Innovative Press Pack Modules for High Power IGBTs

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Abstract

A new IGBT press pack package was developed to meet increasingly challenging requirements for high power converters, such as in power systems applications. The package offers significantly high tolerance to pressure non-uniformity and allows up to 100kN of stacking pressure while effectively protecting sensitive silicon chips by using a flexible contact concept. The package is resilient to explosion and is designed to provide short circuit contact upon eventual failure. Modular design is adapted to achieve high degree of standardization and provide flexibility in current rating at the same time.

Introduction

IGBT technology reached new highs with its deployment in voltage source converters (VSC) for power system applications such as HVDC transmission and power quality management (1,2,3).

Today, the IGBT is the preferred choice for such applications because of the following features:

- Low-power control, since it is a MOS-controlled device. This is advantageous when operating at very high voltage levels (several 100 kV).
- Transistor action, which allows for precise control of the device in a manner that is not possible with latching alternatives. For instance, the converter can be turned off even in short circuit conditions.
- High switching speed, thus making high switching frequency feasible.

While well suited electrically, IGBTs, did not gain much ground in such high power, high profile applications until the advent of a new press pack technology. Advancing from traditional thyristor-based line-commutated converter technology to IGBT-based voltage-source technology was made possible only after re-designing some of the key packaging aspects.

The competing IGBT press pack packages available today are adapted from traditional thyristor "Hockey Puck" packages. This rigid pressure contact technology is not optimized to protect sensitive microstructures on the surface of IGBT chips. As a consequence users are required to provide near-perfect cooler surfaces and handle such devices with a great deal of care during assembly. The issue is further aggravated when the module size is increased for higher current ratings. There is a significant cost impact on system production cost as a result of these shortcomings.

In this paper, key packaging requirements for high power converters are identified and a proposed IGBT-specific packaging solution is discussed in detail. To illustrate the application of this new concept, the properties and reliability of a 5.2kV/ 2kA product under development is summarized.

Key packaging requirements

A. Pressure Management

Converters ranging in power from a few MW to few 100s of MW utilize considerable numbers of semiconductor devices. As converter voltages range from 10s or even 100s of kV, series connection of a large number of semiconductor devices is essential (3). Most suited for series connection is the stacking of devices on top of each other, as it is well known from thyristors. An IGBT module suited for such an application has to fulfill several mechanical requirements:

- In order to provide a satisfactory mechanical stability during transport and operation of an assembled stack, which can be several meters long, a high clamping force of up to 100 kN is mandatory.
- To minimize system and assembly cost, high tolerance to pressure non-uniformity is required.

B. Handling of fault conditions

In HVDC systems operating at high line voltages, numerous devices are normally connected in series. One large VSC based HVDC station, which handles e.g. 200 – 300 MW, is equipped with more than thousand IGBT modules in total (7). By adding extra devices in the stack of series connected devices, redundancy can be built into the system. This will make it possible to operate the system even if some of the individual semiconductor devices fail, securing a high availability of the system and minimizing the need for periodic maintenance.

Since the devices are operated in series connection, it is a prerequisite for such redundancy that the devices fail in a controlled manner, forming a short circuit with sufficiently low resistance to be able to conduct the total current in the system. They are not allowed to fail open circuited and thereby cause disruption of the load current. The failed components, working in the Short Circuit Failure Mode (SCFM), are replaced only during scheduled maintenance.

C. Stack standardization

It is economically advantageous to standardize stack design for converters of various current ratings. It is therefore preferred that the overall package is fixed for a range of IGBT current ratings, without significant increase in the cost of devices with lower current ratings.

Pressure management

A. Individual press-pin

A fresh approach was taken to develop optimized pressure pack solution for IGBTs (8).
A new pressure-contact technology decouples the external clamping force from the direct pressure on the chip. This is achieved by the use of a flexible emitter contact (individual press-pin) in combination with a stiff housing as shown schematically in Fig. 1.

