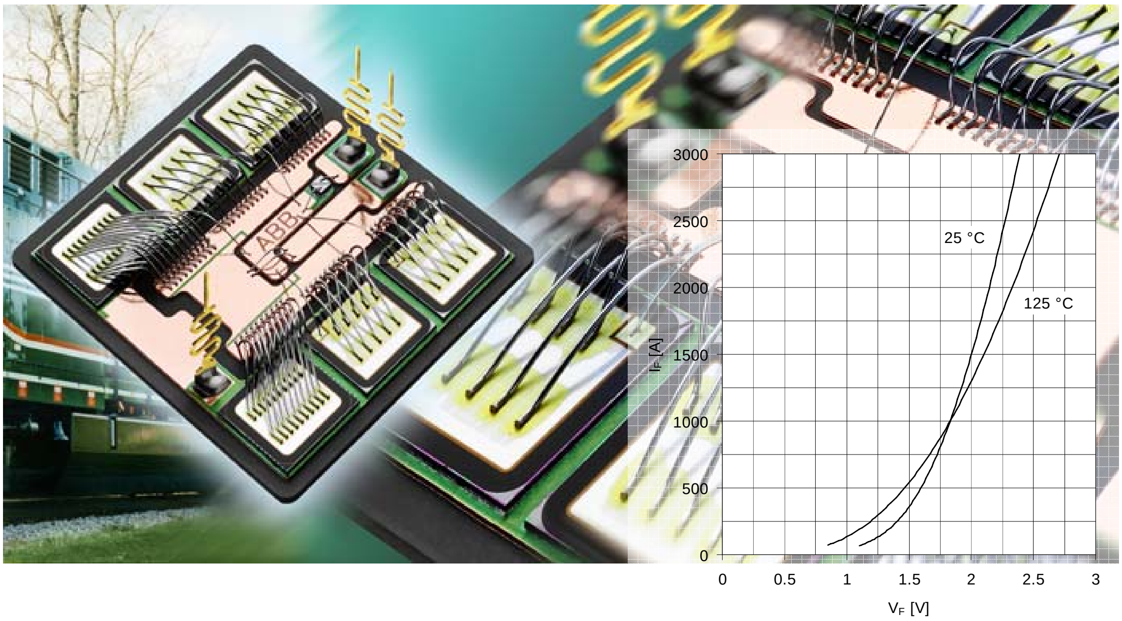
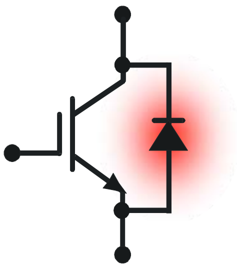
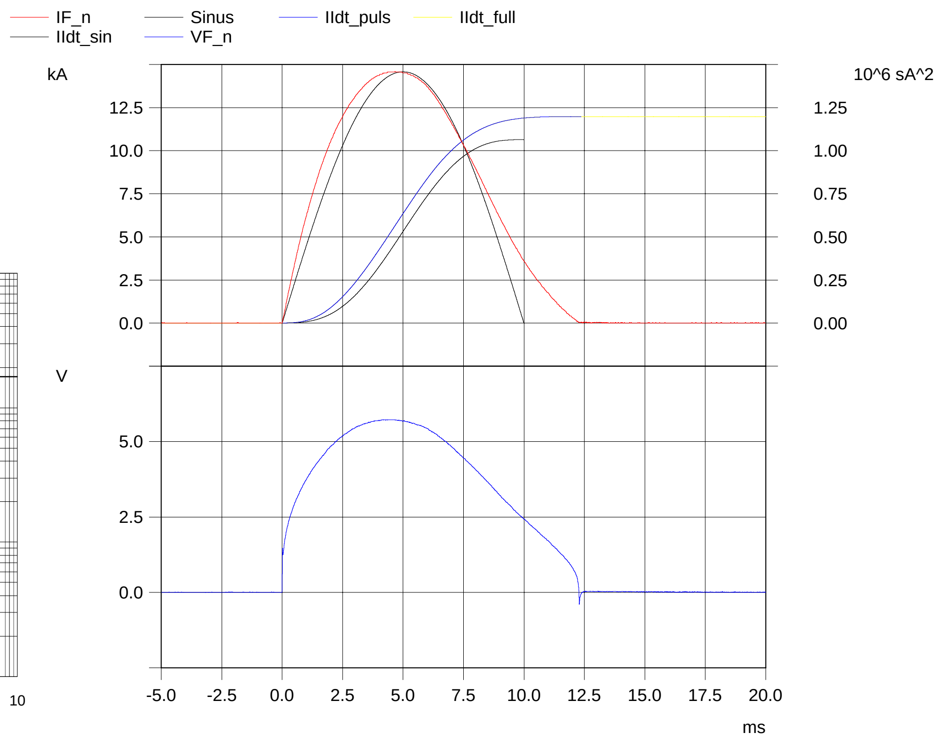
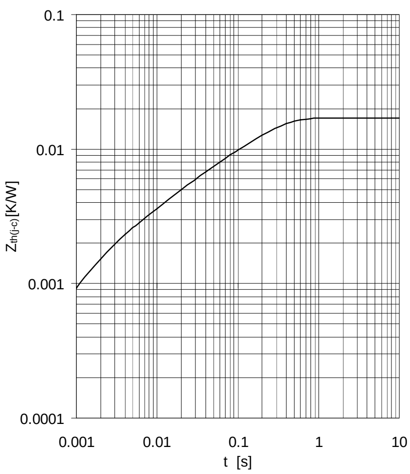
Application Note

