IGBT Press-packs for the industrial market

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Abstract

We present a newly developed 4500 V and 2000 A Press-Pack IGBT module for power transmission and industrial voltage drives applications. The module employs SPT$^+$ IGBT chips with exceptionally low losses and high Safe Operating Area (SOA). The use of SPT$^+$ IGBT chips in this Press Pack IGBT module allows for higher power densities and the package provides a highly flexible modular platform with very good ruggedness.

1. Introduction

The standard Press-pack IGBT (PPI) module uses basically the same packaging concept as high power bipolar semiconductor devices. The main difference is that the high power semiconductor content in the package is square IGBT chip instead of a large, round bipolar device. Originally, it was thought that Press Pack IGBT modules would replace Gate Turn-Off Thyristors (GTOs) in both medium voltage drives and traction drives and be an alternative to the insulated IGBT modules. In 2011, PPIs have not yet penetrated the traction market but have become an established part of the high power semiconductor market segment serving in power transmission and industrial voltage drives applications.
ABB Semiconductors has many years of experience in manufacturing Press-pack IGBTs for power transmission & distribution applications. The ABB Press-pack IGBT, which is known under the name StakPak™ (Fig. 1), has proved its outstanding reliability and ruggedness by serving many years as the principle switching device in the ABB HVDC light application. In HVDC transmission link high voltage, direct current is transported over long distances via overhear lines or sea cables with low transmission link losses. More than 15 of the HVDC light transmission links using StakPak™ devices for valves are currently in successful operation carrying more than 10 GW of power. The first link began operation around 15years ago, and as of today, the reliability record of the PPI's is excellent and unrivalled compared to standard IGBT module solutions.
Strong of this success ABB have decided to developed a PPI which will be dedicated to industrial applications. The StakPak is a PPI specially develop for HVDC application but the high flexibility of the IGBT/Diode ratio, the power scaling capability due to modularity and the proven device's capabilities in ruggedness and reliability makes it an ideal start for a specialized industrial application PPI module.

Figure 1: The 4.5kV StakPak module with 6 submodules.

2. The Press-pack IGBT Module

The ABB Press-pack IGBT, comes in two different voltage classes and shapes. A rectangular package is used for the previously developed 2.5kV class and a square package is used for the newly developed 4.5kV class. Both version of StakPak™ modules are integrating the IGBT and the anti-parallel diode as well as providing a highly flexible modular platform for power scaling of the device. The newly designed 4.5kV StakPak™ has kept its power scaling modularity while increasing the flexibility in the IGBT/diode ratio. It also kept the individual chip contacts through the press pin which increase the cooling capacity and enable a relaxation of the flatness tolerance on the stacking cooler. But the major advantage of those ABB PPI packages for series connection application stand in having the ability for a failed module to still carry the load current [1]. In other words, any chip failure will lead to a short circuit rather than open circuit failure as it is the case for insulated IGBT modules.
This ability of the module to fail into a stable low impedance state is referred as Short Circuit Failure Mode (SCFM). In the SCFM mode, a single failed chip and its contact system must then take up the whole load current, which can represent a current up to 40 times higher than in normal working mode. The electrical resistance in the failed chip must therefore be reduced as much as possible, which is done through the help from a special metal platelet in direct contact with the Si chip [2]. In HVDC application the failed module need to be in a stable low impedance mode up to the next service interval, which is between two to four years. For industrial applications the requirement for the SCFM duration is usually reduced to a couple of 100 ms since long term redundant operation is not required. On the other hand a short term SCFM capability provides the required time to clear a failure with a mechanical interrupter and avoid converter explosion. A reduced SCFM duration though offers the possibility to simplify the PPI design of industrial Press Pack
What makes the PressPak module unique is foremost the modularity of the package combined with the flexibility of the IGBT:diode ratio in the module. The StakPak™ module consists of a number of standard rectangular sub-units, named submodules. In this way, power is configured into the switch based on the number of submodules, 2, 4 or 6, contained in the frame. The layout of the IGBT connections to the gate pad in the 4.5kV PPI allows for at least 3 different IGBT:diode ratios in the submodule. The ratio can be 1:1, 2:1, or even 5:1. The current rating therefore depends on this ratio. As an example, a module with 6 submodules and a 1:1 ratio is rated at 2000A, when with a 2:1 ratio it will be rated at 2600A. The 2600A maximum rating for the complete switch means that one phase leg of the medium voltage drive can be built from one stack only without special considerations concerning the diode and special design rules with respect to the cooling system and the elimination of parasitics. The fact that only one compact stack of StakPak™ modules is needed per phase leg can be highly beneficial in terms of footprint of the drive and manufacturability of the complete drive.