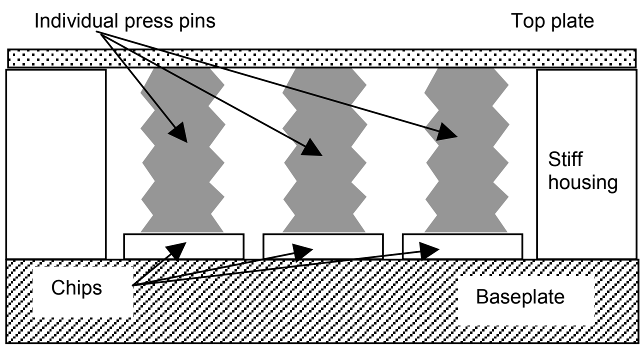

Fig 1: Schematic view of the pressure scheme used to decouple the external clamping force from the direct pressure on the chip. The contact partners on the chips (individual press pins) are flexible and upon clamping, they are compressed until the top plate and the base-plate touch the stiff housing material. When the external force is further increased, the pressure on the chips will remain stable whereas the housing will take the additional force.

To further reduce the stress coming from mechanical unevenness, each chip is contacted by an individual flexible pin. During mounting, a certain amount of the applied pressure is transferred onto the chip by compression of the individual press-pin contacts whereas the excess pressure is taken over by the robust housing. At the same time, the robust housing limits the compression of the flexible contacts. With this design, the pressure on the chip can be adjusted by the stress-strain characteristic of the individual pressure contact.

The significant advantage of this concept is that it is much less sensitive to pressure inhomogeneities compared to traditional hockey-puck designs with stiff copper pole-pieces (4,5) and that it allows very high mounting force as well as much wider mechanical tolerances. The result is a gain in mechanical reliability at reduced costs.

B. Stiff housing

The stiff housing must fulfill several tough requirements as listed below:

- mechanical creep resistance over the specified lifetime
- comparative tracking index (CTI) of at least 600 in order to minimize surface creepage distance
- non-toxic and non-flammable material for environmental and safety reasons
- explosion resistance (see section "Handling of fault conditions")

Of these parameters, the least likely to be found in a standard data-sheet is the mechanical creepage resistance. However, this parameter is very important because otherwise a stable pressure on the chips over the entire lifetime of the module cannot be guaranteed. To determine the creep rate, creep experiments were performed. It was shown that it is in fact possible to use fiber reinforced plastic materials (e.g. polyester based) that can withstand the clamping force under operational conditions with almost no mechanical creep.

Handling of fault conditions

A. Short Circuit Failure Mode

So far, the state-of-the-art to obtain a SCFM has been to place a chip or a thyristor between two molybdenum discs (4,5). This construction is once again inherited from thyristor devices. As described below, molybdenum is not a suitable contact material in forming a stable conductive path. From this it is evident that the SCFM mechanism was not sufficiently known. By developing a new packaging technology with specifically engineered contact partners for the silicon, a long-term stable SCFM could be reached even at low currents (9). The basic idea is to metallurgically alloy the silicon with an optimized contact partner. If the partners are chosen properly, a low melting compound is formed leading to a highly conductive path through the chip. Figure 2 shows this low melting compound.

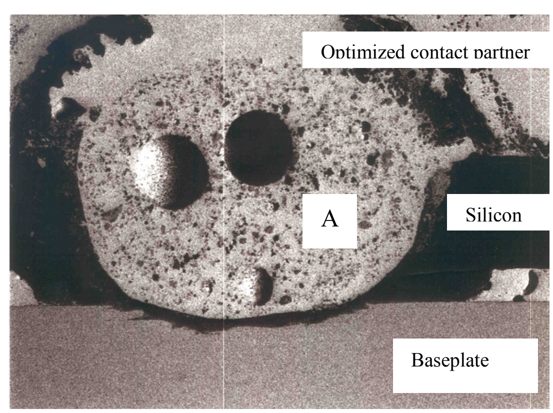

Fig. 2: The low melting compound (A), formed between the silicon and its partners, ensures a highly conductive and long term stable path through the chip.

