a pulse width t_{glitch}, smaller than

$$t_{glitch} < 400 \text{ ns}$$

are ignored. This applies both to the ON and OFF state.

Turn-on delay time

The gate drive turn-on delay time is around 2.8 µs (10% change of light signal to 10% change of gate-cathode voltage). It is slightly smaller than the overall IGCT turn-on delay time tdon, which is specified in the corresponding IGCT data sheet.
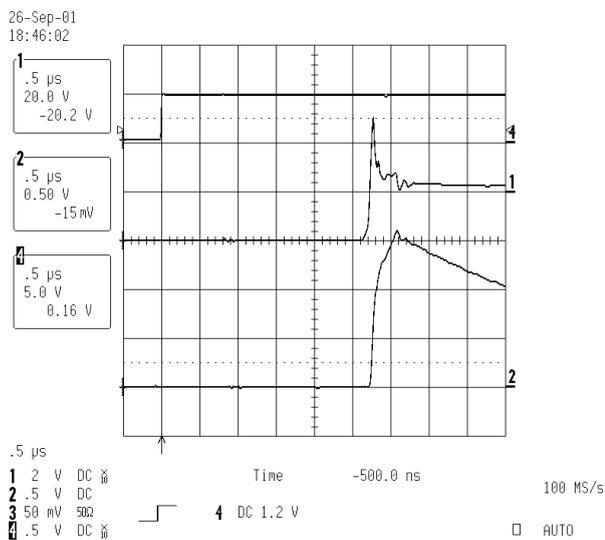
CH4: Command signal (HIGH: Light)

CH1: V_{GK}

CH2: Gate current [50 A/Div]

Fig. 10: Turn-on delay (measurement)

Turn-off delay time

The gate drive turn-off delay is around 2.8 µs (10% change of light signal to 10% change of gate-cathode voltage). It is much smaller than the overall IGCT turn-off delay time tdoff. Further data can be obtained from the specific data sheet.

```
10-Nov-99
11:55:48

.5 µs
10.0 V
 -12.50 V

.5 µs
200 mV
 -125 mV

.5 µs
5.0 V
 -6.69 V

.5 µs    BWL

  1  V  DC
  .2 V  DC        Time      2.784 µs       500 MS/s
  2  V  DC
  5  V  DC         4 DC 2.6 V              □ NORMAL
```

CH4: Command signal (HIGH: light)
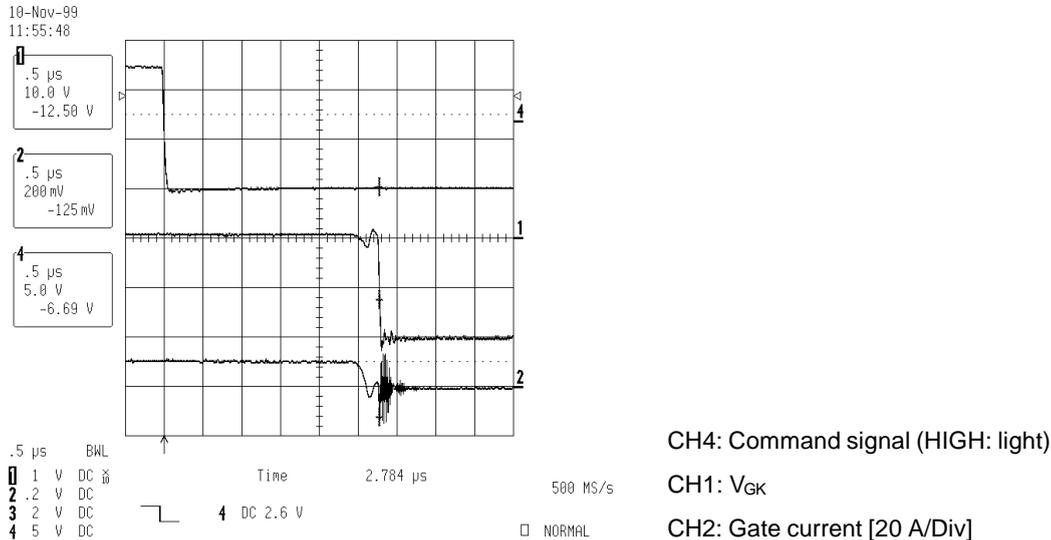
CH1: V_{GK}

CH2: Gate current [20 A/Div]

Fig. 11:   Turn-off delay (measurement)

Minimum ON and OFF pulse widths

Once the gate unit has started to execute a switching command (ON pulse width > 500 ns or OFF pulse width > 1.3 us) the gate unit will execute a minimum pulse width (ON or OFF) of 3.5 µs.