Surge currents for IGBT Diodes









Surge currents for IGBT Diodes

Application Note 5SYA 2058-01

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1 SURGE CURRENTS FOR IGBT DIODES

1.1 Introduction

ABB IGBT modules contain two different types of semiconductors, the IGBT and the anti-parallel 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 it is biased in forward direction, the resulting current depends on external conditions.

During fault cases – as 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 fractions of milliseconds up to many milliseconds. The peak currents are far beyond the nominal rated currents.

During the fault case the peak junction temperature can far exceed the maximum allowed temperature. This may 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.

1.2 Surge current properties

A surge current can appear in various waveforms. Standard tests and datasheet ratings typically use a half-sine wave with duration between 100 µs and 100 ms. 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
- 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 waveform as long as the current waveform is similar to the specified half-sine pulse.
The surge current integral I^2t of a half-sine wave with current amplitude I_{FSM} is calculated using equation 1 from the Standard IEC 60747 [1]:

$$\int_0^{tp} I^2(t) \cdot dt = \frac{1}{2} \cdot I_{FSM}{}^2 \cdot t_p \qquad E^{qn}\ 1$$

The accumulated energy deposited during the pulse can be calculated using equation 2 if v_F, the voltage across the diode, and i_F, the current through the diode, are measured:

$$E_{surge}(t) = \int_0^t i_F(t) \cdot v_F(t) \cdot dt \qquad E^{qn}\ 2$$

The surge current capability is limited by thermal effects. The temperature reached during the surge current event can be calculated through convolution using the power generated in the diode and the thermal impedance Z_{th} of the diode; this is shown in equation 3.

$$T_{vj}(t) = T_{start} + \int_0^t i_F(\tau) \cdot v_F(\tau) \cdot \dot{Z}_{th}(t-\tau) \cdot d\tau \quad \text{with} \quad \dot{Z}_{th}(t) = \frac{d}{dt} Z_{th}(t) \qquad E^{qn}\ 3$$

If the voltage cannot be measured or a current different than a half-sine waveform should be simulated, the use of a temperature dependent forward voltage model of the diode is appropriate. It is important to properly model the areas of interest, especially the high current and high temperature behaviour of the diode.

As the models for forward voltage and thermal impedance normally assume homogeneous conditions, a margin has to be taken into account for non-ideal cases.

1.3 Failure mechanisms

The thermal stress introduced by the surge current pulses will potentially cause damage due to thermal fatigue cumulated during the lifetime of the diode. The degradation of the diode can be detected in the electrical parameters.

- Increase of the forward voltage
- Degradation of blocking capability, increase of leakage current
- Reduction of dynamic SOA capability

The degradation is caused by diffusion of surface contact metal into the silicon (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 (Figure 1).
The conditions under which critical temperatures are reached are influenced by the diode design and the packaging technology. Additional de-rating maybe necessary if a nonuniform current distribution occurs, for instance through unequal contact impedances from the module to the rest of the circuit (contact resistance, loop inductance), or if a different forward voltage drop occurs, due to chip to chip variation or temperature differences between the diodes due to cooling or loss differences.

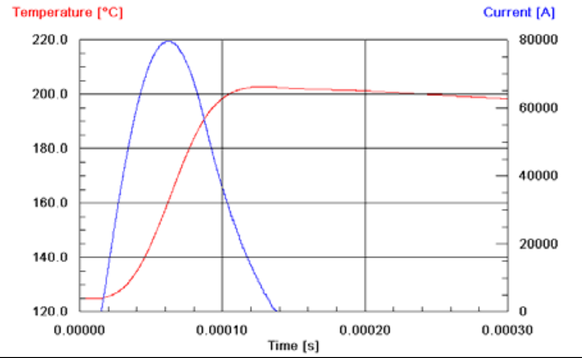
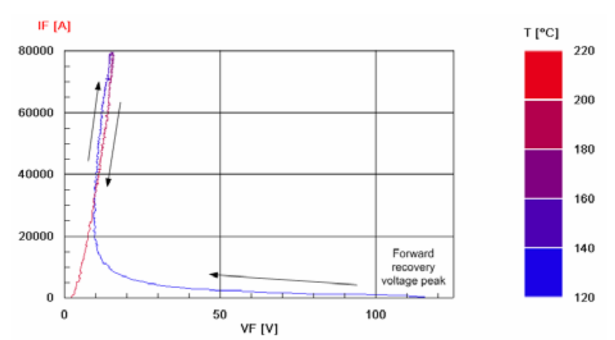
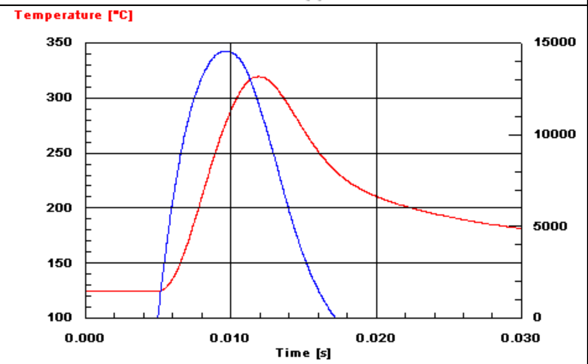
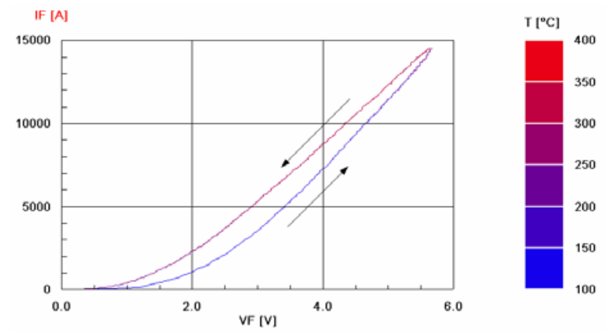
Pulse	Current and temperature vs. time	Voltage and current with temperature coloring
100 µs 80 kA		
10 ms 14 kA		

