Application Note 5SYA 2064-01

Applying fast recovery diodes

ABB Switzerland Ltd, Semiconductors has a long history of producing high power fast recovery diodes for applications such as Voltage Source Converters (VSC), Current Source Converters (CSC) and DC choppers. The diodes are typically used in combination with IGCTs and GTOs as freewheeling diodes, snubber diodes and clamp diodes.

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1 Introduction

When designing with fast recovery diodes, there are certain issues to be considered, the most important of these are addressed in this application note.

2 Fast recovery diode product range from ABB

2.1 GTO diodes

2.1.1 GTO freewheeling diodes

This type of diode is mainly designed for use in anti-parallel to a GTO. A GTO needs a snubber that limits dv/dt and di/dt. These diodes are therefore designed to work under conditions with a turn-off di/dt of some hundred amps per microsecond in combination with a dv/dt in a range of some hundred volts per microsecond. Additional important attributes are high cosmic radiation withstand ratings when blocking and low electrical losses in on-state and during switching.

ABB's GTO freewheeling diode product range is presented in Table 1.

2.1.2 Snubber diodes

Snubber diodes are optimized for the use in GTO snubber circuits. These diodes are designed for switching with high di/dt against high dv/dt. Electrical losses and cosmic radiation withstand rating are not as important as with freewheeling diodes.

ABB's snubber diode product range is presented in Table 2.

2.2 IGCT diodes

The design of IGCT diodes is optimized for switching against highest dv/dt. This is typically the case in applications with IGCTs where the semiconductors don't have any dv/dt snubber but rather a so called clamp circuit. The clamp circuit (Fig. 13) limits the commutation voltage but doesn't limit the dv/dt of IGCTs and diodes during turn-off. To handle the speed of the switching, an inductive snubber is used to reduce di/dt.

ABB's IGCT diode product range is presented in Table 3.

3 Data sheet users guide

Section 3.1 is a detailed guide to the proper understanding of an IGCT-Diode data sheet. Parameters and ratings are defined while following the sequence in which parameters appear in the data sheet. For explanation purposes, data and diagrams associated with the IGCT diode 5SDF 10H4503 have been used. However, this guide is applicable to all IGCT diodes. For actual data of 5SDF 10H4503 please refer to the Datasheet in the ABB internet website.

Data sheets of GTO freewheeling diodes and snubber diodes are similarly specified and are therefore to read similarly.

Parameter	V_{RRM}	V_{DC}	$I_{F(AV)M}$		I_{FSM}	$V_{(T0)}$	r_F	I_{RM}	Q_{rr}	T_{VJM}	$R_{th(j-c)}$	$R_{th(c-h)}$	F_m	Housing
			T_c = 85 °C	1 ms T_{VJM}	10 ms T_{VJM}		T_{VJM}		di/dt=300 A/us					«Type» ø x h
	V	V	A	kA	kA	V	mΩ	A	μC	°C	K/kW	K/kW	kN	[mm]
5SDF 05D2505	2500	1500	420	27	8.5	1.7	0.62	470	840	125	40	8	11	"D" 60 x 26
5SDF 11F2501	2500	1500	950	65	21	1.2	0.38	550	1200	125	20	5	22	"F" 75 x 26
5SDF 07F4501	4500	2800	650	44	16	1.4	1.00	600	1900	125	20	5	22	"F" 75 x 26
5SDF 13H4501	4500	2800	1200	60	25	1.3	0.48	800	3000	125	12	3	40	"H" 95 x 26
5SDF 10H6004	6000	3800	1100	44	18	1.5	0.60	1000	6000	125	12	3	40	"H" 95 x 26