On the other hand, this minimum pulse width given by the gate unit is smaller than the repetitive minimum ON or OFF time the IGCT requires:

$t_{ONMIN} = t_{OFFMIN} = 10 \ \mu s$

Also a repetitive minimum ON+OFF time must be respected:

$t_{(ON+OFF)MIN} = 60 \ \mu s$

For single event protection sequences shorter pulses less than 10 µs are allowed.

Re-trigger command

As will be explained later (Chapter 4), re-firing of the IGCT during on-state might be advantageous or even mandatory in certain applications. Such a re-fire command can be triggered internally by the gate drive itself, or externally. The external re-trigger command is executed when a turn-off pulse (no light) with a pulse width between 0.7 and 1.2 µs is applied to the optical input interface. Shorter OFF-pulses are ignored (glitch-filter) and longer OFF-pulses leads to a minimum OFF pulse of 3.5 µs. Fig. 12 shows an example of an external re-trigger command. The sum of switching frequency f_s and re-trigger frequency f_e must not exceed the thermal limitation of the gate drive. Due to internal gate drive conditions two additional restrictions apply to the use of the re-trigger function:

Earliest turn-off after re-trigger: > 10 µs

Earliest re-trigger after turn-on: > 20 µs
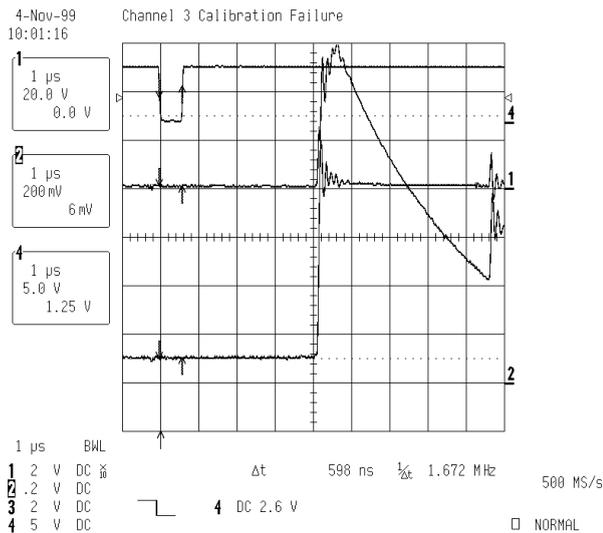
Fig. 12: External re-trigger (measurement)

CH4: Command signal (HIGH: light)

CH1: V_GK

CH2: Gate current [20 A/Div]

For obvious reasons the re-trigger command can be executed during the on-state only.

3.4. Diagnostics / Protection

Status Feedback

The gate unit provides an optical status feedback output signalling either OK or FAULT.

OK: In normal operation, the optical status feedback signal is *inverse* to command signal.

FAULT:

- Supply voltage fault (over-/ undervoltage): Feedback signal in phase to command signal.

- Gate-cathode short circuit (failed IGCT): Feedback signal stays low.

- Gate-cathode open circuit (no load): Feedback signal in phase to command signal.

- Output does not follow input (other fault): Feedback signal dependent on the fault condition signal.

Under normal operation the status feedback signal follows the command signal within 5 µs.

Visual feedback

Some IGCT types are equipped with visual feedback information, which indicates the status of the IGCT.
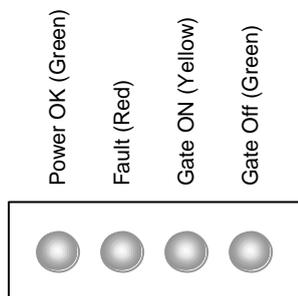

*Fig. 13:   Example of LEDs for visual feedback. This configuration applies to 5SHY xx**L**xx**1**x products*

Diagnostics status table

The optical status feedback output (SF) and the four LEDs (see Fig. 13) provide the user with information according to this table:

