SEMICONDUCTOR SWITCHES REPLACE THYRATRONS AND IGNITRONS

A. Welleman, E. Ramezani, U. Schlapbach
ABB Semiconductors AG, CH-5600 Lenzburg, Switzerland

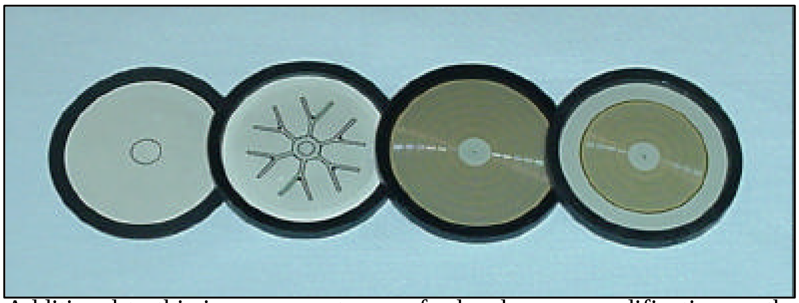
Abstract
A solid state switching system is presented which is designed a high reliable, long life, low maintenance product for short repetitive and high di/dt pulses. The solid state switch uses special designed semiconductor devices with integrated fast triggering circuits which are powered by one closed loop current source power supply. Blocking voltages of over 30 kV are possible by stacking several devices in series connection. The solid state system has no environmental restrictions and can be used in any position

1) INTRODUCTION

Since several years ABB is offering complete solid state switches which are based on a wide range of specific devices which are designed for non-repetitive pulsed power applications. More recently, interest has been shown in fast semiconductor switches which can be used at medium frequencies, to replace thyratrons and ignitrons because of longer life, no use of mercury and almost no maintenance. For this applications, ABB has designed a new platform technology and is using this concept in a range of different switches. These switches are so called Power Parts, as they are built up as an assembly with semiconductors, drivers, clamping, cooling, power supply and triggering, but are without cabinet or control system.

2) SEMICONDUCTOR DEVICES

The evolution of silicon wafers for high di/dt application started about 1975 with the central gate SCR's capable to handle 200 – 400 A/µs, followed later by higher interdigitated gate structures which allowed about to double these values. Since 1992 the use of GTO-like structures has improved the di/dt handling tremendous, but only in combination with special buffer layers and very low electron-irradiation, it was possible to develop an acceptable wafer for high current, high di/dt and repetitive switching. To reduce the inductance between switch component and freewheeling diode, the last one was directly integrated on the same silicon wafer. A GTO-like wafer structure with integrated freewheeling diode is shown in Fig. 1 (right) direct next to a full switching wafer without diode.



Additional to this improvement on wafer level, some modification on the device housing was done to get more through-connections through the ceramic housing to the driver unit. To get the shortest possible low inductance distance to the driver unit, the driver was built-up and integrated around the ceramic semiconductor housing. With this solution the inductance between switch, freewheeling diode and the driver unit can be reduced to only a few nH. This compact component is the base of a platform technology where a family of 3 different sizes (51 / 68 and 91 mm O.D.) can be used to design switch-assemblies for different current levels and thermal requirements. For Thyratron or Ignitron replacement normally a Reverse Conduction device will be used, but Reverse Blocking or Asymmetric versions are also available. The standard blocking voltage is rated at Vdrm = 4,5 kV and max. cont. DC Voltage is 2.8 kV, or 3.6 kV < 1 min. The switching system presented is using a 51 mm reverse conducting semiconductor discharge switch with integrated driver unit, ABB P/N 5SPR 08F4500. See Fig. 2 and Fig. 3.