This compound forms quickly even at low power. The alloying of the chip occurs immediately after the failure, when a high current strike causes the metallurgically optimized material, which is pressed onto the chip, to melt and react with the underlying silicon. The result is reliable SCFM performance during "after-life" operation in the system.

B. Explosion Resistance

In every possible failure case the module has to go into a stable short-circuit (SCFM). However, under rare fault conditions semiconductor packages may be subjected to current discharges of hundreds of kA for durations of hundreds of µs. This could lead to explosive pressure build up by vapor pressure. The requirement for the package here is to withstand such stress without shattering thereby keeping the stack intact. For safety reasons it is also required that no parts be ejected. The housing must take care of this additional requirement. Experiments with different materials have shown that minimum impact strength of 60 kJ/m^2 is needed to provide enough strength to make the housing survive such a stress. The only materials which fulfill this tough requirement are composite materials reinforced with long fibers. The most commonly used short fiber reinforced plastic materials are not sufficient.
Fig. 3 shows the current and voltage waveforms used in the explosion test. The peak power dissipated in the module was about 110 MW. Fig. 4 shows the bottom side of the module after the explosion test. The housing is still undamaged after the test.

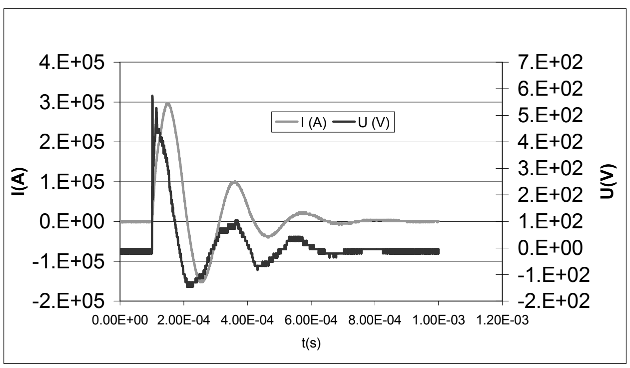

Fig. 3: Current and voltage waveforms used in the explosion test, leading to a peak power of about 110 MW.

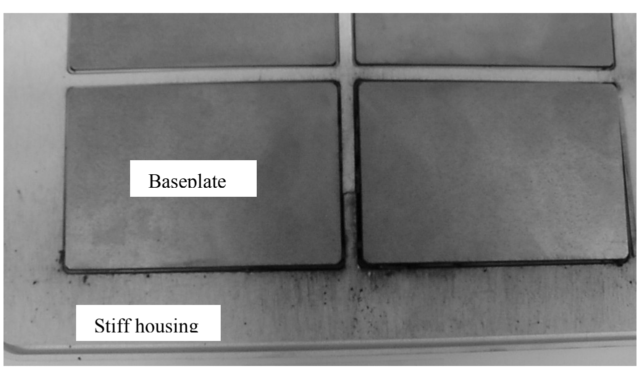

Fig. 4: Bottom side of the module, showing the base-plates as well as the stiff housing. Despite the peak power of 110 MW in the explosion test, the module housing is still intact.

Stack standardization

A versatile (sub-) modular design (Fig. 4) is developed to achieve simultaneously a high degree of standardization and flexibility. Each sub-module is assembled and fully tested according to its rating. Overall current rating of a device is then determined by a number of sub-modules placed inside the housing.
In the next two sections, the sub-module as well as the module design are described.

A. Sub-module design

The desired number of IGBT and diode chips are soldered to a base-plate with a low coefficient of thermal expansion such that reliable solder bonds between the chips and the base-plate are formed. The IGBT to diode ratio can be chosen without any restrictions. It is even possible to build sub-modules which contain only IGBTs. On top of the chips, the individual press-pin contacts are introduced together with the optimized contact partner to provide the SCFM. The individual press pin allows a homogenous pressure distribution even if a large number of chips are used inside one module. The interface between the chip and the next contact partner is optimized from an electrical as well as from a tribological point of view in order to get a high load cycling capability. The gates of the IGBTs are also contacted with highly reliable pressure contacts. All piece-parts used for the contacting are guided by a molded housing which is glued onto the base-plate. Silicon gel is potted into the housing to provide passivation and protection. After curing of the silicon gel, a fully functioning and testable sub-module is available.

