A Medium Voltage Fully Controllable Solid State Switch for Klystrom Modulator

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Abstract—The paper will describe the specification, design, production and test of a fully controllable solid state on-off switch in IGCT-technology. (IGCT = Integrated Gate Commutated Thyristor) This type of switches is often used for linear particle beam accelerators and successful in use in several Institutes and National Laboratories to drive long pulse Klystron Modulators. The described solid state switch is rated for 4.4 kVdc, 1850 A peak, 2 ms pulse and 2 Hz repetition rate under normal conditions and can turn-off 3700 A under fault conditions and a max. peak voltage of 9 kV. The IGCT's used are commercially available devices and have a 91 mm silicon wafer with a monolithic integrated freewheeling diode. To reach a high reliability 3 devices of 4.5 kV blocking voltage are used in series connection which gives the switch one redundant device and a large silicon area to enable a high switch-off current in case of klystron arcing. The rated current of 1850 A is switched continuously at 2 Hz, and therefore air convection cooling can be used. The described switch comes as ready-to-use design including isolated auxiliary power supply, optical triggering and optical feedback.

Keywords: IGCT, Soid State, Reverse Conducting, On-Off switch,

I. INTRODUCTION

The described solid state switch was designed and optimized for the application. The switch is produced in quantities for a long pulse klystron modulator used in a linear beam accelerator at CERN in Geneva / Switzerland.

II. SWITCH SPECIFICATIONS

The IGCT switch is specified for continuous use in a Klystron modulator for a linear particle beam accelerator, driving two Klystrons in parallel. Therefore it is of high importance that a safe turn-off is guaranteed in case of arcing in the tube. To avoid an expensive high voltage solid state switch with a high quantity of devices in series connection, an optimized solution with a medium voltage switch and a step-up pulse transformer was chosen by the end user. In Table 1 the main data of the switch are listed.

Charge Voltage (Vdc)	4.4 kV
Max. Peak Voltage	9.0 kV
Rated turn-off current	1850 A
Max. turn-off current	3700 A
Pulse width (Typical)	2 ms
Pulse width (Maximum)	2.3 ms
Pulse repetition rate	2 Hz
Max. stray inductance	3 µH
Ambient temperature range	5 … 40°C
Cooling methode	Convection Air

Table 1: Main data of the IGCT switch

III. SEMICONDUCTOR DEVICE

The devices used in the pulse modulator switch are normally operating as on-off switches at a nominal current of about 1850A. In case of arcing in the Klystron the switch must be in the position to switch off an increasing current in a very short time period to avoid damage to the tube. 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 basically 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.

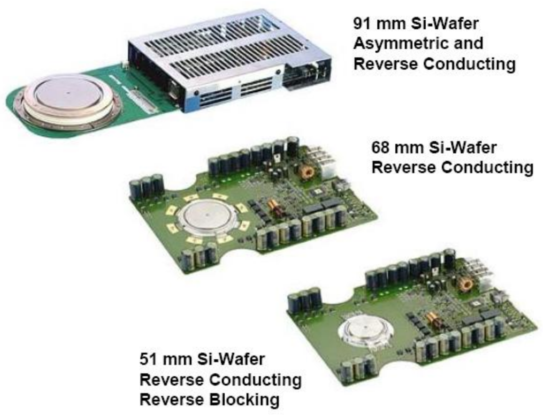

Figure 1: Selection of different sizes IGCT devices

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 / 6000V 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 and is used in the presented switch.