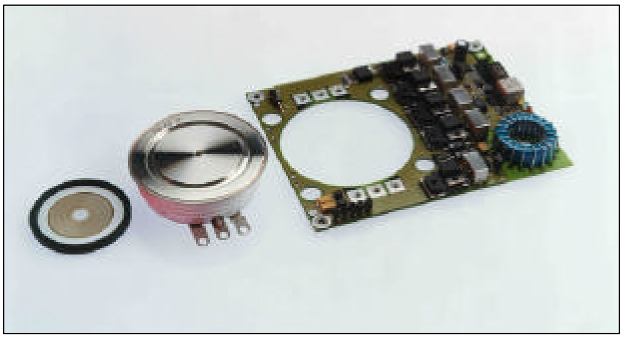


Fig. 2) Reverse conducting 51 mm discharge switch showing wafer, switching device and driver unit separated.

Fig. 3) Device 5SPR 08F4500 complete

The device 5SPR 08F4500 can be used within a wide specification, of which the key parameters like pulse current, pulse length, rep. rate and cooling are the main factors to make a reliable design. The basic specification of the device is Vdrm = 4.5 kV / Vdc max = 3.0 kV / di/dt = 10 kA/μs / peak-pulse current = 10 kA @ tp = 50 μs / Rep.rate $\leq$ 400 Hz.

3) DRIVER UNIT, INTEGRATED WITH 51 mm DEVICE

To reach a very low inductance the driver unit is integrated direct around the semiconductor switching device. With this construction , and the very low induction gate-connection path, high di/dt and very fast switch-on can be reached. As the switching component is designed for repetitive use, the driver unit has an on-board power supply, which needs an external power source. In case of one single device, the isolation can be easily handled, but in case of stacking several devices in series connection, galvanic separation between the driver units is getting dominant. Therefore it was decided to equip the driver unit with an input transformer, using inductive extraction fed by a separate current source. The current source operates with a 25 kHz closed loop, using an HV-cable, which is sloped through the input transformers of all the driver units. The triggering of the switch is activated by an optical signal. The optical receiver in the driver unit is a commercial HP optical receiver for glassfibers. The driver unit accommodates LED's which indicate Status, Power and Faillure mode. The power consumption of the driver unit is depending on switching frequency, which is about 4 W for up to 50 Hz and 10 W for 400 Hz.

4) POWER SUPPLY

A closed loop current source power supply is used to energize the driver units. In standard version this is done with 25kHz / 4 A, using a closed loop high voltage cable sloped through the input transformers of the driver units. The HV-cable has an isolation voltage of over 30 kVdc cont. Therefore the series connection of devices can easily go up to a charging voltage of 25 kVdc, which means about 10 device switching levels. For higher voltages, a master – slave combination of power supplies, or isolation transformers to feed more power supplies has to be used, and series connection of stacks has to be provided. Fig. 4 shows the power supply for the 51 mm devices.

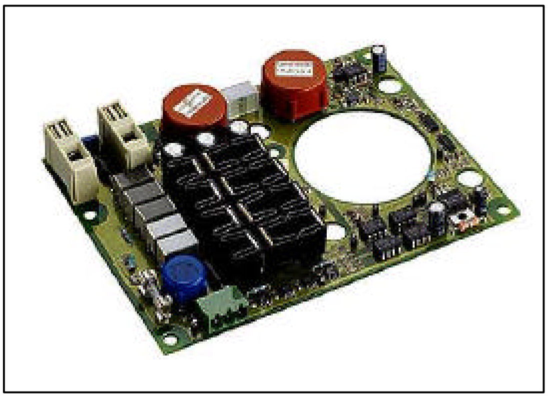


Fig. 4) Current Source Power Supply

5) LIGHT EMITTER BOX

The driver units of the switches are activated by optical signals, which are provided by a light emitter box (Fig. 6). For simultaneous triggering of all devices, the light emitter box has the same amount of optical output sockets as the switch assembly has devices in series connection. In addition there is one optical output to monitor the function of the box. The trigger signal provided to the box can be electrical or optical, depending on system requirements. It is recommended to use optical input for the trigger signal to avoid any interference by high electric fields in the switch area. Therefore it is also recommended to use the light emitter box away from the switch assembly. The pulse-length of the trigger signal is an extreme important value, as the switch needs to be on during the full time of the main pulse. This means that if the main pulse, incl. ev. negative parts, is total f.e. 20 µs, the trigger pulse should be at least 30 µs long, and stopped only shortly before recharging will start again.
This is also shown in Fig. 5. The test was done over 6 device levels (15 kV) and a 12 kA pulse peak.