Optical Command Signal Input	Gate to cathode voltage	Supply voltage	Optical Status Feedback output	Gate drive status	LEDs
CS	**Status GK**	**Status V $_{Gint}$**	**SF**		
LIGHT	ON	OK	Inverse input signal CS	OK	Power OK, Gate ON
LIGHT	OFF (t_{off} < 10 µs)	OK	Inverse input signal CS	OK	Power OK, Gate ON
LIGHT	OFF (t_{off} > 10 µs)	Don't care	CS	FAIL	Power OK, Fault
LIGHT	Don't care	FAIL	CS	FAIL	Fault
NO LIGHT	OFF	OK	Inverse input signal CS	OK	Power OK, Gate OFF
NO LIGHT	ON	Don't care	CS	FAIL	Power OK, Gate ON, Fault
NO LIGHT	Don't care	FAIL	CS	FAIL	Gate OFF, Fault

Table 2:   IGCT Status Table

Re-trigger action does not influence or change optical status feedback or visual feedback.

Protection

A faulty condition will always invert the status feedback signal (SF) and turn on the fault LED. With few exceptions the gate unit will follow the command input (CS) as a slave even under faulty conditions.

- *Loss of power supply*

When power supply is lost the slave function of the gate unit can be guaranteed as long as the logic supply voltage is sufficient. After that the last valid command status will be frozen. Hold up times can be guaranteed as follows:

On state hold-up time (no switching): > 300 ms

Off state hold-up time (no switching): > 500 ms

- *Open circuit gate*

Trying to turn on a gate unit without a GCT connected might cause damage to the gate drive components when the gate current controller is working against an open circuit. Hence this mode is detected and the gate current is turned off. In this mode of operation the output will not follow input.

- *Short circuit gate*

A shorted GCT forces the internal supply voltage to zero and drives the voltage regulator into current limitation. To prevent overheating the power supply is separated from the gate drive after some hundred milliseconds. After another 4 to 5 seconds the power supply tries to power-up the gate drive again. This will only be successful when the gate-cathode short has been removed. In case of a sustained short circuit, the power supply will "pump" current into the short circuit as shown in Fig. 14.

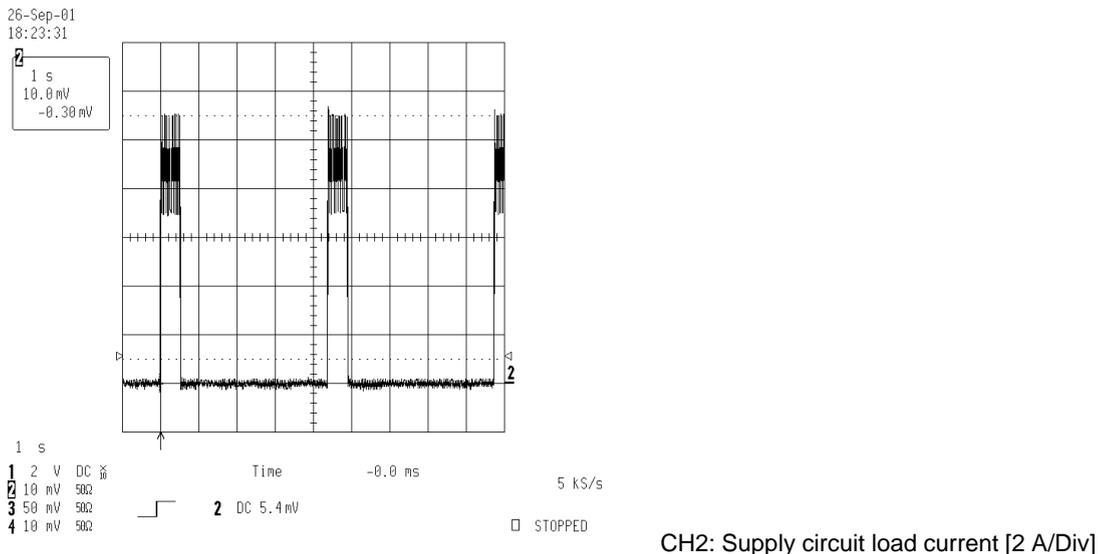
CH2: Supply circuit load current [2 A/Div]

Fig. 14:   Power up during shorted Gate Unit load

- *Supply overvoltage*

A supply overvoltage will result in a faulty condition (SF equal to CS and faulty LED on). Output will still follow input.