3. 4.5kV SPT$^+$ chip-set technology

3.1 SPT$^+$ IGBT technology

The chip technology used for this new press pack IGBT module is the benchmarking 4.5kV SPT$^+$ chip set, which is also found in the ABB isolated IGBT modules. SPT$^+$ is the latest generation of ABB's planar devices [3] which was developed with the goal to substantially reduce the on-state losses while maintaining the low switching losses, smooth switching behavior and high turn-off ruggedness of the standard Soft-Punch-Through (SPT) IGBTs [4]. To obtain those results the well optimized vertical design from the SPT technology was improved with the addition of an N-enhancement layer with an optimized design surrounding the P-well in the IGBT cell. As shown in figure 2, this creates a unique planar structure. The N-layer improves the carrier concentration on the cathode side of the IGBT, thus lowering the on-state voltage drop without significantly increasing the turn off losses [5] [6] [7] [8]. Therefore the SPT$^+$ technology offer lower on-state losses and improved SOA capability as compared to the previous technologies.

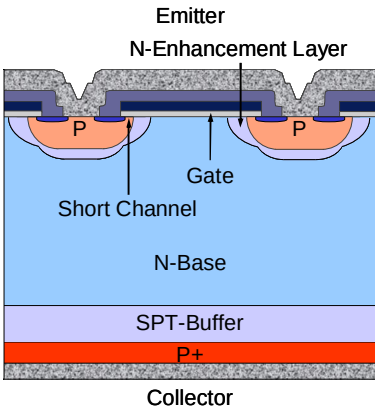

Figure 2: SPT$^+$ IGBT technology.

3.2 SPT$^+$ diode technology

SPT$^+$ diode design is based on a double lifetime control technique for electron-hole plasma shaping [9] [10]. Figure 3 shows the SPT+ diode topology as well as a schematic of the He++ peaks used for plasma shaping. Also seen in figure 3 is that outside of this double life time control technique the SPT+ diode used the same design as the previous SPT diode. The concentrations and positions of the He++ peaks are adjusted to give the plasma the desired shape where the best trade-off between losses and recovery softness can be achieved for the particular application.

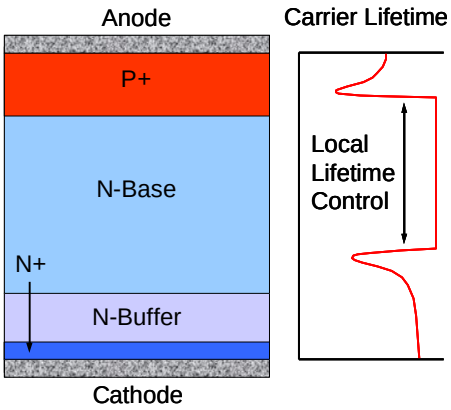

Figure 3: a) SPT$^+$ diode technology, b) Implantation profile of He^{++}

4. 4.5kV/2000A Industrial Press-Pak electrical performance

Since many possible configurations for this PPI module are possible, the intent of this section will be the presentation of the electric characterization of a module made with four submodules. Each submodule having an IGBT/Diode ratio of 2:1(8 IGBTs and 4 diodes per submodule). This give us a 4.5kV device with a nominal current of 2000A corresponding to an approximate current density of 62.5A/cm^2 for the IGBT and 125A/cm^2 for the diode. For dynamic measurements, the nominal DC-link voltage was set at 2800V, while for SOA and softness measurements it was set respectively at 3000V and 3600V.

