SOLID STATE ON-OFF SWITCHES USING IGCT TECHNOLOGY

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Abstract

This presentation is about semiconductor devices used for On-Off pulse switching applications and used in a 12 kVdc / 3.2kA / 10 Hz solid state switch assembly. The switch assembly is built-up with IGCT (Integrated Gate Controlled Thyristors) and used for long pulse (1.6 ms) Klystron modulators. The design was made in 2002 and successfully implemented in the Tesla Test Facility (TTF) at DESY in Hamburg / Germany. The components and switches are in the position to switch and interrupt safely up to 4 kA. The presentation will inform about the IGCT devices, switch development, construction, production and commissioning of the complete assembly. Also reliability figures will be presented, and the last 4 years of operation have shown that the switches are extremely rugged. Several IGCT switches are in use in pulse modulators built by PPT Puls Plasmatechnik GmbH and this technology has resulted in a breakthrough for solid state switches in modulator applications. By using different silicon diameters for the devices, different current and pulse repetition rates can be achieved. A new improved version of the switch design is under development.

I. SEMICONDUCTOR DEVICE

The devices used in the PPT pulse modulator switch are normally operating as on-off switches at a nominal current of about 1800A. In case of arcing in the Klystron the switch must be in the position to switch off in a very short period to avoid damage to the Klystron. For this the IGCT technology was selected and because of the relatively high current, it was decided to use a 91 mm silicon wafer. The IGCT is basicly a hard driven GTO with an on-board driver unit and very low induction gate path. There are multiple gate entrances through the ceramic housing to the gate contact. The semiconductor supplier does a routine test on the combination of semiconductor and driver as one component. In Fig. 1 the mechanical construction of the IGCT is shown.

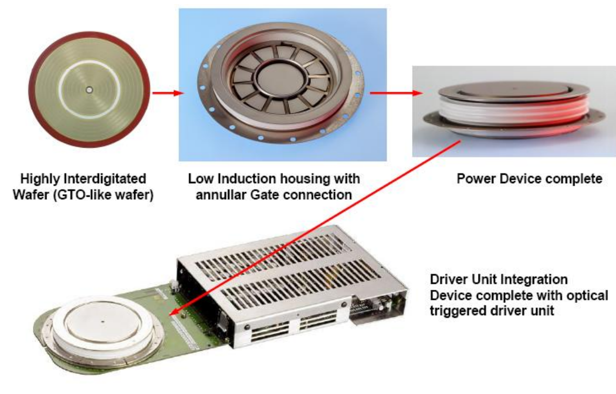

Figure 1. Built-up of IGCT device

ABB has a wide variety of IGCT devices with wafer sizes from 38 mm till up to 91 mm. Different versions are available i.e. Asymmetric Blocking devices Vdrm= 4500 /6500V and Vrrm=17V, Reverse Blocking devices Vdrm=Vrrm, and Reverse Conducting devices Vdrm=4500/Vrrm=0V. The last one has a monolithic integrated freewheeling diode. The devices used in the PPT / DESY application is a symmetric blocking device with Vdrm / Vrrm = 4500V. This device has the standard 91 mm asymmetric switching wafer and an additional diode wafer in series in the same ceramic housing. Reverse Conducting devices are used if the pulse is a full or damped sine wave. Fig. 2 shows different standard IGCT's.

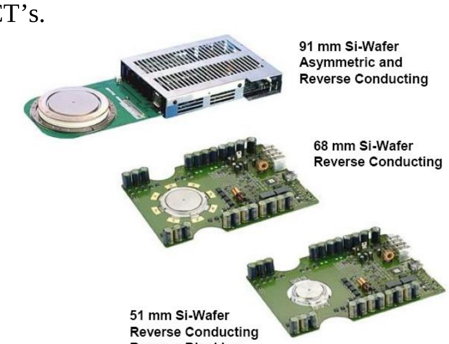

Figure 2. Different sizes standard IGCT's

Advantages of the IGCT

The IGCT as component offers several advantages for the user, some of these advantages are especially important for applications where high reliability is of vital importance:

- Integrated Driver Unit from same manufacturer.
- Device and Driver Unit are tested together
- Over 10 years of field experience.
- High Quality due to volume production (> 60.000 pcs)
- One monolithic wafer, no wafer or chip combinations which means excellent current sharing in the device.
- Pressure contact, no wire bonds which can lift.
- Double sided cooling capability.
- Short circuit failure mode, which is important in case of redundancy in series connections.
- Good availability because of industrial needs.