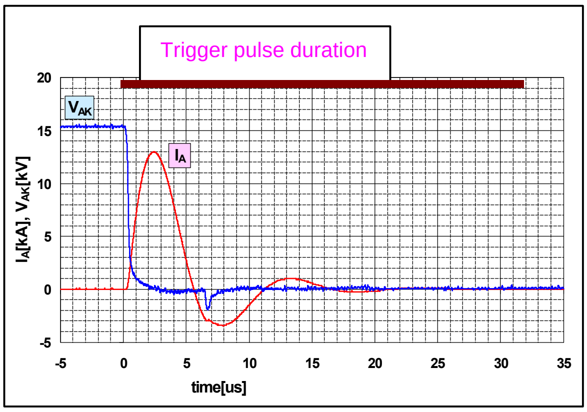


Fig. 5) Example for trigger pulse duration vs. main pulse

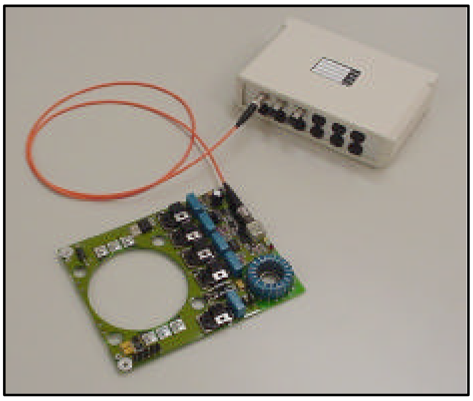


Fig. 6) Light distribution box with optical cable and driver unit

6) THYRATRON REPLACEMENT

Based on the circuit diagram for thyratron with freewheeling diode, ABB has designed a switch assembly, which offers the same performance, but is superior in handling, maintenance and lifetime expectancy.

