Surge Current Capability of Fast Recovery Diodes

With the continuous demand for increased power densities, HiPak modules employing the latest SPT and SPT+ IGBT and diode technologies are required to function at higher current densities. This trend is realised by substantial reductions in the total losses while attaining higher ruggedness levels. Therefore, this article will address an important performance factor, namely the fast diode surge current capability.
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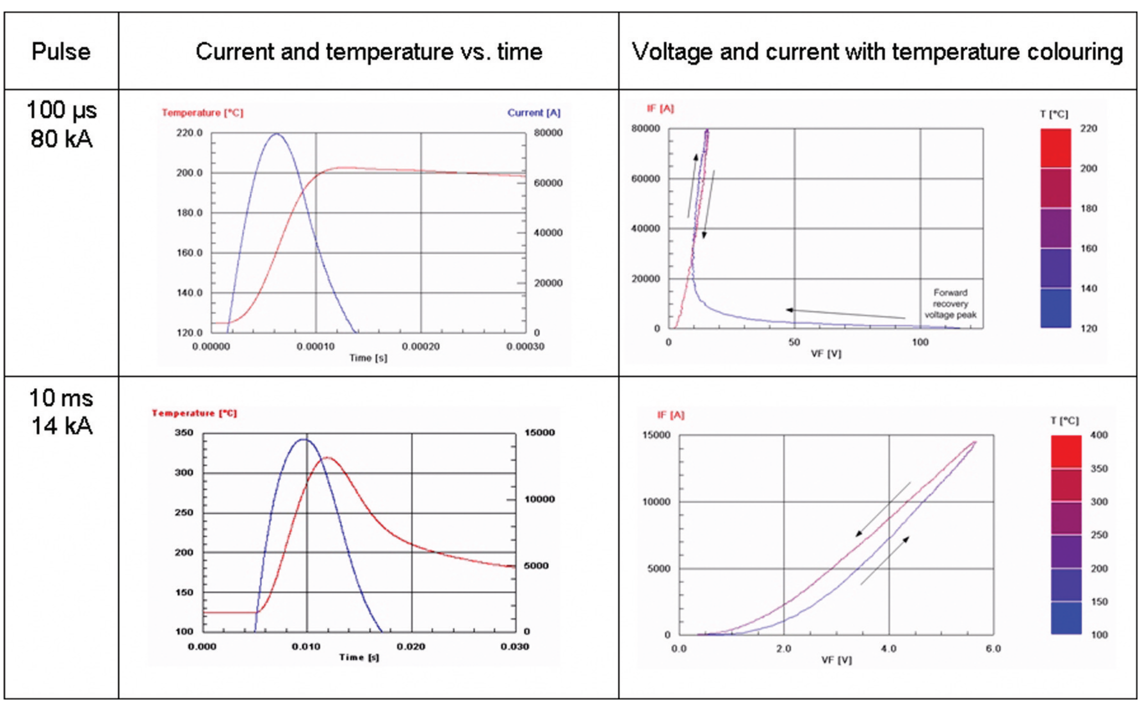
The IGBT HiPak module range from ABB contains the IGBT and the fast recovery diode. The current through the IGBT can be switched on and off through the gate-emitter voltage, whereas the diode is not self-controlled. When the diode is biased in the forward direction, the resulting current depends mainly on the operating conditions. During fault cases – as in after a load short circuit or the failure of adjacent devices in the inverter – the combination of inductances and capacitances will lead to a surge current through the diode. The specific waveform and duration depend on the type of fault and can vary from a fraction of a millisecond up to many milliseconds, while peak currents can reach far beyond the nominal rated currents. During such fault cases, the peak junction temperature can exceed the maximum allowed temperature by a long way. Hence, this could lead to a certain degradation of the diode at each surge event. Therefore, it is mandatory to know the number of fault cases during the diode lifetime to correctly specify the maximum allowed surge current. A surge current can appear in various waveforms. Standard tests and datasheet ratings typically use a half-sine wave with duration between 100µs and 100ms.

The following parameters influence the peak junction temperature: initial diode junction temperature T_{vj}, pulse duration t_p and surge current amplitude I_{FSM}, diode forward voltage V_F (as a function of temperature and current), thermal impedance Z_{th} of the diode, and initial module case temperature T_c (for long pulses only). The losses generated in the diode during the surge current event depend on the forward voltage of the device, which again depends on the current and the device temperature. However, the voltage can not always be measured or simulated, therefore the surge current integral I^2t is introduced, which eliminates the need to know the forward voltage waveforms, as long as the current waveform is similar to the specified half-sine pulse.