3.5. Environmental aspects

Electromagnetic Immunity (EMI)

The dominant EMI stress on the IGCT gate drive stems from the gate drive itself and the noisy converter switching environment. The noise generated in the gate drive itself comes from high di/dt turn-on and turn-off pulses, whereas the switching environment typically produces

- high di/dt repetitive switching and surge transient currents flowing in bus bars, cables and di/dt chokes.
- high dv/dt potential shifts within the stack construction (heat sinks, clamping equipment) and between stack components and equipment grounding potential.

Immunity type tests are designed to simulate the worst case of the above phenomenon:

- dv/dt stress: 13 kV/µs with amplitude 3 kV

- di/dt stress: 5 kA/µs with amplitude 7 kA

- 250 A/µs with amplitude 40 kA

Based on these tests a minimum distance between the optical receiver part (CS) and bus bars carrying high di/dt currents is recommended:

- L-housing IGCT: 15 cm
- D, F, H-housing IGCT: 5 cm

Thermal management

Due to the strongly load dependent power consumption (see chapter 3.1), the recommended maximum ambient temperature is also a function of load. Figure 14 shows the resulting operating diagram for lifetime operation of an asymmetric 91 mm IGCT device (5SHY 35L4510). Continuous operation outside these limits will not cause immediate malfunction, but will reduce the lifetime of the on-board turn-off capacitors.
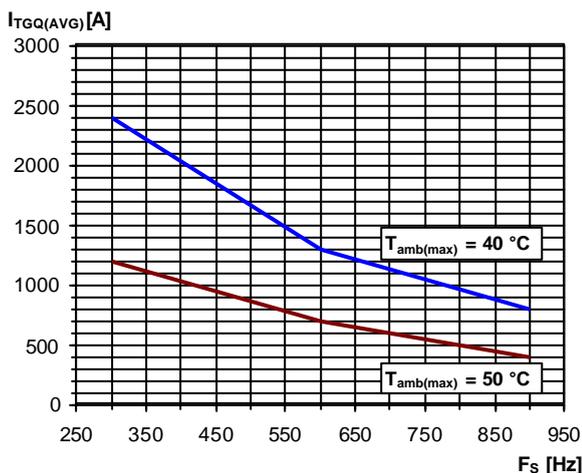

- **Calculated lifetime of on-board capacitors 20 years.**

- **With slightly forced air-cooling (air velocity > 0.5 m/s).**

- **Strong air-cooling allows for increased ambient temperature.**

Fig. 15:   *Maximum turn-off current for life time operation*

Short-time operation outside recommended area in an overload situation might be still allowed, if continuous operation has acceptable margin to the limits. If operation outside the area recommended in Fig. 15 is required in steady state, improved air circulation will help to keep capacitor temperatures below acceptable limits.

Due to the poor predictability of the effect of equipment air circulation it is advisable to measure gate drive capacitor temperature under worst case converter continuous operating conditions as part of a type test program. This to verify operation within acceptable limits.

Vibration compliance

Vibration compliance and testing is thoroughly described in [1].

Pollution, surface treatment

The boards are varnished with Humiseal 1B73. The conformal coating process is carried out according to IPC-A-610A.

The idea of the surface treatment is to protect the PCB board against moisture and condensation according to IEC 60664. In the terms of this standard the Humiseal coating yields a type A coating fulfilling the requirements of pollution degree 2. Beyond that, the Humiseal coating also yields a limited protection against corrosion and conductive particles although not sufficient for the higher pollution degree 3.

4. The hard drive principle of IGCT technology

An IGCT is far more than a hard driven GTO with improved switching robustness. However, the key to substantial improvement in switching robustness compared to the conventional GTO technology stems from the ultra low inductance of the gate drive circuitry and its low inductance connection to the GCT. In the following a brief explanation of ON and OFF state circuitry and generation of turn-on and turn-off pulses is given.