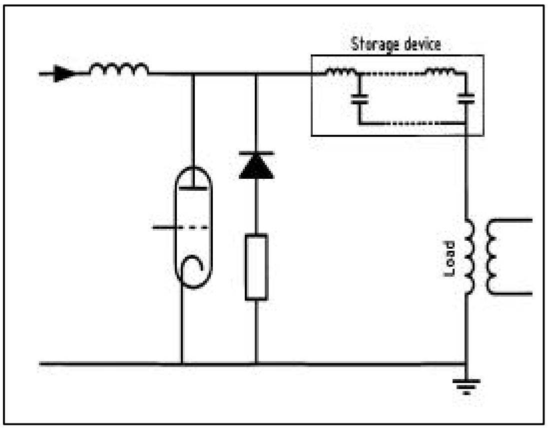


Fig. 7) Circuit diagram thyratron switch

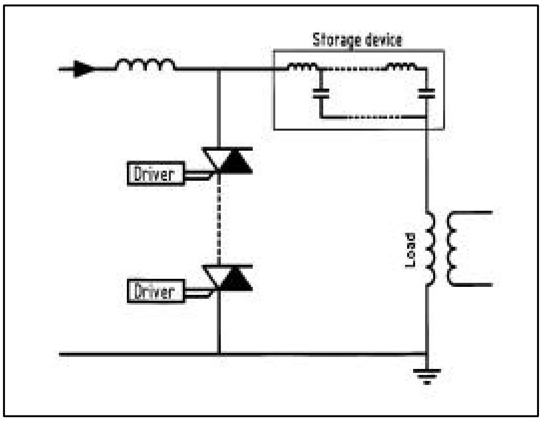


Fig. 8) Circuit diagram solid state switch

7) SOLID STATE SWITCH ASSEMBLY

The solid state switch assembly was designed for 12 kVdc charge voltage, using reverse conducting devices and typical specified for I-peak = 1,5 kA / di/dt = 1,5 kA/µs / tp = 10 µs and a rep. rate of 300 - 400 Hz. For this a series connection of 6 devices is used, which results in a Vdc of 2,0 kV per level. By using only 2 kV per level it is possible to keep the sharing resistors at a moderate level and cosmic ray has no influence on the life-time of the devices. There is also at least one redundant device in the assembly in case of device faillure. Depending on ambient temperature and cooling capability in the system it is possible to operate the assembly with deionized water cooling or forced air blowing to the assembly. The right cooling method depends on the application condition and can be calculated. Larger systems, with larger semiconductor devices, offering higher currents but based on the same principle are available, but are not part of this paper.

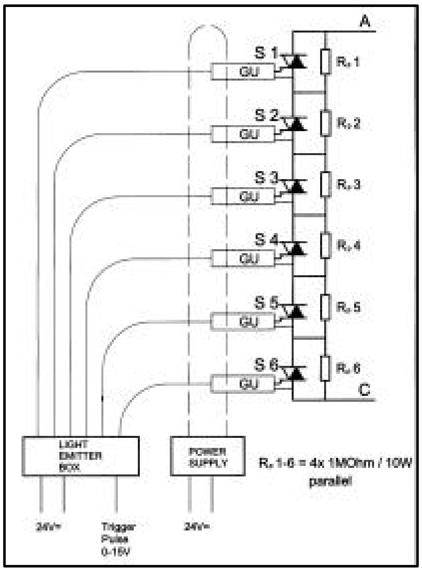


Fig. 9) Basic circuit diagram of solid state assembly.

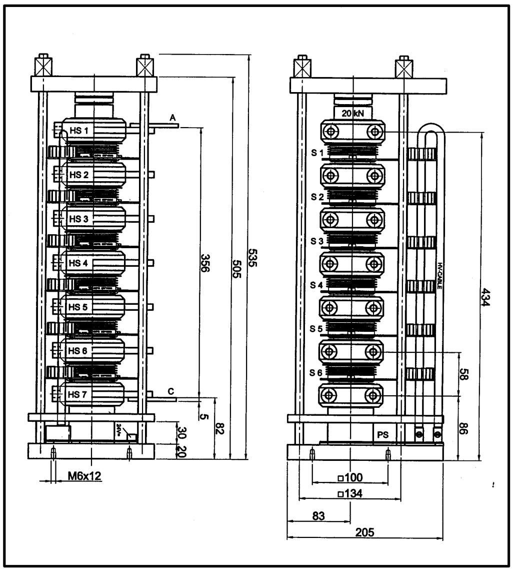


Fig. 10) Design drawing of solid state assembly.

The described switch is using standard ABB water-cooled heatsinks with 60 mm contact area. These heatsinks have two functions, one is the cooling of the devices at higher rep.rates, and second is the spacing between the driver units, giving enough isolation distance to avoid flash-over if used in air. The clamping system is built-up with fiberglass epoxy (Vetresit) parts and rods for good isolation and eliminating inductive heat-up. A 20 kN pressure pack with Belleville springs assure the clamping. In Fig. 11 the complete 6-level switch assembly is shown, including the power supply at the bottom of the assembly. The Light Emitter Box with optical cable to each driver board is shown at the top side of the stack assembly, but it is recommended to move this box away from the assembly to avoid any interference coming from the system or surrounding parts. Tests have shown that the delay time of the total solid state switch is typical less than 600 ns, and the Δ td between the different driver units is less than 50 ns.