Figure 1 Calculated temperature rise during two surge current events and their influence on the forward voltage drop (5SNA 1500E330300).

2 SURGE CURRENT CAPABILITY OF ABB IGBT MODULES

2.1 ABB IGBT diode technology to achieve high surge current capability

ABB IGBT diodes use the well proven SPT and SPT+ concept which results in a positive temperature coefficient at nominal current. 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. The strong P+ anode (Figure2) together with an optimized local lifetime control helps to provide an excellent low forward voltage characteristic at high current. This is mandatory to limit a rise in temperature and therefore allows a higher surge current capability.

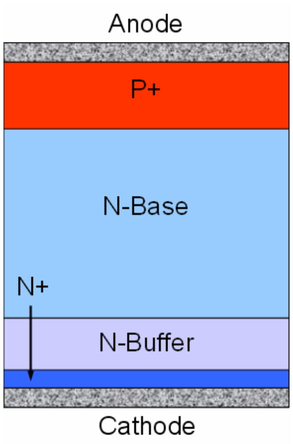


Figure 2 Cross-section of an ABB diode utilizing a strong P+ anode design

In ABB IGBT modules the packaging of the diode is optimized to distribute the resistances in the package evenly between the diode chips, helping to balance the currents. In addition, the contact through bond wires is optimized (Figure 3) to achieve homogeneous current flow through each diode die, avoiding excessive temperatures at local hot spots.

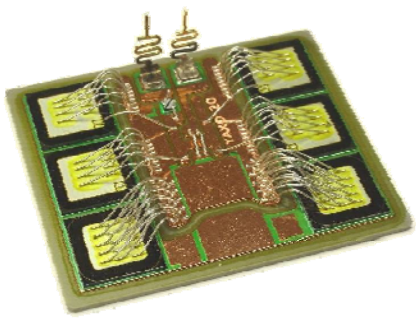


Figure 3 Layout of a substrate to optimise current sharing between the diode dies.

2.2 Definition of surge current capability

ABB IGBT diodes 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 fulfill the guaranteed safe operating area (SOA) conditions. In addition, the anti-parallel IGBT will not be not deteriorated.

Surge current testing is part of type testing, but not part of outgoing inspection.
As an example the graph in Figure 4 shows the surge current characteristics for a 3300V 1500A HiPak2 module 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 destruction limit of the diode, whereas the continuous blue line shows the limit for 100 pulses.
The dotted lines shows the expected performance through extrapolation; however these points have not been tested.

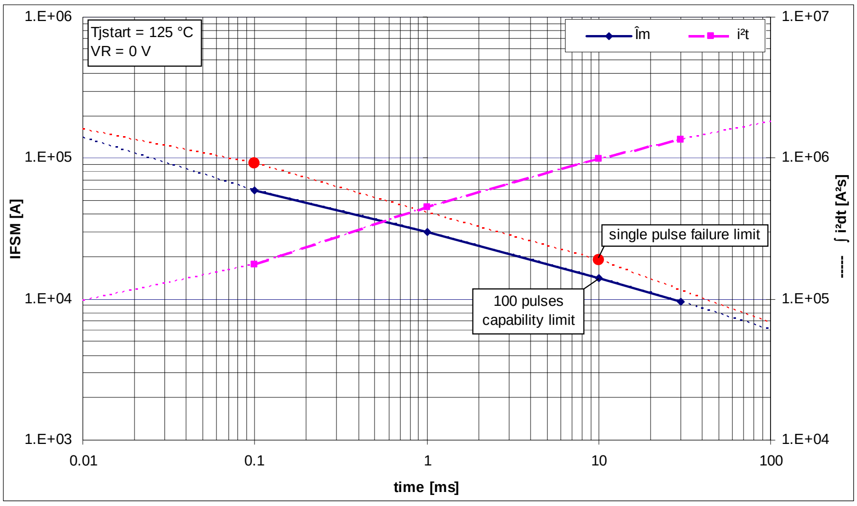


Figure 4 Surge on-state current vs. pulse length, half-sine wave for 5SNA 1500E330300

The black waveform in Figure 5 shows an ideal half-sine current of 10ms base width and 14.5 kA peak current, resulting in a surge current integral of 1.05 x 10^6 A^2s. The red curve is a typical test waveform; the resulting surge current integral is slightly above the target. The forward voltage of the diode during the pulse is shown in blue on the lower axis.