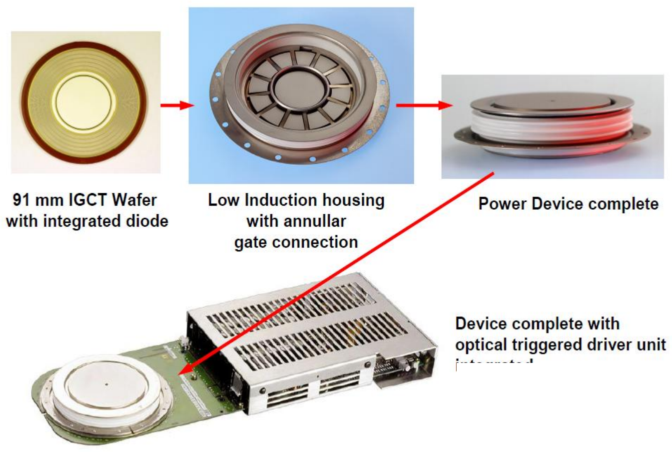

Figure 2: Reverse Conducting IGCT with 91 mm wafer. Device P/N 5SHX 26L4510-HPT [3]

IV. SWITCH DESIGN

A. *Electrical design*

In table 1 the specification is shown. The devices used for this solid state switch have a forward voltage blocking capability of 4500V, but due to the integrated freewheeling diode no reverse blocking capability. Figure 3 shows the basic circuit diagram of the klystron modulator.

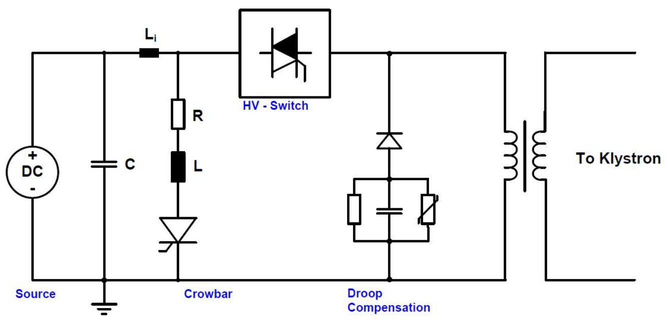

Figure 3: Basic circuit diagram modulator

The main capacitor (C) charge voltage is 4.4 kV, nominal operating current of the switch is 1850A and a peak switch-off current of 3700A. The 4500V IGCT devices are rated for continuous 2800Vdc. By using 3 devices in series connection, a total DC withstand ability of 8400Vdc is given, less 2800V for the redundant device, means the switch can reliable operate at 5600Vdc continuously. The IGCT driver units are powered by a closed loop 8A/25kHz current source power supply feeding the input transformers of the inductive coupling at the driver unit. The isolation value of the HV cable which is sloped through the input transformers gives the isolation between the individual driver levels. Figure 4 shows the circuit diagram of the IGCT switch including power supply and trigger box.