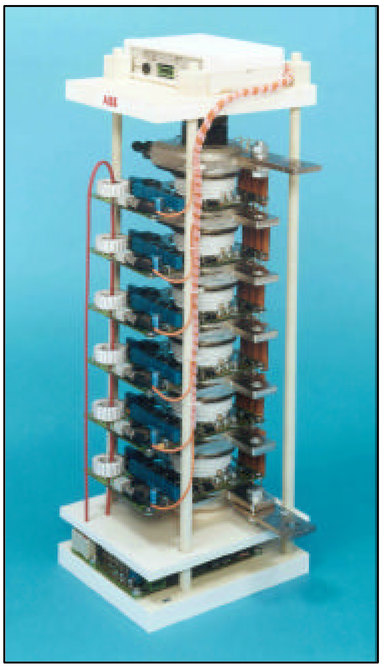


Fig. 11) Solid State Switch Assembly EFM-SPR 08F4500-6-WC

Vdc:	12 kV
I-pulse:	1,5 kA
tp:	10 µs
di/dt:	1,5 kA/µs
f:	400 Hz
Devices:	6 x 5SPR 08F4500 in series connection
Cooling:	Deionized water
Supply:	24 Vdc
Trigger:	Optical input

8) TEST RESULTS

Extensive testing is done on wafer, device and driver unit level, this includes the standard factory routine testing. Beside the component test the switch assembly is functionally tested per device level and as full assembly as such. This includes also recording of the data, as far as possible oriented to the customer application. The presented switch assembly was designed for an application to replace a thyratron tube with the given data. As shown in Fig. 5, the assembly is capable to reach different values, like higher peak current and shorter or longer pulse widths. Fig. 12 is showing a test result with a 1,5 kA pulse measured over one device level (2 kVdc) and the related trigger pulse duration.

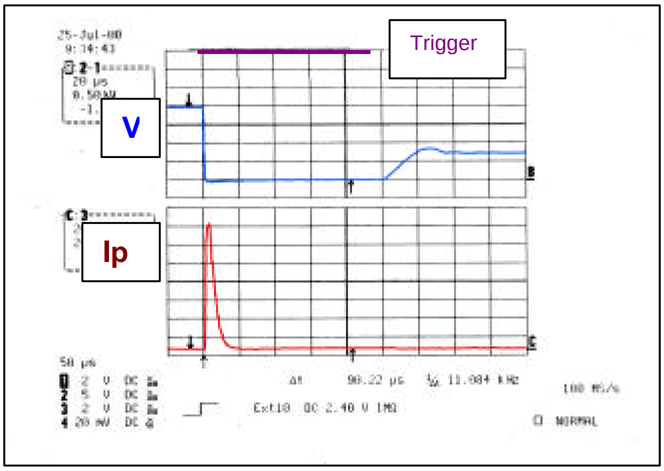


Fig. 12)
Test result over one device level
51 mm device P/N 5SPR 08F4500

The presented devices, drivers units, power supplies, heatsinks and complete switches are available since the end of 1999 with moderate delivery times of about 8 weeks. Because of using a modular platform technology, most of the parts can be combined into custom specific switch assemblies. The cost of a ready-to-use assembly as described in this presentation is about 2 x the costs of a comparable thyratron including driver- and heating circuit. (Status Y 2000) The main advantage of the solid state version is the more than 10 x longer life-time, practically no need for maintenance, no restrictions in positioning, and is environmental clean as there is no mercury inside.

10) CONCLUSION

It has been shown that ABB Semiconductors AG produces a range of specific designed components assembled as complete switches which are fulfilling a wide demand for repetitive use in Pulse Power. Circuit requirements and reliability considerations make it favorable to realize a very close interaction between the power semiconductor device, driver-unit, power supply and mounting stack. The switches, which ABB has designed, can replace thyratrons and ingnitrons for medium pulse repetition rates, and offer higher reliability in combination with almost no maintenance.

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ABB ABB Semiconductors AG, Fabrikstrasse 3, CH-5600 Lenzburg, Switzerland
Tel.: +41-79-540-9381 / Fax: +41-62-888-6310 / E-mail: pulsepower.abbsem@ch.abb.com
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