Depending on the application, some disadvantages have to be mentioned, which are the increasing power losses in the driver unit if used at repetition frequencies above 400Hz and the relatively slow reaction time of about 5 - 6µs from optical trigger input till full conductivity.

II. SWITCH DESIGN

Several IGCT switches were supplied for different pulse applications and are operational in the field. Main applications are Klystron modulators and modulators for food processing. The switch for a long pulse Klystron modulator, using IGCT's was designed by ABB/PPT in the year 2000. It was decided to use a reverse blocking design because of the expected reverse voltage of several thousand volts from the system. Table 1 shows the data of the reverse blocking IGCT device used for the switch assembly.

Table 1. Date Reverse Blocking IGCT

ABB P/N:	5SPB 35L4503
Forward Blocking:	4500V
Reverse Blocking:	4500V
Max. Vdc:	2800V
Switch-Off Current:	4000A @ Cs=4µF
T-on delay time:	$\leq$ 3µs
T-off delay time:	$\leq$ 5µs
Wafer size:	91 mm

The operating voltage of the switch is for continuous Vdc=12kV, pulse current 1.8kA at a pulse length of 1.7ms and pulse rep. frequency of 10 Hz. The switch must be in the position to safely turn-off within a few micro seconds the increasing current caused by klystron arcing. The detection level for arcing is set at 2.2kA, and because of the delay time, the current still will increase to about 2.8 kA before it actually will be switched off. The device can switch-off 3.5 kA with a snubber capacitor of 2.5 µF. In the switch assembly, seven devices are used in series connection, of which two devices are redundant. This in combination with the strong snubber circuit and additional varistors, gives the switch an extremely high reliability.

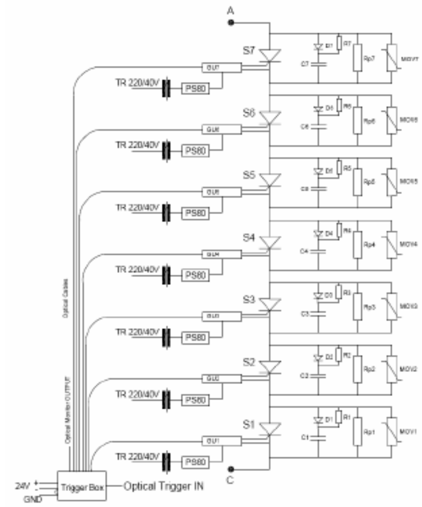

Figure 3. Circuit Diagram IGCT Modulator Switch

The 4500V IGCT devices are rated for continuous 2800Vdc. By using 4 IGCT devices in series connection the 12 kVdc charge voltage can be reached, but for series connection a derating of 10 – 15% has to be taken into consideration. Therefore a series connection of 5 devices plus 2 redundant devices was chosen. In case of device failure there will be a short circuit failure mode and the switch will continue to operate. In case a second device should fail, the switch will still operate but should be controlled switched off within about one minute to avoid overload of the snubber and sharing components. The IGCT driver units are optical triggered from one light distribution box. The driver units are individually powered by a stabilized power supply which is connected to an isolation transformer (24kV / 1 min). All components, except isolation transformers and power supplies, are assembled in one stack which is vertical built-up in a glass-fiber epoxy clamping system. However the average power losses are only about 100W per device, water cooled copper heatsinks are used to avoid that heat will accumulate at the top of the assembly and temperature differences between the devices will result in switching time differences. Large size 47 mm press pack varistors are used over every device level, which will protect the devices at max. turn-off, which can result in an overvoltage spike of up to 21 kV on switch-level. (Fig. 5) The overall dimensions of the complete switch assembly is about H=760 x W=270 x D=640 mm. Several of these switches are used in the DESY Tesla Test Facility (TTF) and are in operation since 2002. In Table 2 the specification of the switch assembly shown. Fig. 4 shows a picture of one of the switch assemblies as they actually are used in the modulator. In front of the IGCT devices which are clamped with 40 kN the press-pack varistors are visible which are clamped with 10 kN.