4.1. The off-state

The gate-cathode terminal is kept negative biased (V_{GK} = -20 V) as shown in Fig. 16. During the off-state the switch V6 is ON.
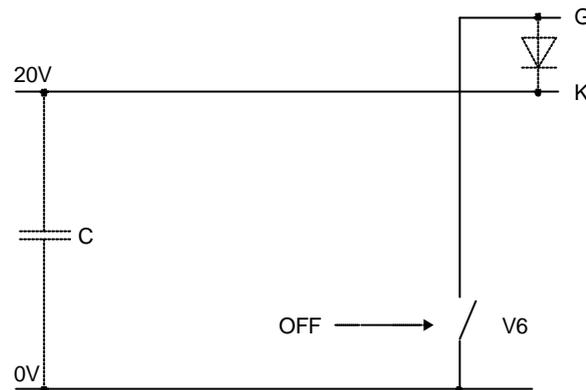

Fig. 16:   Off state and turn-off circuitry

Due to the very low inductance (5 to 15 nH dependent on IGCT type) of this circuit and the large capacitor bank, the IGCT is extremely insensitive to electromagnetic noise at the gate-cathode terminal.

This in comparison to a conventional GTO driver which typically has an inductance of ca. 200 nH and a smaller capacitor bank.

4.2. Hard driven turn-on

The turn-on pulse is generated by the turn-on circuitry of Fig. 17.
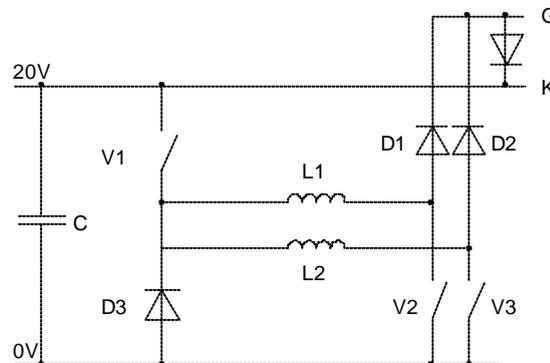

Fig. 17:   Turn-on pulse generation

The pulse current is built up in chokes L1 and L2, V1, V2 and V3 being ON. When the necessary amplitude is attained, the choke current is commutated into the gate terminal in two steps by turning off switch V2 first, and then V3. See turn-on pulse current waveform in Fig. 18.
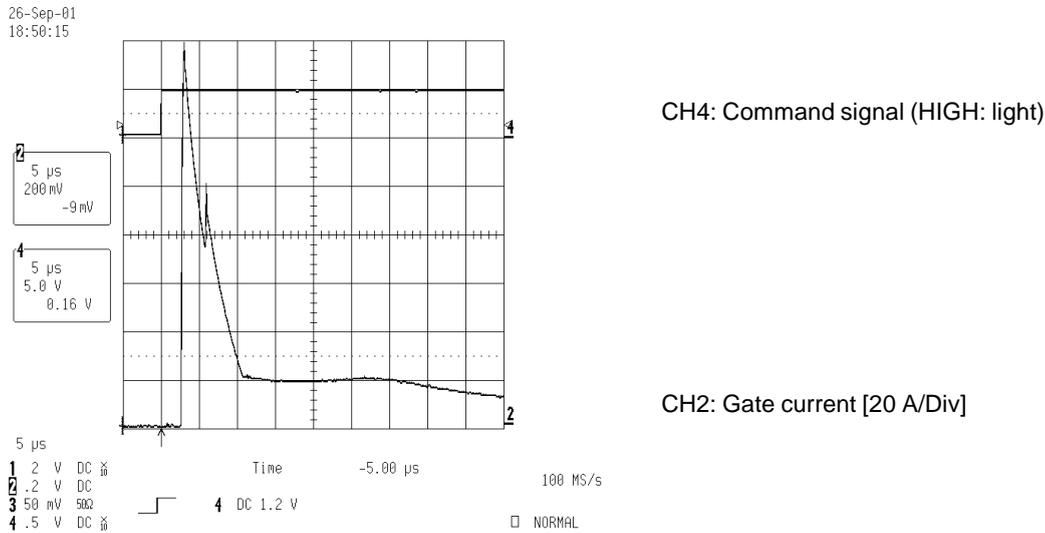


```
26-Sep-01
18:50:15

    2
    5 µs
    200 mV
        -9 mV

    4
    5 µs
    5.0 V
        0.16 V

    5 µs
    1  2  V  DC  ¼
    2  .2 V  DC
    3  50 mV  50Ω
    4  .5 V  DC  ¼

         Time        -5.00 µs

                          100 MS/s

         4  DC 1.2 V

                          NORMAL
```

                                                    CH4: Command signal (HIGH: light)

                                                    CH2: Gate current [20 A/Div]

Fig. 18:   Turn-on pulse (measurement)

Due to the very low gate circuit inductance, an extremely low-rise time of gate current is achieved, which in turn ensures homogeneous and reliable IGCT turn-on across the operating temperature range.