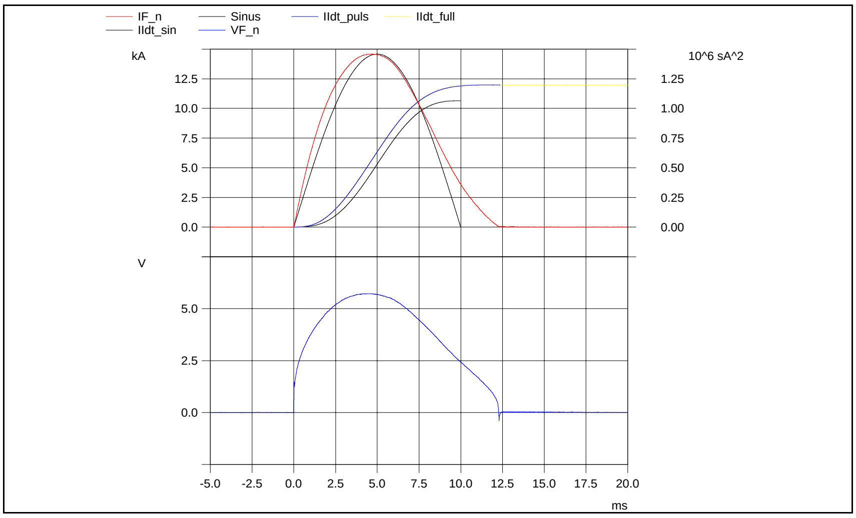


Figure 5 Typical wave forms at surge current testing

Figure 4 is made for half-sine waves and cannot be used for current wave forms deviating a lot from half-sine. For these cases a type test may be needed to correctly assess the feasibility.

3 SURGE CURRENT CAPABILITY PER VOLTAGE CLASS

In this section we show surge current capability diagrams for the largest available module per voltage class, which is typically the HiPak2 single switch module, followed by the smaller modules with lower current ratings.

3.1 1700 V HiPak

3.1.1 Graph for 5SNA 2400E170100

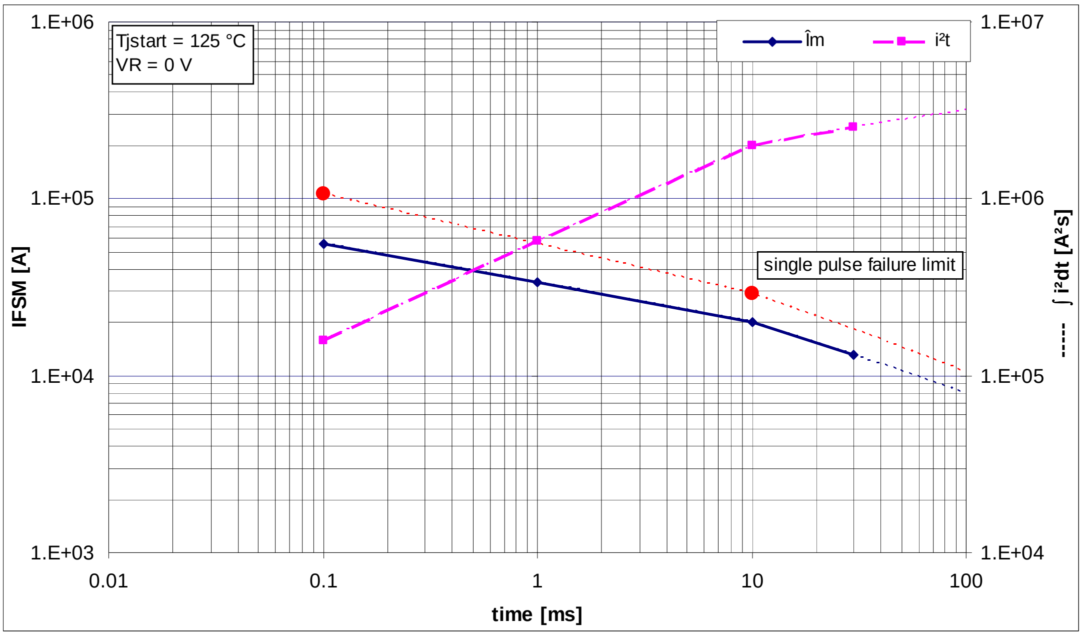


Figure 6 Surge on-state current vs. pulse length, half-sine wave for 5SNA 2400E170100