4.1 Static characteristics

This new design of 4.5kV press pack modules is providing for high voltage system designers an enhanced current rating combined with a smooth switching characteristic. Figures 4 and 5 show respectively the forward characteristics of the IGBT and diode employed in the new PPI module (4 submodules with 2:1 IGBT/diode ratio). The module exhibit low static losses

together with positive temperature coefficient for both IGBT and diode. At nominal current (2000A) and with a junction temperature around 125°C, the SPT$^+$ IGBT has a typical on-state voltage drop of 3.5 V. As for the diode, the advance plasma shaping created with the double He^{++} irradiation offers the positive temperature coefficient of the V_F which is around 3.1V at nominal current and with a junction temperature of 125°C.

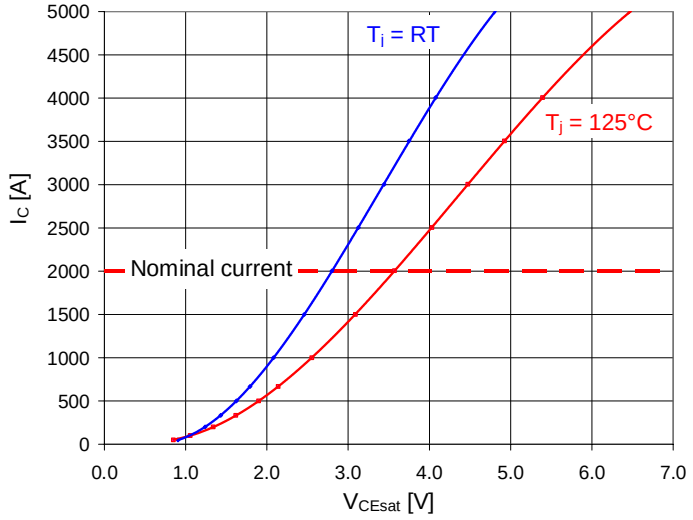

Figure 4: Forward characteristics of the SPT$^+$ IGBTs in a 2000A, 4.5kV Press-Pak module.

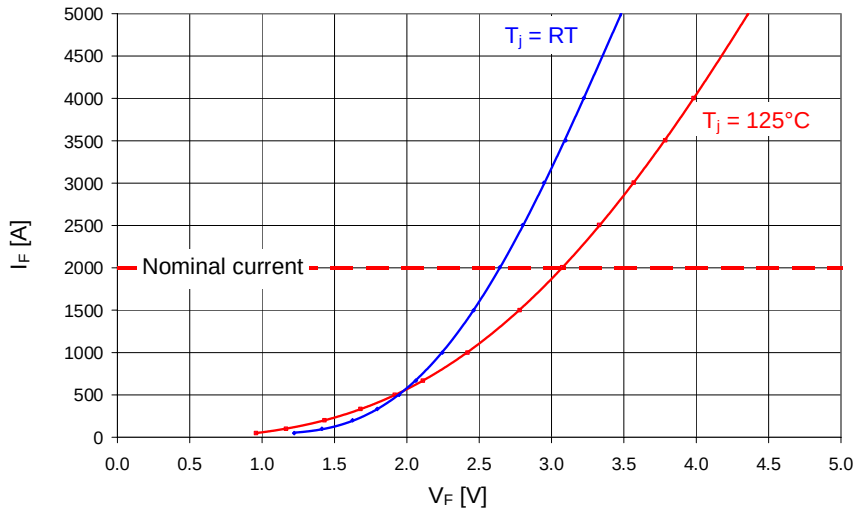

Figure 5: Forward characteristics of the SPT$^+$ diodes in a 2000A, 4.5kV Press-Pak module.

4.2 Switching characteristics

The Figure 6 and 7 show respectively the module-level turn-on and turn-off waveforms measured under nominal conditions (V_{DC}=2800V, I_C=2000A, T_j=125°C). The consequence of the planar SPT$^+$ cell low input capacitance is seen with the fast drop of the IGBT voltage during module turn-on. The fast voltage drop combined with the low losses SPT$^+$ diode limited the turn-on losses to a typical value of 14J. Under the same nominal conditions the turn-off losses of the PressPak module are typically around 10J. Even though the good ruggedness of the SPT$^+$ IGBT could allows for a faster dV/dt when switching the module which should reduced the turn-off losses, a slightly higher gate resistor was chosen to demonstrate the good module behavior even in non-optimal driving condition. For the example shown in figure 7, the module was switched off using an $R_{g,off}$ of 8.2Ω and a

maximum voltage rise around 2000V/µs can be seen. Further more by applying our well-established Soft-Punch-Through (SPT) buffer structure, a good switching controllability and soft turn-off waveforms, which is vital for high current and high voltage modules, is ensured.