Thus the hard drive principle contributes to reliability and robustness at turn-on. As a consequence, anode current di/dt at turn-on can be increased, thus reducing cost, size and losses of the turn-on di/dt snubber.

Anode current does not always flow immediately after turn-on of the IGCT. This is the case in current source inverters where diode turn-off sometimes delays the commutation of current into the ongoing IGCT. The second part of the turn-on pulse is designed to meet the requirements of this commutation type.

Prior to turn-on pulse execution the switch V6 of Fig. 16 is turned off.

4.3. On state

While the turn-on pulse is executed, the on-state gate current is built up in the circuit of Fig. 19.
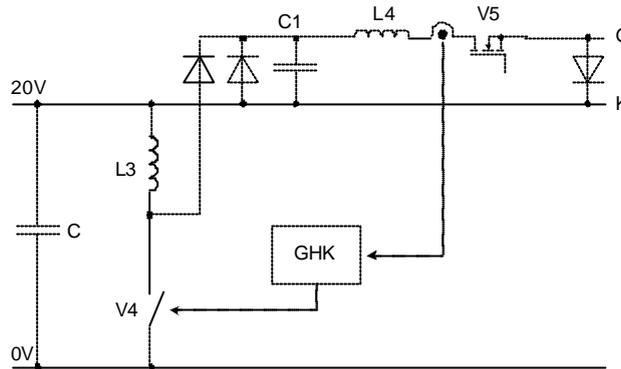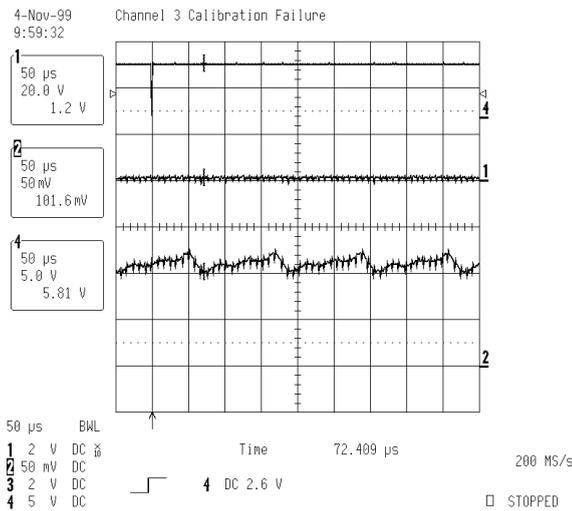

Fig. 19:   Back porch current generation

A tolerance band current controlled "chopper" gives the characteristic ripple current waveform in Fig. 20.

CH4: Command signal (HIGH = light

CH1: Gate-to-cathode voltage, V_{GK}

CH2: Gate current [5A/DIV]

Fig. 20:   Back porch current (measurement)

The on state gate current reference value is controlled by the ambient temperature. A high level at low temperature is required by the GCT, whereas a lower level at high temperature reduces losses and board operating temperature.