Failure mechanisms due to surge current pulses

The thermal stress introduced by the surge current pulses will eventually cause damage due to thermal fatigue cumulated during the lifetime of the diode. The

Figure 1: **Calculated temperature rise during two surge current events and their influence on the forward voltage drop**



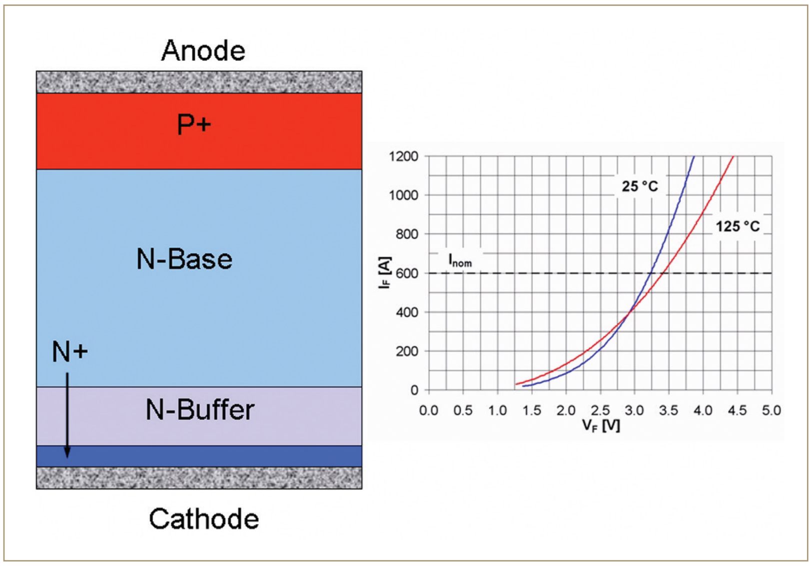


Figure 2: **Cross-section of an SPT diode utilising a strong P+ anode and N+ cathode design and the corresponding diode forward characteristics of the 6500V/600A HiPak module**

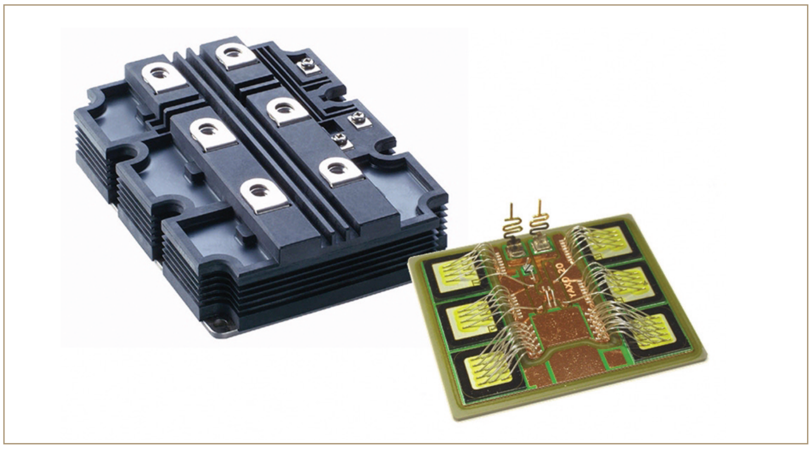


Figure 3: **The 6.5kV/600A HV HiPak module with SPT IGBT and diode technology showing layout of a substrate to optimise current sharing between the diode dies**

degradation of the diode can be detected in the electrical parameters through increase of the forward voltage, degradation of blocking capability with increase of leakage current, and reduction of dynamic SOA capability.

The degradation is mainly caused by diffusion of the surface contact metal into the silicon (i.e. Al-spiking), melting of the contact metal near the bond wires (long pulses) or melting of the silicon in overstressed areas, especially at short pulses, as shown in Figure 1. The graphs show the calculated temperature rise during two surge current events and their influence on the forward voltage drop. The conditions under which the critical temperatures are reached are influenced by the diode design and the packaging technology. Additional de-rating maybe necessary if a non-uniform current distribution occurs, for instance through unequal contact impedances from the module to the rest of the circuit (contact resistance, loop inductance), or if different forward voltage drops occur, due to chip to chip variations or temperature differences between the diodes due to cooling or losses differences.

HiPak diode technology for high surge current capability

The fast recovery diodes employed in HiPak modules are using the SPT and SPT+ technology concepts which always result in a positive temperature coefficient already at nominal current, as shown in Figure 2. During a surge current event, the current distribution is therefore well-balanced among parallel diode chips, resulting in homogeneous current distribution up to very high temperatures.