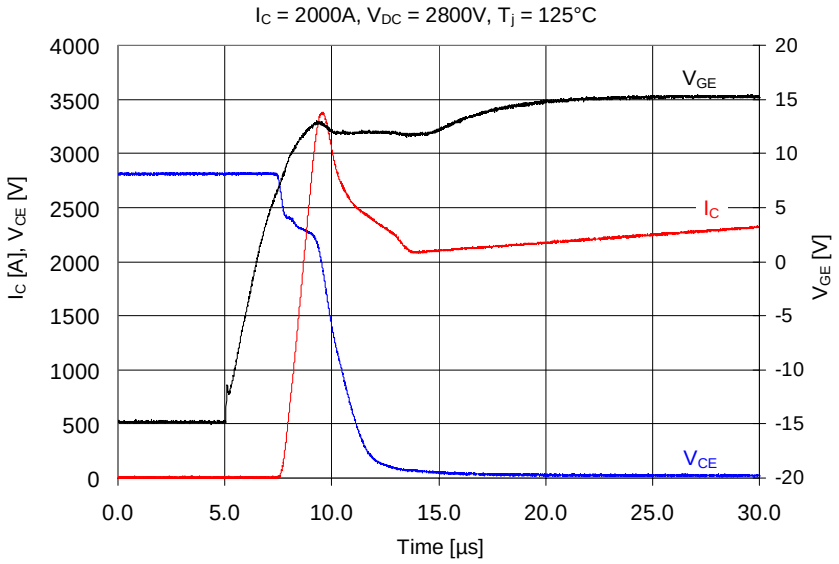

Figure 6: Turn-on characteristics under nominal conditions of the 2000A, 4.5kV Press-Pak module, E_{on}=14J.

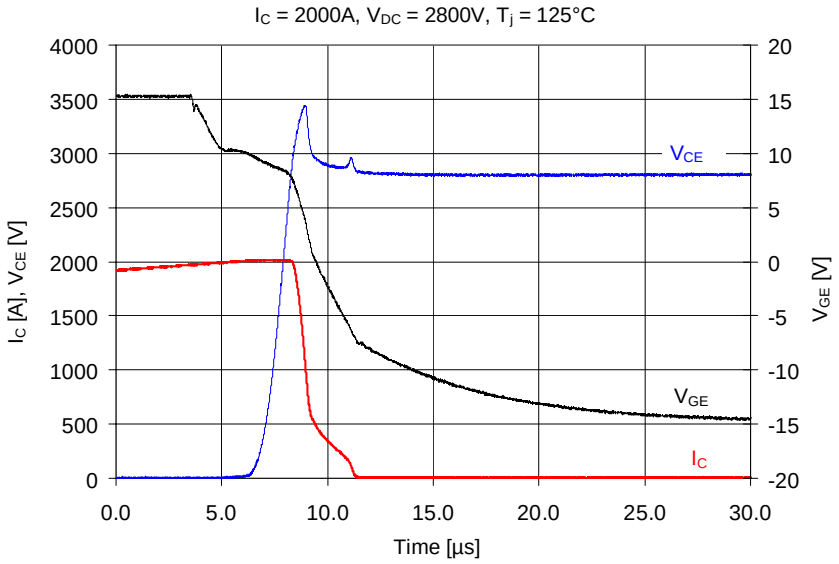

Figure 7: Turn-off characteristics under nominal conditions of the 2000A, 4.5kV Press-Pak module, E_{off}=10J.

In Figure 8, the reverse recovery waveform of the module diodes under nominal conditions is shown. As seen in the figure 8, the implantation of the He^{++} peak on the cathode side produced a relatively short but still very smooth current tail. Under nominal conditions (2000A and 2800V) and with an $R_{g,\,on}$ of 3.3Ω, the diode recovery losses are around 3.7J.