Table 1: GTO freewheeling diode product range

Parameter	V_{RRM}	V_{DC}	$I_{F(AV)M}$		I_{FSM}	$V_{(T0)}$	r_F	I_{RM}	Q_{rr}	T_{VJM}	$R_{th(j-c)}$	$R_{th(c-h)}$	F_m	Housing
			T_c = 85 °C	1 ms T_{VJM}	10 ms T_{VJM}		T_{VJM}		di/dt=100 A/us					«Type» ø x h
	V	V	A	kA	kA	V	mΩ	A	μC	°C	K/kW	K/kW	kN	[mm]
5SDF 05D2501	2500	1100	490	27	8.5	1.4	0.5	250	900	125	40	8	11	"D" 60 x 26
5SDF 03D4501	4500	2400	320	12	5.0	2.0	1.5	200	1000	125	40	8	11	"D" 60 x 26
5SDF 07H4501	4500	2400	900	40	16.0	1.8	0.9	260	1700	125	12	3	40	"H" 95 x 26
5SDF 02D6002	6000	3000	250	11.4	3.6	2.5	2.5	260	2000	125	40	8	11	"D" 60 x 26

Table 2: GTO snubber diode product range

Parameter	V_{RRM}	V_{DC}	$I_{F(AV)M}$		I_{FSM}	$V_{(T0)}$	r_F	I_{RM}	di/dt	T_{VJM}	$R_{th(j-c)}$	$R_{th(c-h)}$	F_m	Housing
			T_C = 70 °C	1 ms T_{VJM}	10 ms T_{VJM}		T_{VJM}		max.					«Type» ø x h
	V	V	A	kA	kA	V	mΩ	A	A/us	°C	K/kW	K/kW	kN	[mm]
5SDF 03D4502	4500	2800	275	10	5	2.15	2.80	355	300	115	40	8	16	"D" 60 x 26
5SDF 05F4502	4500	2800	435	32	16	2.42	2.10	610	430	115	17	5	20	"F" 75 x 26
5SDF 10H4502	4500	2800	810	40	24	2.42	1.10	1150	650	115	12	3	44	"H" 95 x 26
5SDF 10H4503	4500	2800	1100	47	20	1.75	0.88	1520	600	125	12	3	40	"H" 95 x 26
5SDF 10H4520	4500	2800	1440	56	25	1.75	0.88	1600	600	140	10	3	40	"H" 95 x 26
5SDF 16L4503	4500	2800	1650	47	26	1.90	0.79	1200	600	125	6.5	3	40	"L" 120 x 26
5SDF 02D6004	5500	3300	175	8	3	3.35	7.20	300	220	115	40	8	16	"D" 60 x 26
5SDF 04F6004	5500	3300	380	22	10	2.70	2.80	600	340	115	22	5	20	"F" 75 x 26
5SDF 08H6005	5500	3300	585	40	18	4.50	1.30	900	440	115	12	3	44	"H" 95 x 26

Table 3: IGCT diode product range

3.1 IGCT-Diode data sheet

V_{RRM}	=	4500 V
$I_{F(AV)M}$	=	1100 A
I_{FSM}	=	20×10^3 A
$V_{(T0)}$	=	1.75 V
r_T	=	0.88 mΩ
V_{DClink}	=	2800 V

Fast Recovery Diode

5SDF 10H4503

- Patented free-floating technology
- Industry standard housing
- Cosmic radiation withstand rating
- Low on-state and switching losses
- Optimized for snubberless operation

The key features give the basic voltage and current ratings of the diode. These ratings are repeated later in the data sheet where the conditions at which the value is valid are shown. Each of them is explained at the appropriate place in this section. The parameter values are followed by a short description of the main features of the diode.