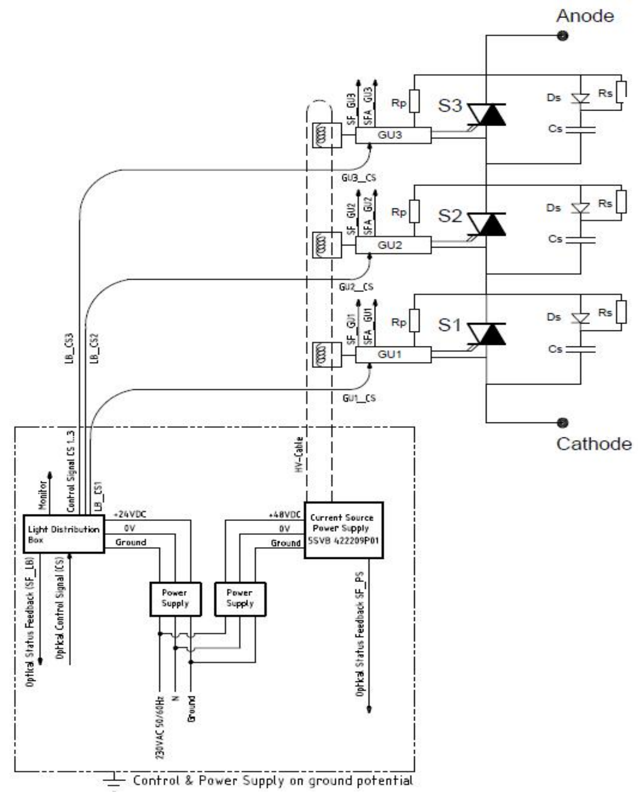

Figure 4: Circuit diagram solid state switch assembly

Over every device level a relatively large RCD snubber circuit is connected to make sure that the 3700 A can be switched off under all circumstances. The trigger signal for the switch is an optical signal which is split in the light distribution box to trigger all three IGCT driver units simultaneously. Every individual driver unit has an optical status output for monitoring the trigger function and also to monitor device failures like gate-cathode shortage.

B. *Mechanical design*

All components, except the power supply and light distribution box are assembled in one stack, built-up in a glass-fiber epoxy clamping system which can be mounted into the modulator in any position. The clamping force on the devices is 40kN which is assured by a bellville spring pressure pack. Large Ni-plated copper blocks are used between the devices and have a function as spacer, snubber support and cooling. Due to the low pulse repetition rate of 2 Hz the power losses under normal operation are below 100W per device the cooling can be done by air convection. The total weight of the switch, without the light distribution box and power supply, is approx. 50 kg and overall dimensions are 360 x 625 x 470 mm. In Figure 5 the dimensional drawing of the switch assembly is shown.

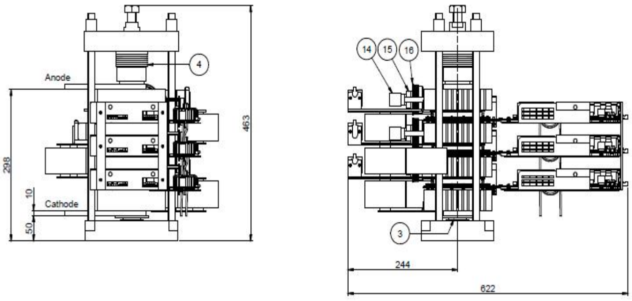

Figure 5: Mechanical built-up of the switch assembly

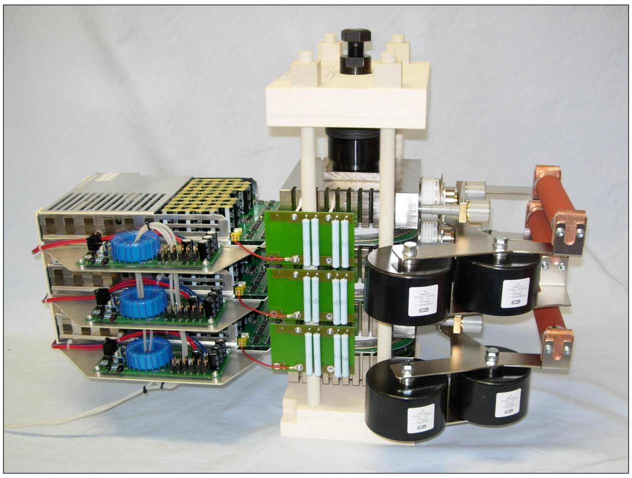

Figure 6: Picture of complete switch assembly P/N 5SVG 0131409E01

In Figure 6 the inductive couplings with the input transformers (blue) to power the driver units are visible. The high voltage cable (white) is sloped through the input transformers and connected to the current source power supply [2]. In case of auxiliary power failure at the closed loop current source power supply, the power supply is still in the position to charge the driver units to switch-off once.