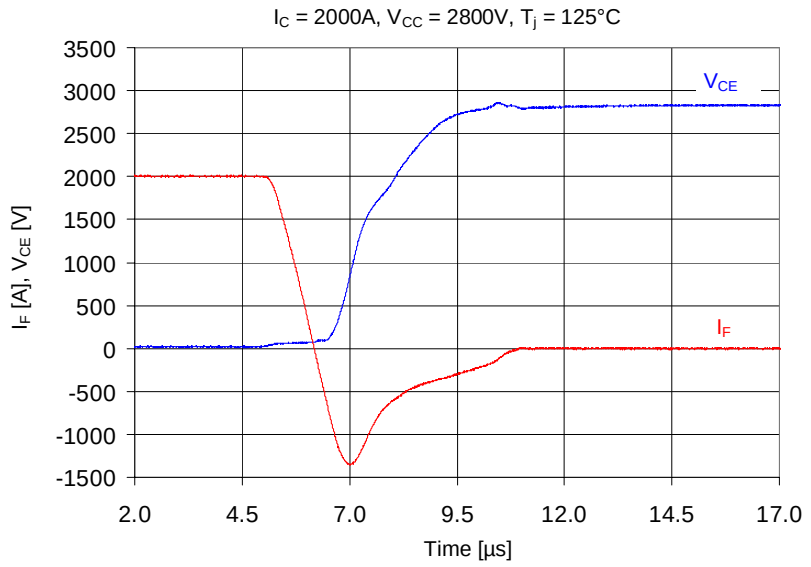

Figure 8: 2000A 4.5kV Press-Pak module diode reverse recovery under nominal conditions, E_{rec}=3.7J.

One of the main advantages of the 4.5kV SPT$^+$ IGBT chip is its high turn-off ruggedness and thanks to the good paralleling capability of the chip this ruggedness can also be seen on module level. Figure 9 shows the standard module-level RBSOA test on which each outgoing 4.5kV SPT+ PressPak modules are subjected to. This test was conducted with a junction temperature of 125°C and a gate resistance of 8.2Ω In this test, the module (4 submodules with 2:1 IGBT/diode ratio) turns off a current of 4800A (more than 2 times nominal current) at a DC-link voltage of 3400V. In comparison to standard traction module this means that even though more IGBT were put in parallel the same multiplication factor for the RBSOA current was obtained. The diode recovery under SOA condition is also part of the standard test sequence. Such a test result is shown in figure 10.

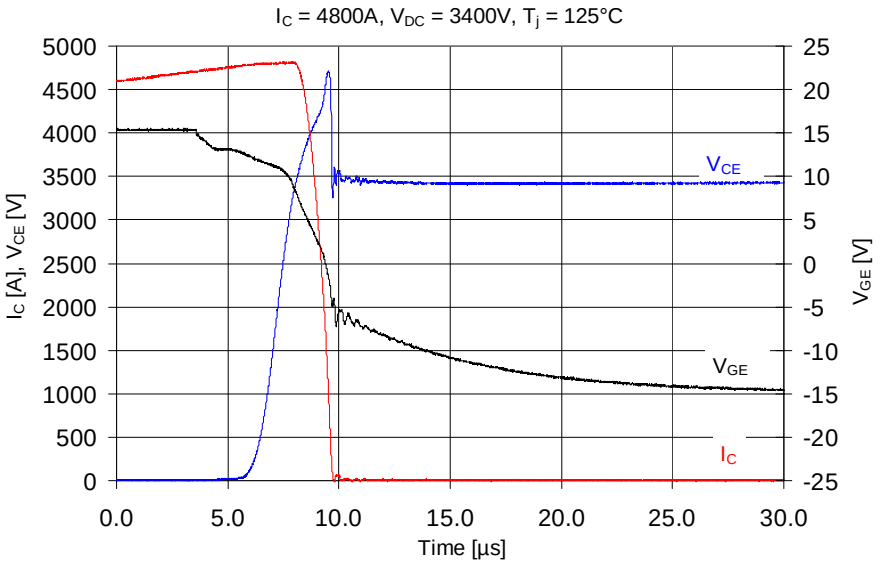

Figure 9: 2000A 4.5kV Press-Pak module IGBT turn-off under SOA conditions.