B. Module design

Depending on the current rating, a certain number of pre-tested sub-modules are paralleled inside the stiff housing. The emitter cover plate closes the module The low inductance gate and emitter auxiliary connections are mounted on the cover.

C. Properties of this design

The careful choice of material, focused on reliability of the material itself and their interfaces, leads to a high reliability of the wireless press-pack modules. The low thermal resistance (see Table 1) is achieved by the semi-free floating construction which enables single-side cooling in a stack. In addition, these modules have an advantageous aspect ratio (height to width) which leads to a very stable stacking.

Excellent paralleling of sub-modules is achieved due to the symmetrical nature of construction for this module and by proper routing of gate signals. This, together with the PTC behavior of the chips, has made it possible to parallel a number of sub-modules with little current de-rating.

D. Cost efficiency

The most desirable aspect of modular design is its cost effectiveness. This is principally brought about by significantly higher production yields, particularly for modules with large current ratings, using this approach compared to these using non-modular approaches. Small sub-modules can be produced in high volumes at high yields. Whole module yields are near perfect as sub modules are fully pre-tested and in the event of some failing in final test, the faulty sub-module is simply lifted from the housing and replaced.

Properties and reliability of the innovative press pack IGBT module

In this section some key figures of the newly developed 5.2 kV, 2000 A press pack IGBT module are given. Fig. 5 shows a photograph of this module.

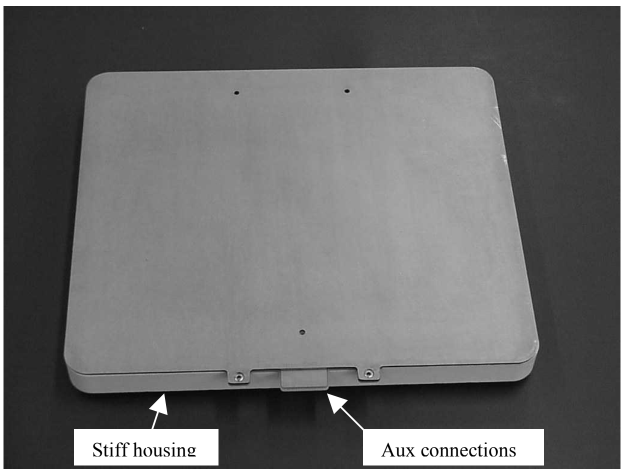

Fig. 5: This picture shows the newly developed IGBT press pack module from top view. The cover (serving as emitter contact) as well as the auxiliary connections and the stiff housing are visible.

At the front of the module, the reliable and low inductance gate and emitter auxiliary connections are visible. They can easily be plugged into the gate unit even if the module is already clamped in a stack with low clearance.

Table 1 shows mechanical, electrical and thermal properties of the 5.2 kV, 2000 A press pack IGBT module:

Mechanical properties		
Dimensions (clamped)		$260*220*26\ mm^3$
Mounting force		75 ± 10 kN
Surface creepage distance		52 mm
Weight		3.5 kg
Electrical properties		
Max. Collector-Emitter Voltage		5200 V
Nominal Collector Current		2000 A
Switching Safe Operating SOA		3000 V, 4000 A
Thermal Properties		
	IGBT	Diode
Rth j-c	7 K/kW	8.5 K/kW

Table 1: mechanical, electrical and thermal properties of the 5.2 kV, 2000 A press pack IGBT module

Extensive reliability testing is being performed and will be reported in detail elsewhere (6). However, to date more than 100’000 load cycles are achieved at $\Delta T_j = 70°C$ without failures.

Conclusions

IGBTs have become the preferred switch in high power converter applications such as for power systems. The versatile functionality of IGBTs, born of its non-latching nature, can be exploited for synchronous switching as well as for system protection.

Until recently, packaging technology has been a major impediment in freeing up IGBTs for wide spread usage, particularly in power systems applications.

The new IGBT specific press pack package presented here was developed to address demanding requirements posed by high power converter systems.

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