V. SWITCH TESTS

Before producing the switch assembly the IGCT devices undergo the standard routine test in the production line, which means full blocking voltage of 4500V and full switch-on / switch-off capability as per device specification. All tested values are recorded and protocolized. As all devices for one switch assembly are taken from the same production lot it is possible to minimize differences in leakage current and optimize voltage sharing. The devices used in the assembly have a leakage current of only 0,2 mA and a difference in voltage sharing of only 20 V in the stack assembly. After the assembly is produced, a functional application oriented test is done. Because of series connected devices, the trigger delay and jitter between the devices is important. One of the tests is gate-signal-delay at turn-on and turn-off. The acceptable tolerance is 100 ns. All devices were well within this tolerance. Beside the single pulse tests also a type test is done under full load conditions with 1850A / 4400Vdc / tp= 2 ms / 2 Hz during 10 minutes till thermal stabilization. Figure 7 shows the circuit diagram used for the test.

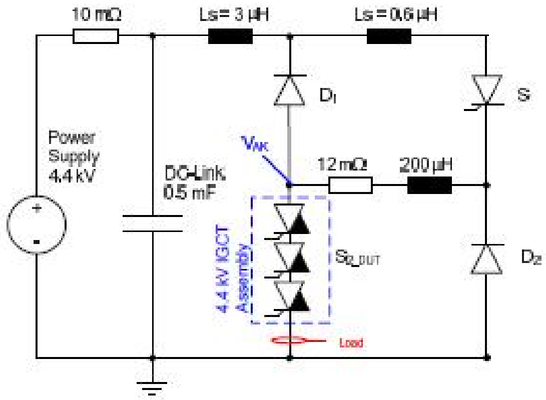

Figure 7: Circuit diagram of test set-up

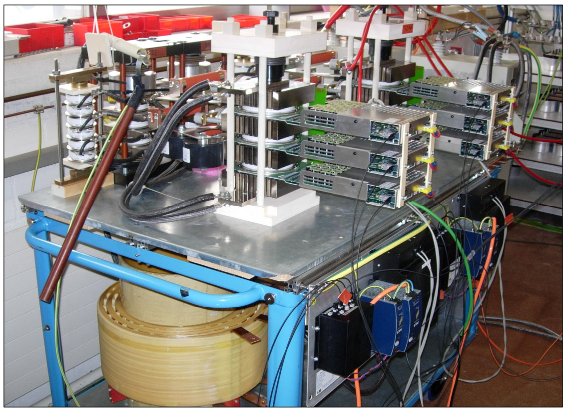

Figure 7: Test set-up in ABB Test laboratory. The light distribution box and power supply are also visible.

In Figure 8 the voltage and current wave-form are shown, of which the I_{load} 1.85 kA is normal condition and and the I_{load} 3.7 kA is Klystron arcing condition.

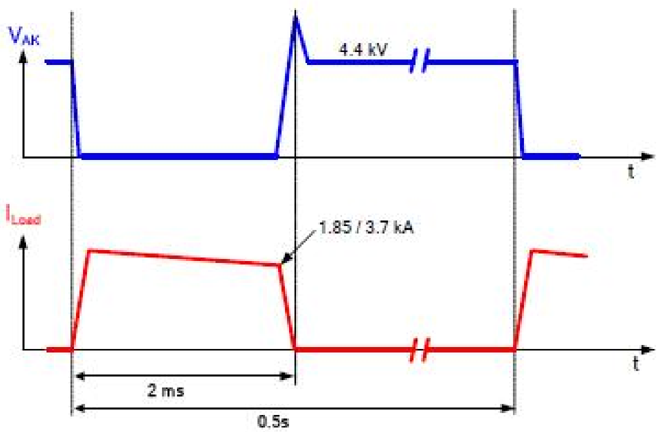

Figure 8: Voltage and Current Wave-forms

VI. TEST RESULTS

Routine tests were done under nominal condition with Vdc charge = 5.1 kV / I-peak = 2.4 kA / f = 2 Hz. The current was switched off after 2 ms at V_D = 4.7 kV / V_{DM} = 6.7 kV / 1.9 kA. In Figure 9 the results are shown.