Blocking

Maximum rated values [1)]

Parameter	Symbol	Conditions	Value	Unit
Repetitive peak reverse voltage	V_{RRM}	f = Hz, t_p = 10ms T_{vj} = 125 °C	4500	V
Permanent DC voltage for 100 FIT failure rate	$V_{DC\text{-}link}$	Ambient cosmic radiation at sea level in open air. (100% Duty)	2800	V
Permanent DC voltage for 100 FIT failure rate	$V_{DC\text{-}link}$	Ambient cosmic radiation at sea level in open air. (5% Duty)	3200	V

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Repetitive peak reverse current	I_{RRM}	$V_R = V_{RRM}$, T_{vj} = 125 °C			50	mA

V_{RRM}: Maximum voltage that the device can block repetitively. Above this level the device may be damaged or become destroyed. This parameter is measured with 10 millisecond (ms) half-sine pulses with a repetition frequency of 50 hertz (Hz). The limit for maximum single-pulse voltage (V_{RSM}) is normally not stated in the ABB datasheets since it is equal to V_{RRM}.
$V_{DC\text{-}link}$: These numbers define the maximum DC-link voltage of a voltage source inverter or a chopper application to achieve maximum 100 FIT (Failure in Time, 1 FIT corresponds to 1 failure in 10^9 component hours) under the defined conditions. For more details please read the ABB application note 5SYA2061 «Cosmic ray on FRD». Switching against higher voltage than the maximum stated $V_{DC\text{-}link}$ is not recommended since it can lead to abrupt cut-off of the reverse recovery current of the diode, so called snap-off.
I_{RRM}: The maximum leakage current at the given conditions.

Mechanical data

Maximum rated values [1)]

Parameter	Symbol	Conditions	min	typ	max	Unit
Mounting force	F_m		36	40	46	kN
Acceleration	a	Device unclamped			50	m/s^2
Acceleration	a	Device clamped			200	m/s^2

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Weight	m				0.83	kg
Housing thickness	H		26.0		26.4	mm
Surface creepage distance	D_s		33			mm
Air strike distance	D_a		20			mm

F_m: The mounting force is the recommended force to be applied for optimal device performance. Too low a mounting force will increase the thermal impedance thus leading to higher junction temperature excursions resulting in a lower operating lifetime for the diode. Too high a clamping force may crack the wafer during load cycling. It is important to apply a homogeneous force over the whole contact area. Otherwise, electrical and reliability performance are reduced. For details please consult the ABB application note 5SYA2036 «Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors».
a: Maximum permissible acceleration in any direction at the given conditions. The value for a clamped device is only valid within the given mounting force limits.
m: Weight of the device.
H: Height of the device when clamped at the given force.
D_s: The surface creepage distance is the shortest path along the housing between anode and cathode.
D_a: The air strike distance is defined as the shortest direct path between anode and cathode.

On-state

Maximum rated values [1)]

Parameter	Symbol	Conditions	min	typ	max	Unit
Max. average on-state current	$I_{F(AV)M}$	Half sine wave, T_C = 70 °C			1100	A
Max. RMS on-state current	$I_{F(RMS)}$				1740	A
Max. peak non repetitive surge current	I_{FSM}	t_p = 10 ms, T_{vj} = 125 °C V_R = 0 V			20×10^3	A
Limiting load integral	I^2t				2×10^6	A^2s
Max. peak non repetitive current	I_{FSM}	t_p = 30 ms, T_{vj} = 125 °C V_R = 0 V			12×10^3	A
Limiting load integral	I^2t				2.16×10^6	A^2s

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
On-state voltage	V_F	I_F = 2500 A, T_{vj} = 125 °C		3.1	3.8	V
Threshold voltage	$V_{(T0)}$	T_{vj} = 125 °C			1.75	V
Slope resistance	r_T	I_F = 500...2500 A			0.88	mΩ

$I_{F(AV)M}$ and $I_{F(RMS)}$: are the maximum allowable average and RMS device currents defined for 180 ° sine wave pulses of 50 percent duty cycle at the specified case temperature. The definitions are arbitrary but standard thus allowing device comparisons.
I_{FSM} and I^2t: The maximum peak forward surge current and the integral of the square of the current over one period are defined for 10 ms and 30 ms wide, half sine-wave current pulses without reapplied voltage. Above these values, the device may fail (short-circuit). These parameters are required for protection co-ordination. For currents that clearly differ from half sine wave shape the above stated numbers and the curves in Fig. 4

and Fig. 5 are not applicable. For evaluation of such cases please contact ABB's Application Support. Additional information is provided in section 4.3.3.