3.1.2 Graph for 5SNA 1800E170100

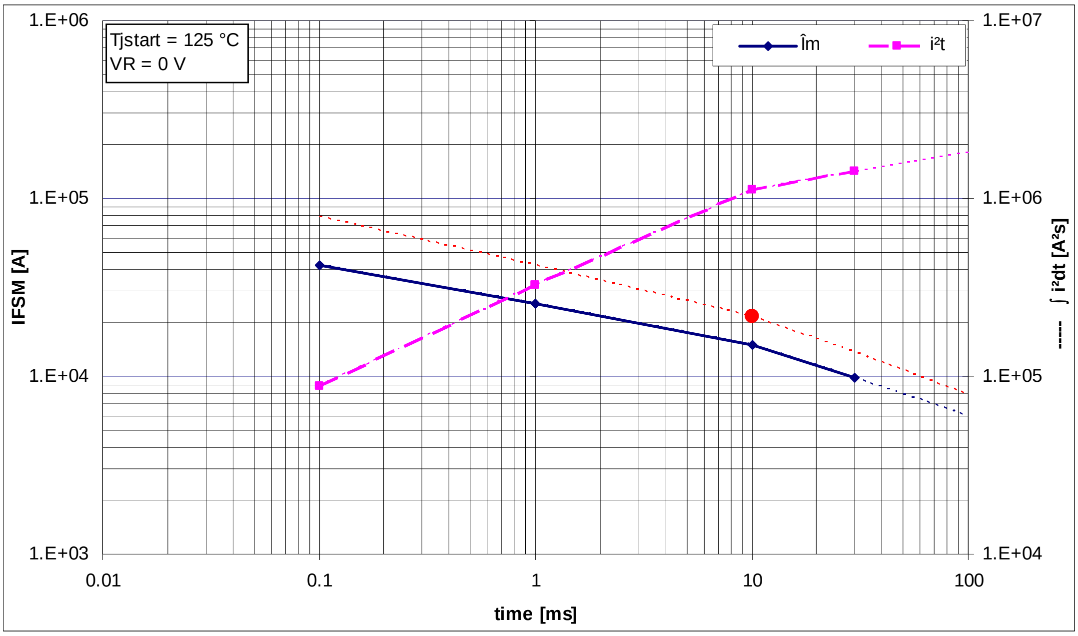


Figure 7 Surge on-state current vs. pulse length, half-sine wave for 5SNA 1800E170100

3.1.3 Graph for 5SNA 1600N170100

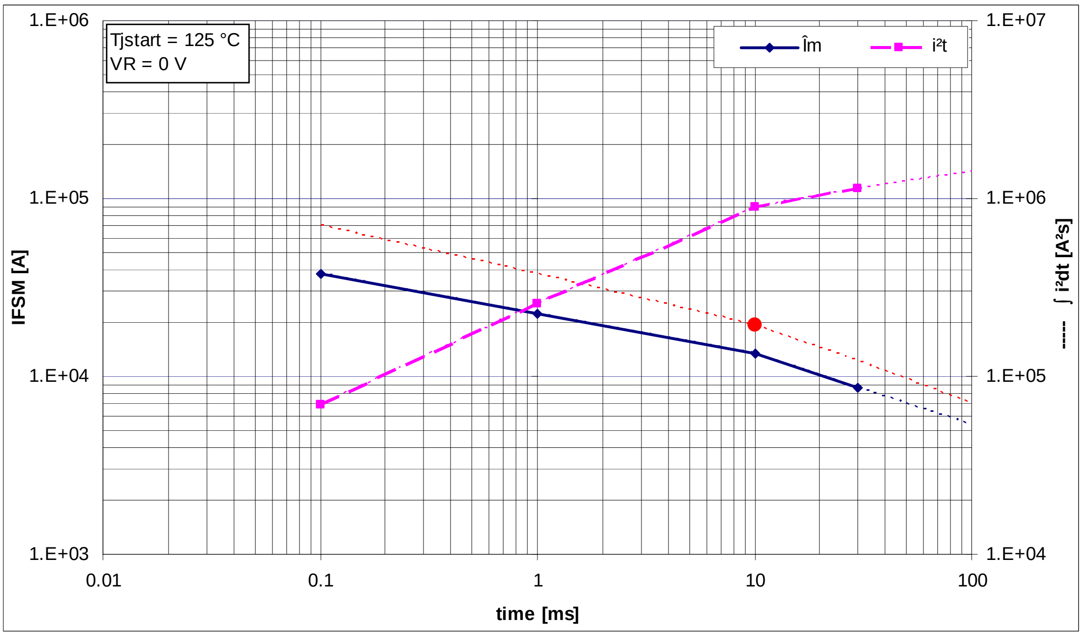


Figure 8 Surge on-state current vs. pulse length, half-sine wave for 5SNA 1600N170100