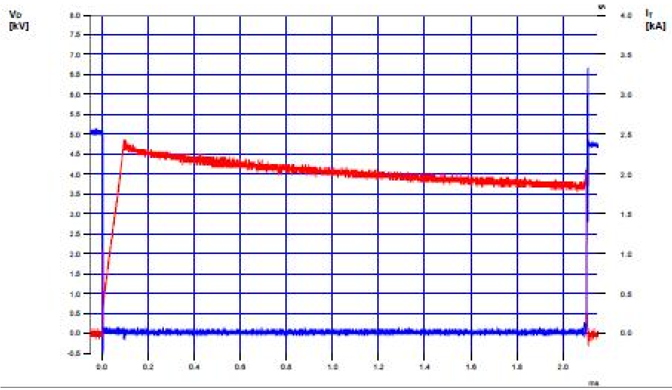

Figure 9: Test results switch routine test.

As type test the Klystron arcing mode was taken as reference, the following single pulse switch-off values were used: Turn-on at Vdc = 5500V / Ip = 4.5 kA, Turn-off with 3.7 kA / V_D = 4.5 kA / V_{DM} = 7.9 kV. In figure 10 the results are shown. Under this condition the V_{DM} ramps up to 7.9 kV.

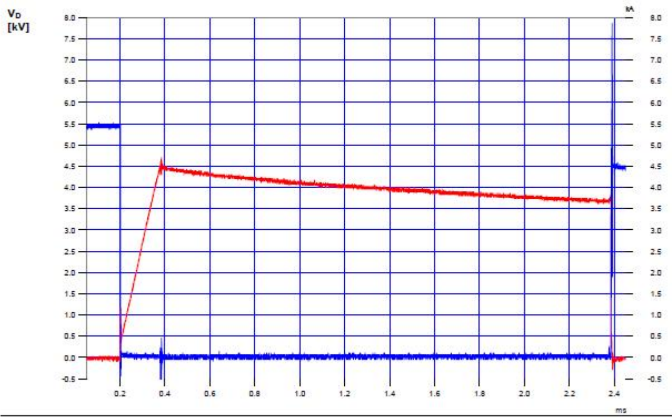

Figure 10: Single pulse test Klystron arcing condition

The switches have past the tests successfully.

VII. RELIABILITY

As mentioned already before the IGCT switches are extremely reliable and several switches in the field with higher series connection and higher repetition frequency in other modulator applications, which are already in use since 8 years, have confirmed this. The cumulated hours of operation for this type of IGCT devices in comparable modulator applications is 80^{-6} hours without any failure. For the actual design the FIT rate (FIT = Failure In Time) of all components in the assembly were carefully checked and because there are many small components in the driver units and power supply the risk is higher to lose some of these parts before the semiconductor device itself. The semiconductor device of the IGCT has under given conditions a rate of only 1 FIT, the driver unit which has much more parts, has a FIT rate of nearly 2000 and the power supply approx. 1000. Calculations have shown that for the complete switch with all components, if used at sea-level and +40°C, the first failures are not expected before 11 years after continuous use. Definition of 1 FIT = 1 failure per 10^{-9} hours of operation.

VIII. SUMMARY

The presentation has shown the design, production and test of an IGCT switch assembly for long pulse modulators. Since more than 12 years ABB is producing IGCT devices in volume and a large field experience is gained with more than totally 125.000 devices which however are mainly used for motor drives, frequency converters and wind energy applications. For long pulse modulator switches the IGCT technology has proven to be most reliable because of the very rugged press pack construction with one single wafer and a large contact area. The integrated driver unit, which is assembled around the semiconductor device and is tested together with the device, gives the IGCT an almost unbeatable position in this application field. Reliability figures over the last 8 years with several pulse modulators used in particle beam accelerators have shown no problem with the devices or switches. The IGCT is still further developed for higher voltages and higher currents.

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[3] Datasheet ABB Switzerland Ltd, Semiconductors 5SHX 26L4510 as adapted standard version HPT (www.abb.com/semiconductors)