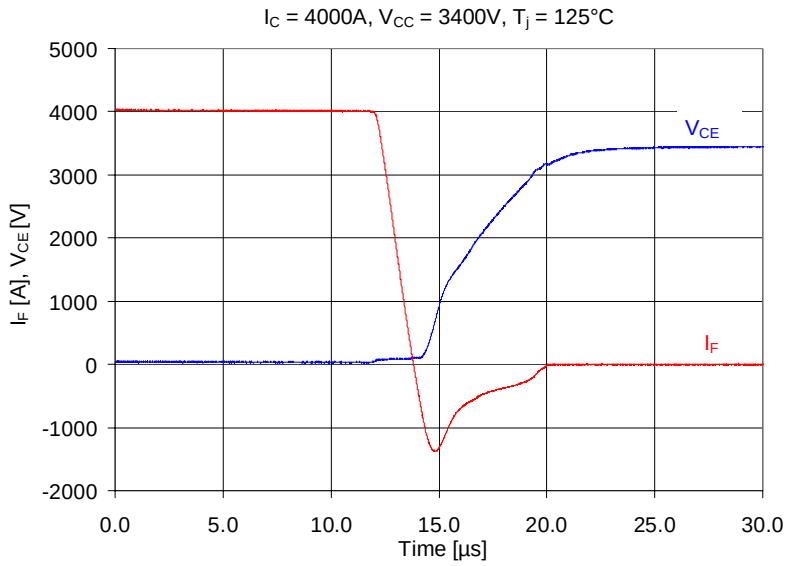

Figure 10: 2000A 4.5kV Press-Pak module diode reverse recovery under SOA conditions.

Finally, the IGBT also need a short circuit capability and this for a junction temperature comprise between -40°C to 125°C and with a gate voltage of 15V. In figure 11 the short-circuit waveforms at module level measured at V_{DC}=3400V and T_j=125°C can be seen.

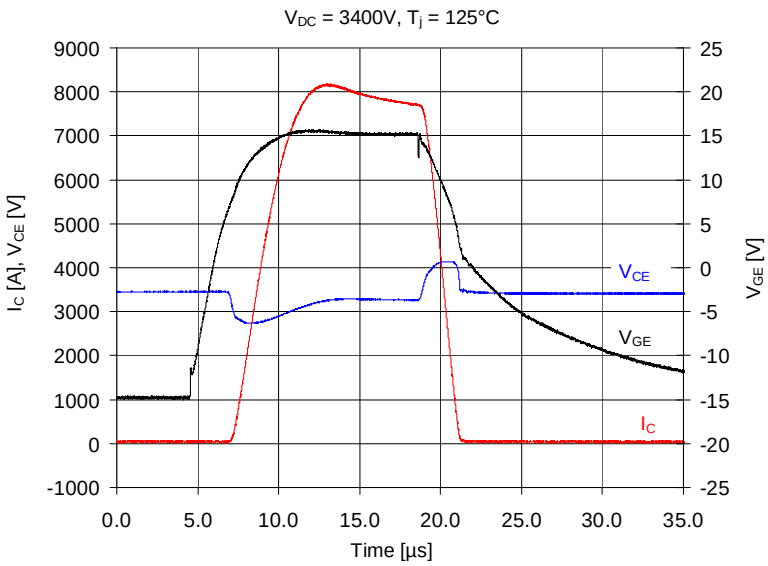

Figure 11: 2000A 4.5kV Press-Pak module short circuit characteristic.

5. Conclusions

In this paper, the new 4500V/2000A Press-Pak module employing SPT$^+$ IGBTs and diodes has been presented for the first time. The SPT$^+$ chip technology provides to the module a very good combination of low losses, high ruggedness and smooth switching behavior. The presented module is derived from a module specially developed for the HVDC application but with the modular platform for power scaling, the flexibility of the IGBT:diode ratio and the Short Circuit Failure Mode, this module is also well suitable for industrial voltage drive applications.

6. Literature

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