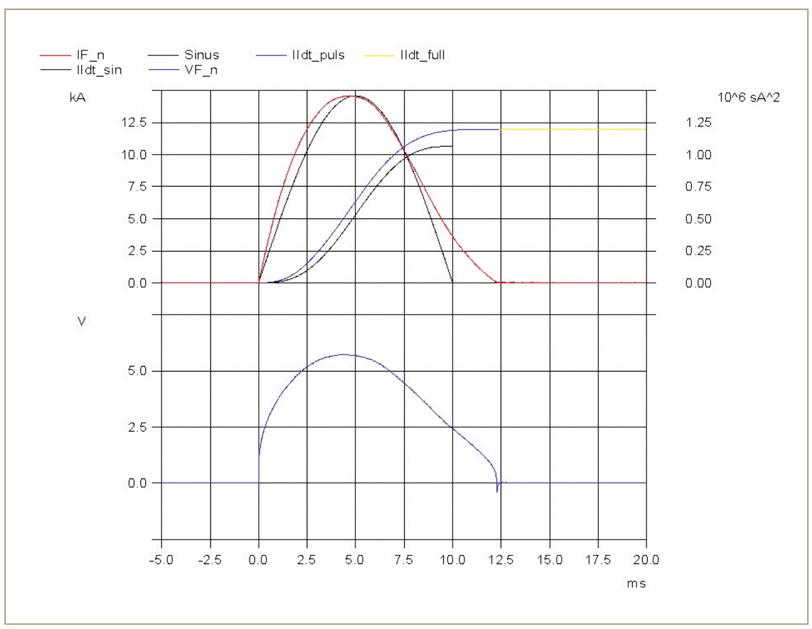


Figure 4: **Typical waveforms at surge current testing**

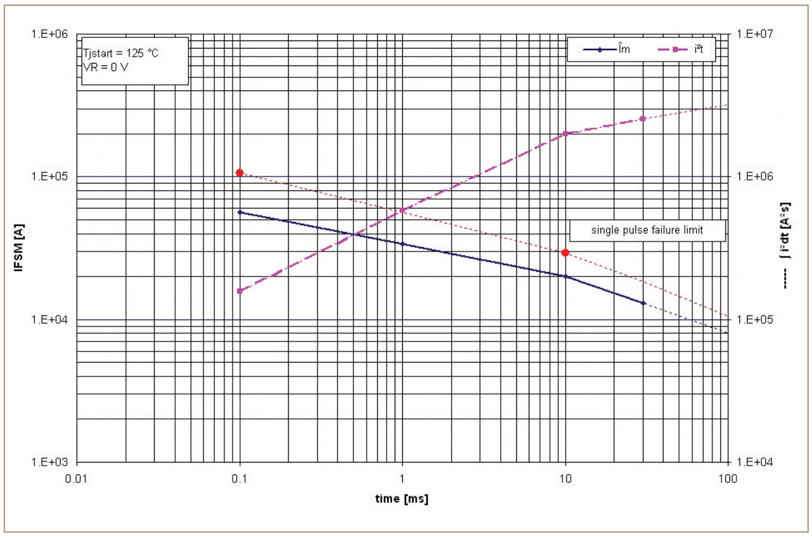


Figure 5: **Surge on-state current versus pulse length, half-sine wave for the 1700V/2400A HiPak**

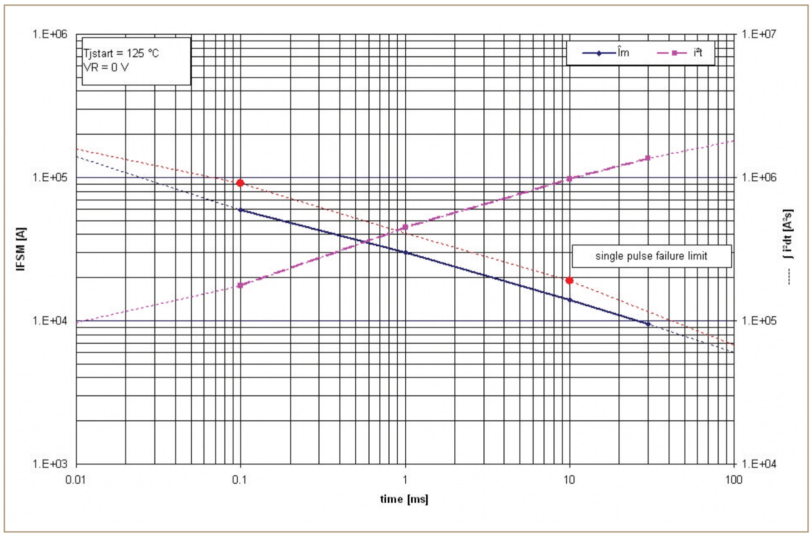


Figure 6: **Surge on-state current versus pulse length, half-sine wave for the 3300V/1500A HiPak**

The strong P+ anode and N+ cathode, together with an optimised local lifetime control, helps to provide a low forward voltage characteristic at high currents. This is mandatory to limit the temperature rise and therefore allows a higher surge current capability. It is important to point out that the SPT^+ technology differs only in the lifetime control scheme when compared to the SPT generation.