3.1.4 Graph for 5SND 0800M170100, 5SNE 0800M170100

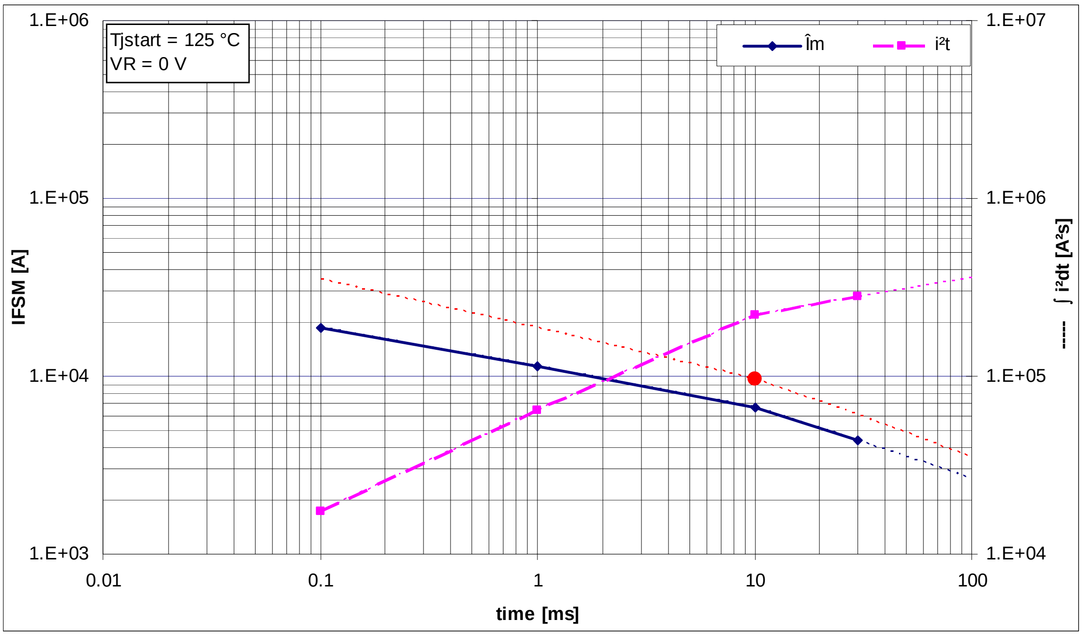


Figure 9 Surge on-state current vs. pulse length, half-sine wave for 5SND 0800M170100 and 5SNE 0800M170100

3.2 3300 V HiPak

3.2.1 Graph for 5SNA 1500E330300

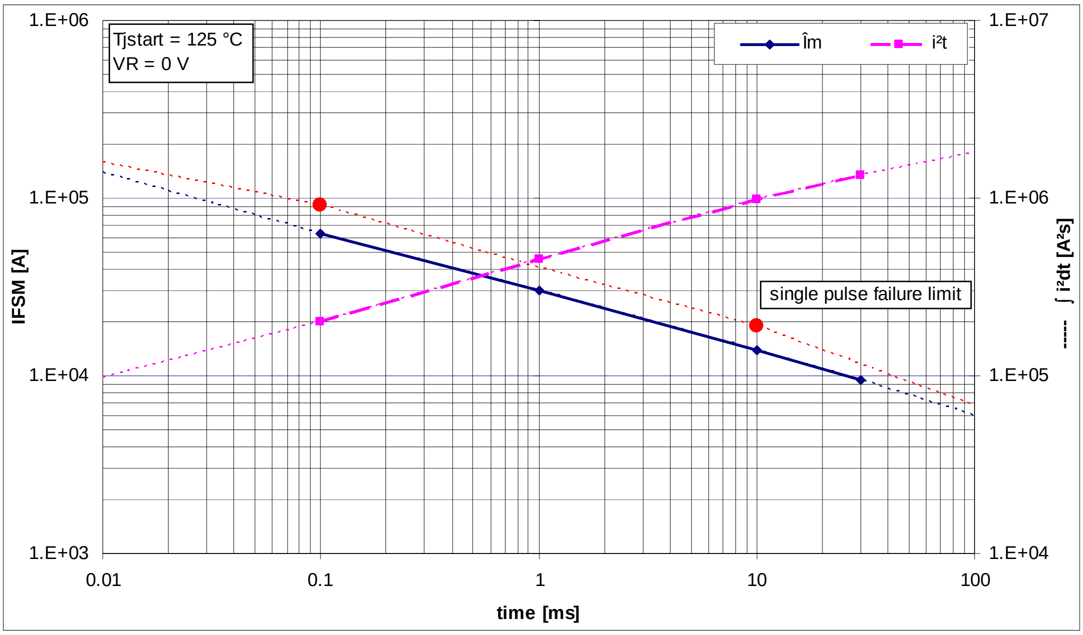


Figure 10 Surge on-state current vs. pulse length, half-sine wave for 5SNA 1500E330300