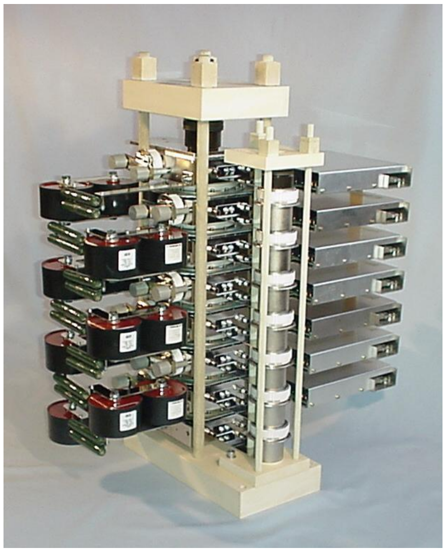

Figure 4. IGCT switch assembly complete

Table 2. Basic specifications of the switch

Charge Voltage:	12 kVdc
Reverse Blocking:	> 20 kV
Nominal Current:	1.8 kA
Pulse Duration:	1700 µs
Max. switch-off:	3500A @ Cs=2.5µF
Pulse Rep. Rate:	10 Hz

III. SWITCH TEST

The complete switch assembly was tested at the semiconductor suppliers test laboratory. Especially for series connected devices the trigger delay and jitter is important to avoid that there is a difference in switching behaviour between the individual devices. Because the devices are from normal volume production, a test was done on gate-signal-delay at turn-on and turn-off. The acceptable tolerance is 50 ns. All devices were well within this tolerance. Also a pulse switch-off test at I-peak of 3kA was done and documented in Fig. 5 below

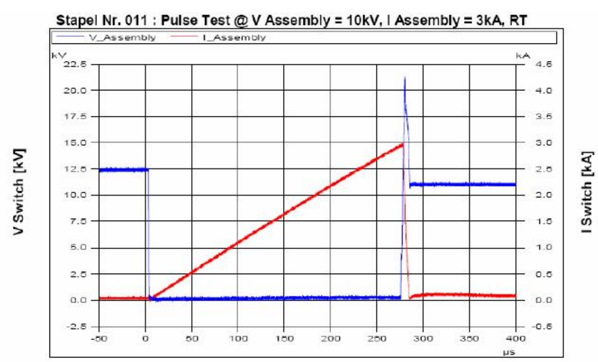

Figure 5. Switch-Off test at 3 kA

During switch-off at 3 kA a sharp voltage peak was noticed but this will be clamped by MOV's when the spike should rise over 22 kV.