Aside from to the diode chip technology, the packaging of the diode in the HiPak modules is optimised to distribute the package resistances evenly between the diode chips, helping to balance the currents. In addition, the contacts through bond wires are optimised to achieve homogeneous current flow through each diode die, as shown in Figure 3, avoiding excessive temperatures at local hot spots.

SPT and SPT^+ diode surge current capability

The SPT and SPT^+ diodes in HiPak modules are designed to survive 100 thermally independent pulses of the maximum current specified in the device data sheets. If the surge current stresses are kept within the given limits, the diode will stay within the guaranteed datasheet characteristics and it will still fulfil the guaranteed safe operating area (SOA) conditions. Thus, no degradation results in the diode performance.

In Figure 4, the surge current half-sine waveforms of the 3.3kV SPT^+ diode are shown for the 3300V/1500A HiPak module. The measurements were made on module level, which means that 12 diodes with a total active area of $13.8cm^2$ were tested in parallel, with a pulse duration of 10ms in this test. The diodes reached a peak current of 14.5kA, resulting in a surge current integral I^2t value of 1.05 x 106 A^2s. The forward voltage of the diode during the pulse is shown in blue on the lower axis.

It is important to note that Figure 4 is made for half-sine waves and cannot be used for current waveforms deviating a lot from half-sine. For such cases, a type test may be needed to correctly assess the capability. The achieved surge current capability is also very similar to the one of the standard SPT diodes. The different irradiation schemes differentiating the SPT^+ from the SPT technology do not have an influence on the capability. The high surge current capability is therefore achieved, mainly thanks to the strongly doped and deeply diffused anode and cathode emitter profiles.

Surge current capability per voltage class

In this part, we show surge current capability diagrams for the largest available HiPak module per voltage class, which is typically the HiPak2 single switch module. First, Figure 5 shows the surge current characteristics for a 1700V/2400A HiPak module utilising SPT IGBT and diode chips when half-sine waves are applied. The dashed pink characteristic, using the scale on the right side, gives the I^2t value as function of the pulse width. The continuous blue characteristic, using the scale on the left side, shows the equivalent peak current assuming a perfect half-sine current pulse of the respective pulse width. The markers show where test data have been gathered. The red dotted line shows the approximate value for a single pulse just at the

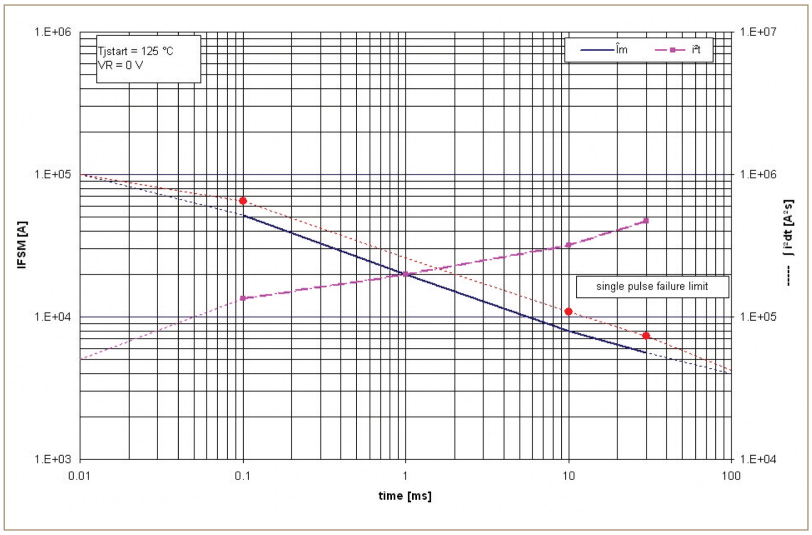


Figure 7: Surge on-state current vs. pulse length, half-sine wave for the 6500V/600A HiPak

destruction limit of the diode, whereas the continuous blue line shows the limit for 100 pulses. The dotted lines show the expected performance through extrapolation; however these points have not been tested.

The 3300V/1500A and 6500V/600A surge current capability diagrams are shown in Figures 6 and 7. The surge current limits described so far will not allow reapplying a reverse voltage directly after the pulse, because the diodes are running too hot during the pulse and will not be able to stabilise the leakage current. If reapplied voltage is needed, a further de-rating has to be taken into account to prevent thermal runaway after the pulse.

Further improvements

The trend towards higher junction temperatures further reduces the surge current capability when a higher starting temperature is assumed. A careful assessment about the needed surge current capability will be mandatory. As the limiting factor for today's diode is the peak temperature, three possible investigation areas are given to increase further the surge current capability. Firstly, reductions in the forward voltage drop; secondly the reduction of the thermal impedance of the diode; and lastly an increase of the maximum allowable temperature during the surge current event.

Literature

New 4500V SPT+ HiPak Modules, Power Electronics Europe 4 May/June 2007, pages 40-42