3.2.2 Graph for 5SNA 1200E330100, 5SNA 1200G330100, 5SLD 1200J330100

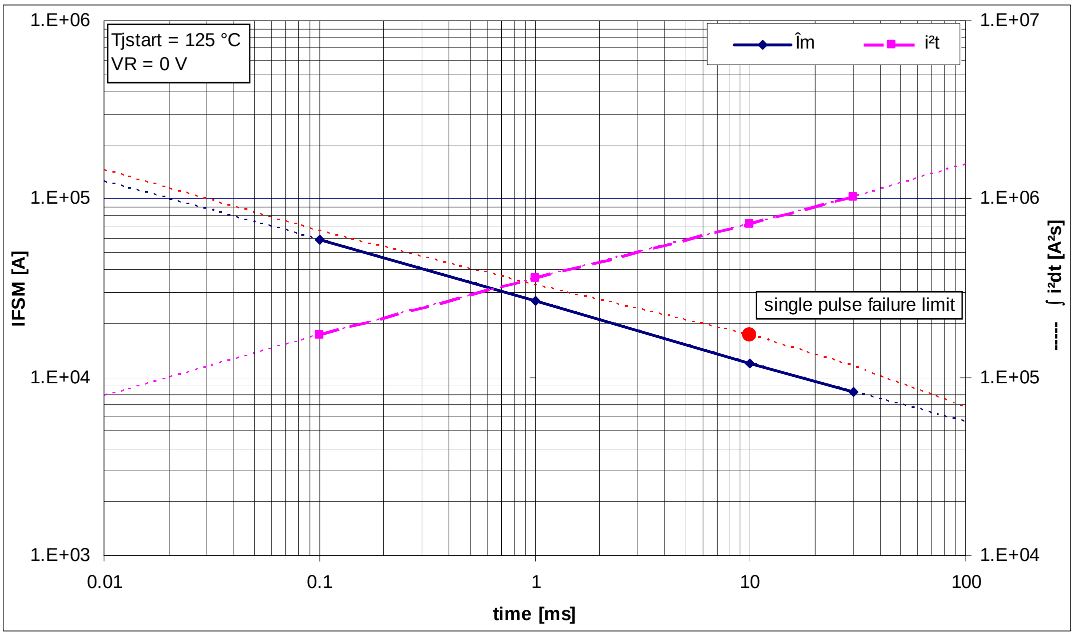


Figure 11 Surge on-state current vs. pulse length, half-sine wave for 5SNA 1200E330100, 5SNA 1200G330100 and 5SLD 1200J330100

3.2.3 Graph for 5SNA 0800N330100, 5SNE 0800E330100

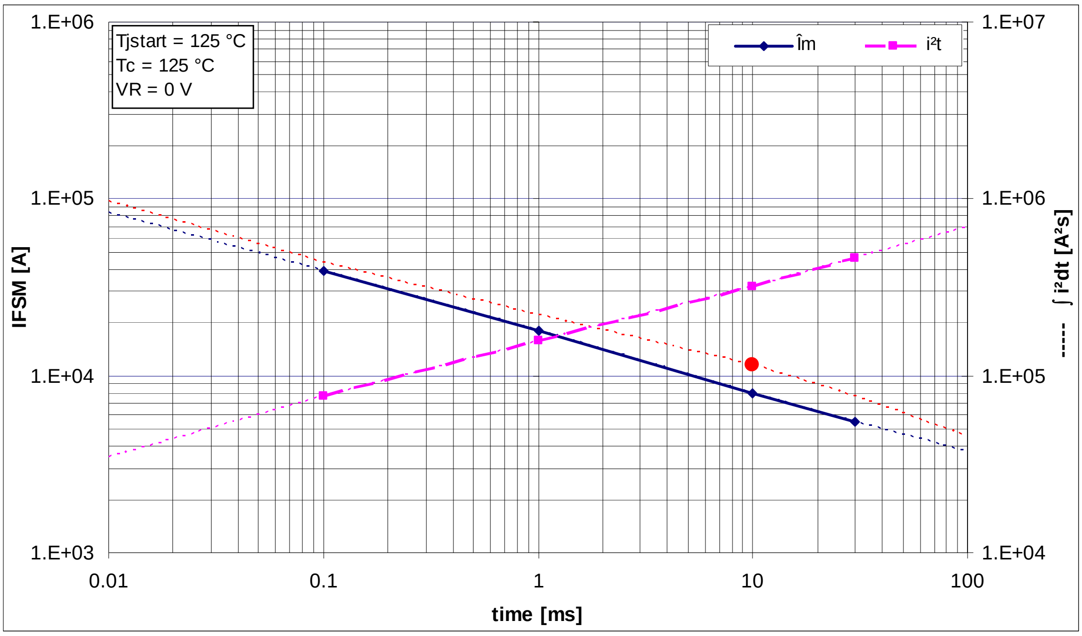


Figure 12 Surge on-state current vs. pulse length, half-sine wave for 5SNA 0800N330100 and 5SNE 0800E330100