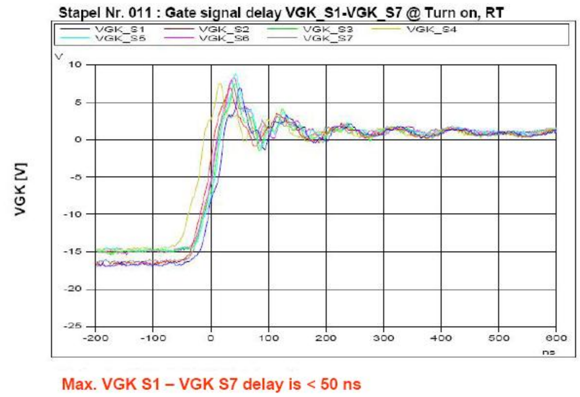

Figure 6. Gate signal delay and jitter at Turn-On

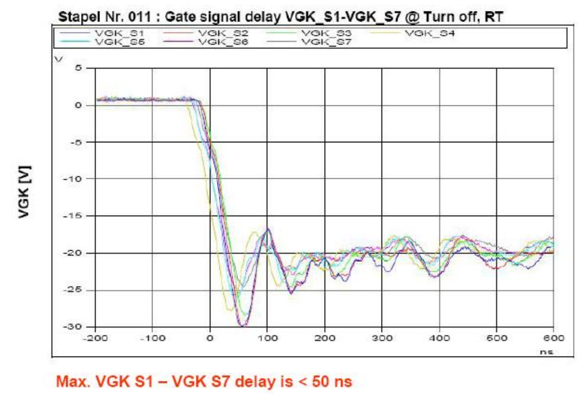

Figure 7. Gate signal delay and jitter at Turn-Off

IV. LIFE TIME

IGCT type switches are succesfull in use for several years and field experience is collected and compared with the calculated results. Most important to get a long life-time is the right design of the assembly on behalve of blocking voltage, cont. DC voltage (cosmic ray), snubbering, protection circuit, homogeneous clamping and thermal management. In total 11 switch assemblies were delivered and since 2002 in service at different places in Europe, most of them at DESY in Hamburg, Germany. Total cumulated hours in operation are more than 250.000 with a repetition rate of 10 Hz. During this period no device failures were detected. The expected calculated life-time under the given conditions is clearly more than 20 years continuous operation. The single device levels are at a conservative DC voltage of 1715 Vdc, which gives a redundancy of 1 device for continuous operation and 2 devices for controlled switch-off within a few minutes to avoid that the sharing resistors and varistors will get overheated.

V. REVERSE CONDUCTING DESIGN

For modulators using discharge pulses with damped sine waves, normally a free-wheeling diode has to be used. In such cases it is preferred to use semiconductor devices which have the free-wheeling diode direct monolithic integrated on the same silicon as the switching wafer. This gives the advantage of almost no induction between diode and switching part. Fig. 8 shows a circuit diagram of a 12kVdc reverse conducting IGCT switch assembly used also for a long pulse modulator at CERN, Geneva.

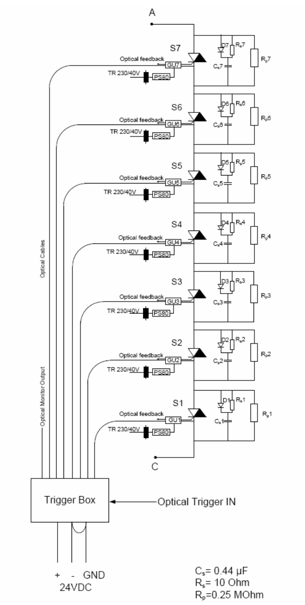

Figure 8. Circuit Diagram of Reverse Conducting Switch

This switch was designed for lower current, using smaller IGCT devices with 51 mm silicon wafer. The switching current in the application is specified for 300A only. In Fig. 9 the switch-on and switch-off wave form are shown. The negative current, which is taken by the integrated diode, is clearly visible.

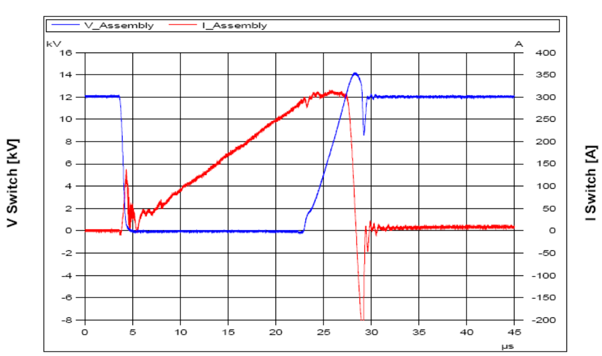

Figure 9. Switch-on and Switch-off wave-form

Some oscillations occur because the test was done on a 7 level switch with 2 levels shorted to test redundancy.

Because of the the low PRF of 2 Hz, the switch is cooled by air convection only. Devices used for this 300A reverse conducting switch assembly are ABB standard p/n 5SHX 08F4510.

Figure 9. Reverse Conducting Switch (Photo CERN)

The designs presented are for pulse frequencies of 2 – 30Hz. New designs are under construction to realize higher frequencies in combination with better cooling and integrated power supplies. Further development on the large size IGCT's has given higher switching capability and therefore more relaxed operation in the application.

VI. CONCLUSIONS

Since more than 10 years ABB is producing IGCT devices in volume and a large field experience is gained with more than 60.000 devices. For long pulse modulator switches the IGCT has proven to be most reliable because of the very rugged construction with single wafer large area silicon. The integrated driver unit, which is tested direct together with the semiconductor part, gives the IGCT an almost unbeatable position in this field as long pulse modulator switch if moderate voltages (up to 20 kVdc) are used. Reliability figures over the last 6 years with several pulse modulators from PPT Germany used at the DESY Tesla Test Facility and other institutes have shown no problems with these devices. Further improvements to use designs at higher frequencies for Free Electron Lasers are under development.

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