SOLID STATE SWITCHES FOR PULSE POWER MODULATORS

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Abstract

An overview is given about solid state switches using semiconductor components, which are optimised for pulsed power applications and power modulator systems. The semiconductor components, which are based on Bipolar or BIMOS technology, are assembled with heatsinks, driver units, triggering system, protection circuits and power supplies into ready-to-use switches which are suited for different applications. The presentation is also showing a range of Reverse Blocking, Reverse Conducting and Asymmetric devices which are used to design switches for high di/dt, high peak current, single- and repetitive use, discharge switches and on-off switches using a modular platform technology.

1 INTRODUCTION

During the last few years the demand for replacement of thyratrons and ignitrons has increased steeply, and the technology for solid state switches has improved drastically, especially in the medium frequency range. For these applications ABB is producing components which can be used in a modular design of switches for applications in different pulse modulators. This paper describes a few examples of high power solid state switches.

2 SELECTION OF TECHNOLOGY

Basically two different main technologies are available today, i.e. Bipolar and BIMOS technology. The SiC technology is not yet available for practical use in systems which are actual built. ABB has production lines for Bipolar (Thyristors and GTO / IGCT type devices) and BIMOS devices (IGBT's) in one facility and is using both technologies for pulsed power switches. The experience with the Bipolar technology has covered already more than one decade, but BIMOS devices for HV applications in pulsed power are only since a few years under investigation. ABB has more than 3 years experience with stacking HV IGBT press pack modules for HVDC (High Voltage DC) transmission systems and is producing with this proven technology the first switches for modulators. To select the best possible technology for an application we have to distinguish between different categories of applications, i.e. into cases where the switch has to turn on and off, and others where it has to turn-on only (discharge application). Especially the pulse repetition rate is one of the important parameters which can have a strong influence on the selection. Technology selection criteria are frequency range, current rating, and waveform. Bipolar designs cannot be used for all applications. Limitations for Bipolar technology are mainly the frequency range, whereas the IGBT has its dominant limitation in current capability.

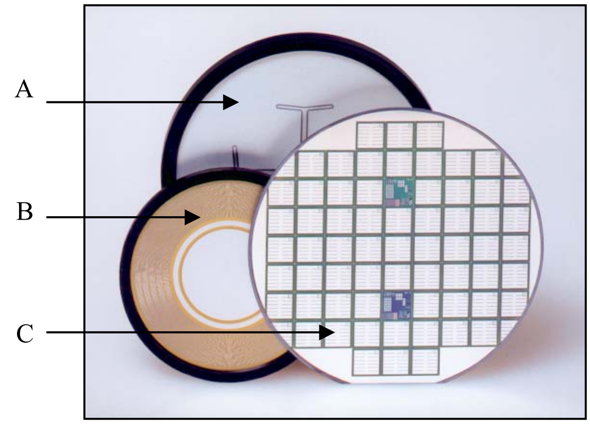

Figure 1: A+B = Bipolar wafers, C = IGBT chip wafer

The above picture shows a large Thyristor (A) wafer which is able to block up to 8 kV and handle several kA, but has a limited di/dt capability and rep. rate. The highly interdigitated wafer (B) will block up to 6 kV and handle several kA at very high di/dt, and has a monolithic integrated freewheeling diode in the middle. This structure is also used in GTO and IGCT devices. Because it is a latching device the driver unit needs very high energy if the pulse rep rate is increasing. The IGBT chips have a blocking voltage of up to 5.2 kV but have a limited current rating, which means that several chips have to be used in parallel. The reach a good current sharing between the chips it needs special configuration in the modules. In press pack IGBT devices it is relative simple to get a good current sharing among the individual chips.

Fig. 2)

Fig.3)

Figure 2: Bipolar Switch with integrated driver unit showing an asymmetric and reverse conducting wafer.
Figure 3: Press Pack IGBT Module with 6 Sub-Assemblies and one separate 9-Chip Sub-Assembly.
Vces = 2500V / Chip size 12 x 12 mm

For system voltages up to 2 kV, single LoPack standard IGBT modules with wire bonding technology can be used, but for higher voltages where series connection is required it will be necessary to go for Press Pack IGBT modules which in case of failure will result in a short circuit instead of an open circuit.

3 SWITCH DESIGN

As there are almost no standards, the solid-state switches are normally designed as per application request. Therefore ABB has designed a modular technology for bipolar devices which includes 3 different wafer sizes (51 / 68 / 91 mm). All are available as Reverse Blocking, Asymmetric or Reverse Conducting version. In the switch designs we have to take all parameters of the application into consideration which includes device selection, series connection of devices, snubbering, cooling, powering and distribution of optical trigger signals. A typical example of a solid state switch is shown in Fig. 4. This switch is used to replace a thyratron which operates at 40 kVdc, 4 kA at tp = 10µs, di/dt = 4 kA and F = 25 Hz, and water-cooled heatsinks.