3.3 6500 V HiPak

3.3.1 Graph for 5SNA 0600G650100, 5SLD 0600J650100

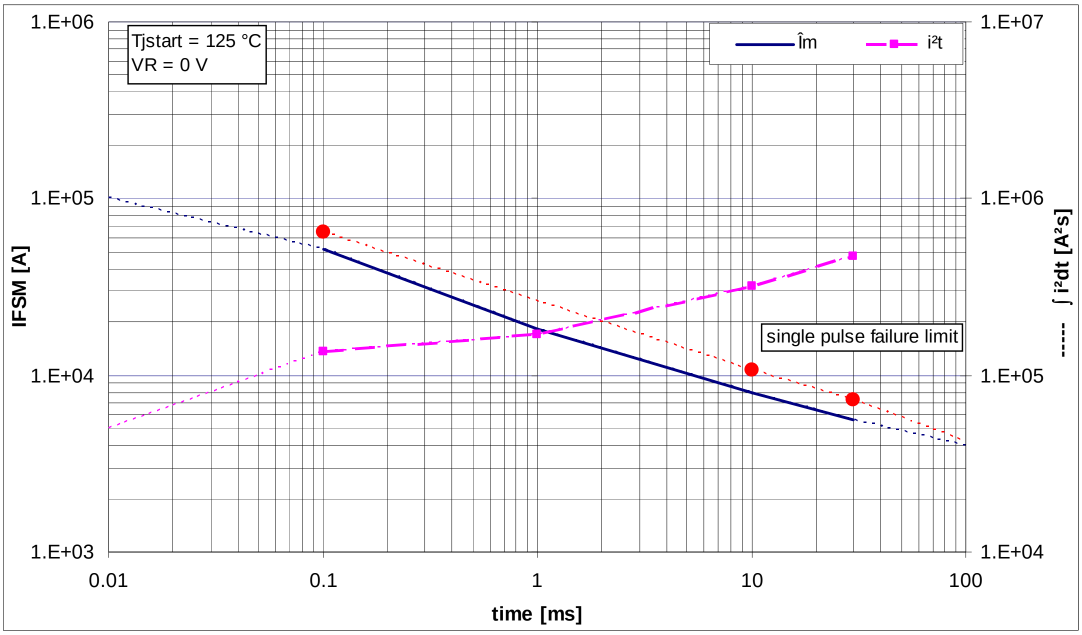


Figure 13 Surge on-state current vs. pulse length, half-sine wave for 5SNA 0600G650100 and 5SLD 0600J650100

3.3.2 Graph for 5SNA 0400J650100

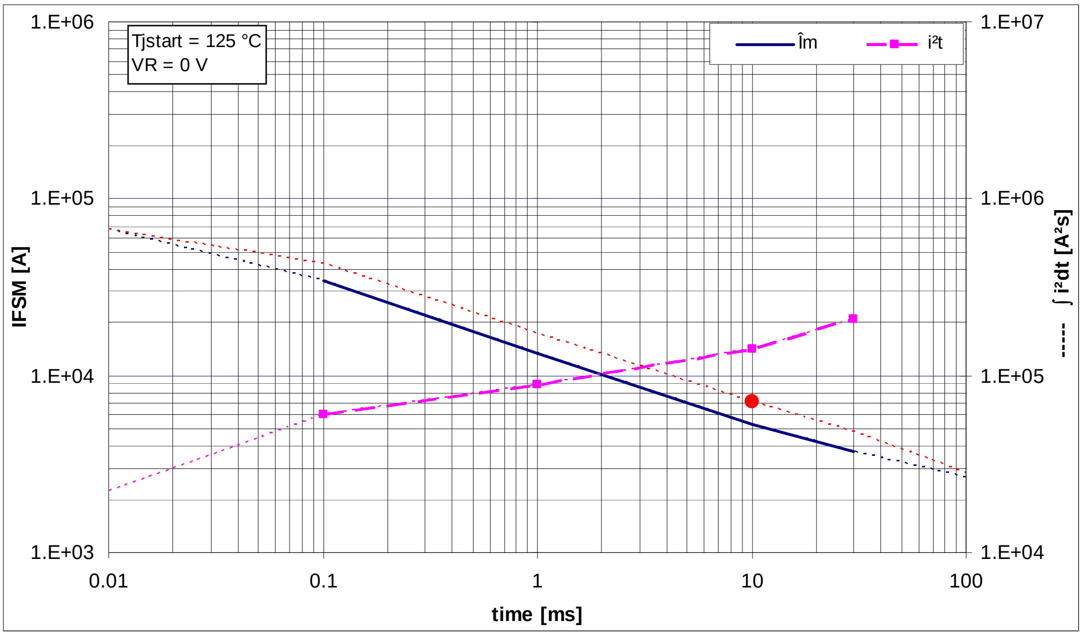


Figure 14 Surge on-state current vs. pulse length, half-sine wave for 5SNA 0400J650100

4 ADDITIONAL NOTES

4.1 Reapplied voltage

The surge current limits described so far will not allow a reverse voltage to be reapplied directly after the pulse, because the diodes are running too hot during the pulse and will not be able to stabilize 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, see also [2], [3]. Application specific support can be provided upon request.

4.2 Further improvements

The trend towards higher junction temperatures at operation conditions 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 working areas are given to further increase the surge current capability. Firstly the reduction of 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.

4.3 References

[1] IEC Standard 60747 "Semiconductor Devices"

[2] 5SYA2053 "Applying IGBT"

[3] 5SYA2042 "Thermal Runaway"

The application notes, references [2], [3] are available at www.abb.com/semiconductors.

4.4 Application support

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