4.4. Re-firing during on-state

A negative gate bias during on state is a cumbersome mode of operation for IGCT and GTO gate drives. This mode occurs in any VSI circuit when an antiparallel freewheeling diode is conducting; i.e. the switch current is negative. Firstly, in this mode the power dissipation in the gate drive increases. Secondly, the gate current flows through the anode and not through the cathode where it is supposed to flow. Thirdly, at the zero crossing of the switch current, the GCT is not quite ready for conduction and anode voltage is built up before latching takes place again. A so-called "power pulse" which is the product of the transient voltage and current pulse can be observed on the oscilloscope. It is not the magnitude of the power pulse which is harmful, but the accompanying inhomogeneous current distribution in the semiconductor which might lead to device failure if "power pulses" are generated in a repetitive mode and nothing is done to suppress them.

```
26-Sep-01
19:13:06

1
20 µs
5.0 V
  -2.66 V

2
20 µs
0.50 V
  -11 mV

20 µs
1 .5  V  DC  x10        Time      -39.84 µs
2 .5  V  DC
3 50 mV  50Ω            2  DC 0.93 V         100 MS/s
4 .5  V  DC  x10
                                             □ NORMAL
```
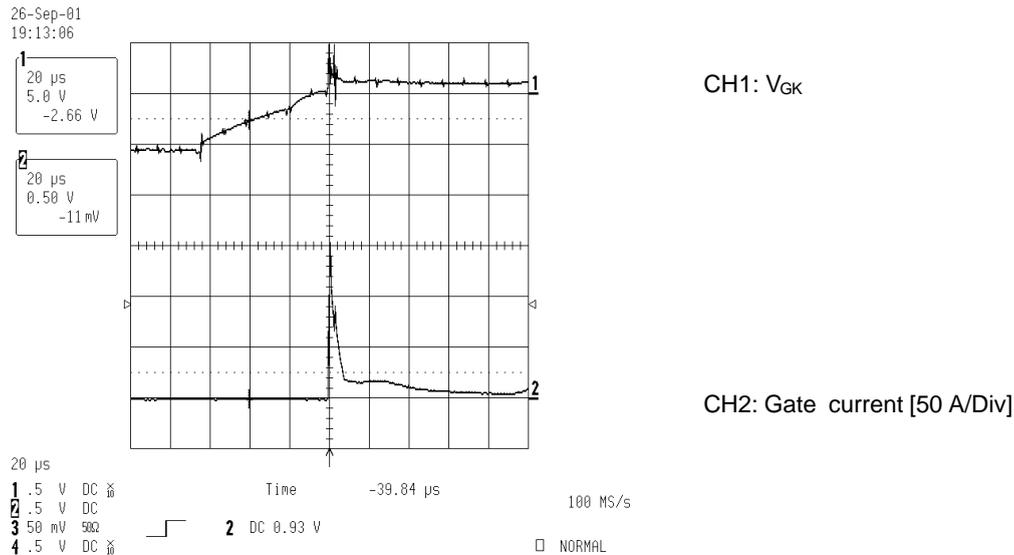
CH1: V_{GK}

CH2: Gate current [50 A/Div]

Fig. 21:   Simulation of negative biased gate and re-trigger pulse (measurement)

IGCT gate drives have features implemented in order to ensure robust and reliable operation in the negative-biased on-state mode:

a). Detection of gate-cathode voltage polarity V_{GK}.

b). Reduction of gate current when the gate-cathode junction is negative biased (freewheeling diode is conducting)

c). Automatic re-execution of turn-on pulse (called internal re-trigger) when the gate-cathode voltage V_{GK}, becomes positive again

d). External re-trigger of the turn-on pulse during on-state

Features a) – c) are sufficient to handle freewheeling diode conduction in topologies with "normal" di/dt values typically caused by the zero crossing of an inverter phase output load current of less than 50 A/µs. However, in some applications the internal re-trigger execution might be too slow. This is the case if a high di/dt current pulse (> 50 A/µs) is repetitively applied to an IGCT switch in a freewheeling diode conduction mode or very low anode current conduction (quiescent mode).

For these rather seldom applications the external re-trigger command described in Chapter 3.3 was implemented.

More information about the re-trigger function and GCT anode current di/dt stress during quiescent on-state is given in [1]

4.5. Hard driven turn-off

By turning on switch V6 of the turn-off circuit of Fig. 16 a complete commutation of the anode current from cathode to gate is achieved before the GCT starts to build up anode voltage. Immediately prior to it, the on-state gate current is turned off by turning off the switch V5 of Fig. 19.

Thus well-known GTO-effects like current crowding in cathode segments and inhomogeneous current conduction during turn-off are avoided and a robust and low loss high turn-off capability is achieved without use of turn-off snubber circuitry, which is mandatory in GTO applications.

5. Reference

[1] B. Ødegård, R. Ernst, "Applying IGCT's", ABB Application Note 5SYA 2031-01, December 2002

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