Figure 4: 5SPR 08F45-16-WC
16-Level Reverse Conducting Switch Assembly.

The reverse conducting bipolar devices used in this assembly have a wafer diameter of 51 mm. The driver unit is integrated with the device and a current source power supply with HV closed loop cable will assure the insulation between the element levels. For higher currents, the same principle can be chosen, but larger diameter semiconductor devices have to be used. Fig. 5 shows a switch built-up with devices using 91 mm wafers giving much higher current capability and thermal values. By using this larger area, also the di/dt and operating frequency can be increased as well.

Figure 5: 5SPR 26L45-8-WC
Water Cooled Reverse Conducting Discharge Switch

The switch shown above is in continuos operation at 20 kVdc, 15kA, tp = 10 µs, di/dt = 12 kA/µs and f = 300 Hz, water cooled heatsinks are mounted to dissipate the power losses. The power level of the switch is about 125 kW. For those applications which require turn-off capability as well the use of so-called “turn-off” devices is needed. Since several years Integrated Gate Controlled Thyristors (IGCT) are used because these devices exhibit a particular good turn-off capability. On the other side their turn-on behaviour and di/dt is less good than the discharge switches mentioned before.

Figure 6: 5SHB 35L45-10-CC
Reverse Blocking IGCT Switch with RCD and Press Pack MOV protection.

The example in Fig. 7 shows a switch which is designed with 10 pcs reverse blocking IGCT devices using 91 mm wafers. The blocking voltage is 4500 V per level, results in a total blocking voltage of 45 kV for the switch. The max. continuous operation voltage is up to 25 kVdc if redundancy is required. The switching capability is 3.5 kA at tp = 200 µs with a frequency of 10 Hz. The switch has an RCD clamping and has additional protection with press pack MOV's. The application is in the field of Klystron power supplies. In the lower frequency range (< 500 Hz) the IGCT shows a very robust behaviour under heavy load conditions, but at higher frequency the IGCT will show increased power consumption in the driver units. Therefore the IGBT module is an alternative which is becoming now available for those applications where higher frequencies are needed. By using conventional IGBT modules, which are original designed for motor drive applications, it has been observed that dynamic current sharing among the chips in the modules is not ideal. The bonding wires of the chips getting most current will thus lift off the chip, and, in extreme cases, the device will explode. This will result in an open circuit which results in a malfunction of the switch. Therefore it is preferred to use Press Pack IGBT Modules which have no bonded wires to the chip. In case of a failure the junction will melt and the chip will be shorted. This will enable the series connected devices to safely operate the switch until the failed device can be exchanged. ABB has spent significant development effort to fulfil the short circuit failure mode requirements and has more than three years experience in the use of Press Pack IGBT modules in series connection, such as for High Voltage DC (HVDC) transmission lines. These devices can now be used for applications in pulsed power, especially for switches in modulator applications where higher frequencies are required. State of the art technology is Vces of 2500 V and Ic up to 2500 A per module. New chips are developed this year with Vces of 5200V. This voltage level will be introduced in Press Pack modules by the end of 2002.

Figure 7: IGBT Press Pack Vces = 5200V and Sub-Assembly with 8 IGBT + 3 Diode chips.

The first switches for 12 kVdc with press pack IGBT devices are supplied already into the some applications for pulsed power to gain more experience.

For these switches a series connection of 8 pcs 2500V devices was used, resulting in an operating voltage of 1750V per device. The switch is designed for a pulse current of 2 kA with a rep. rate of 330 Hz, and able to switch off up to 3 kA in fault condition.

Figure 8: 12 kVdc / 2 kA / 100 µs / 330 Hz water cooled 8-level press pack IGBT switch for modulator application.

The IGBT switch above shown set up includes driver units, snubber boards, heatsinks, isolated clamping and a closed loop current source power supply. The triggering is done with an optical signal, which is distributed to all the IGBT levels.

4 CONCLUSION

It has been shown that ABB Switzerland is producing a large variety of specific components and switches which fulfil the demand for pulsed modulators. Circuit and reliability requirements make it favourable to realise a close interaction between the power device, driver unit, power supply, mounting stack and test specification. The modular technology which is offered, makes the use of solid state devices more feasible than in the past and is an interesting alternative to thyratrons and ignitrons. The solid state solutions presented offer higher reliability in combination with almost no maintenance, and are getting more and more accepted in a wide range of pulsed power applications.

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