V_F: The forward voltage drop of the diode at the given conditions. The threshold voltage $V_{(T0)}$ and the slope resistance r_T allow a linear representation of the diode forward voltage drop and are used for simple calculations of conduction losses in the current range stated under «conditions».

Turn-on

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Peak forward recovery voltage	V_{FRM}	dI_F/dt=600A/µs, T_{vj} = 125 °C			80	V
		dI_F/dt=3000A/µs, T_{vj} = 125 °C			250	V

V_{FRM}: The dynamic peak forward voltage drop of the diode during turn-on. V_{FRM} and dI_F/dt are defined in Fig 12. A more detailed description is written in section 4.3.1.

Turn-off

Maximum rated values[1)]

Parameter	Symbol	Conditions	min	typ	max	Unit
Max. decay rate of on-state current	di/dt_{crit}	I_F = 4000 A $V_{DC-Link}$ = 2800 V $-dI_F/dt$ = 600 A/µs L_{CL} = 300 nH $C_{CL-Link}$ = 10µF $R_{CL-Link}$ = 65Ω T_{vj} = 125 °C D_{CL} = 5SDF 10H4503			600	A/µs

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Reverse recovery current	I_{RM}	I_F = 3300 A $V_{DC-Link}$ = 2800 V			1520	A
Reverse recovery charge	Q_{rr}	$-dI_F/dt$ = 600 A/µs L_{CL} = 300 nH			5250	µC
Turn-off energy	E_{rr}	C_{CL} = 10µF R_{CL} = 65Ω T_{vj} = 125 °C D_{CL} = 5SDF 10H4503			9.5	J

di/dt_{crit}: Maximum turn-off di/dt that the device can handle at the stated conditions. Above this level the device may be destroyed. Especially higher values in L_{CL} or $V_{DC-Link}$ drastically reduce turn-off capability.

I_{RM}: Maximum reverse recovery current at the stated conditions. Dependencies of di/dt and forward current I_F are shown in Fig. 9.

Q_{rr}: Maximum reverse recovery charge at the stated conditions. Dependencies of di/dt and forward current I_F are shown in Fig. 8.

E_{rr}: Maximum turn-off energy at the stated conditions. The E_{rr} value is highly depending on the on-state voltage of the individual diode. This should be considered when doing loss simulations. Since V_F typically shows a scatter in the range of some 100 millivolts (mV) we recommend doing diode total-loss calculations at application conditions with the extreme combinations E_{rr-1}_@ V_{F-max} and E_{rr-2}_@ V_{F-min}. This corresponds to either a diode with high on-state or a diode with low on-state. Please see Fig 10. In this particular case we recommend to simulate diode losses with a device

A) **VF = 2.6V @ IF = 3300A -> E_{rr-2} = 9.5 Ws @ the stated conditions**

B) **VF = 4.25V @ IF = 3300A -> E_{rr-1} = 6.0 Ws @ the stated conditions**

To adapt the datasheet conditions to the application conditions, di/dt and IFM can be linear interpolated between the curves in Fig 6 and Fig 7. Small differences in the range of 15 percent in $V_{DC-link}$ can be linear extrapolated. For loss calculations with parameters that greatly differ from the stated datasheet conditions please contact ABB's Application Support.

Thermal

Maximum rated values[1)]

Parameter	Symbol	Conditions	min	typ	max	Unit
Operating junction temperature range	T_{vj}		0		125	°C
Storage temperature range	T_{stg}		-40		125	°C

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Thermal resistance junction to case	$R_{th(j-c)}$	Double-side cooled F_m = 36...46 kN			12	K/kW
	$R_{th(j-c)A}$	Anode-side cooled F_m = 36...46 kN			24	K/kW
	$R_{th(j-c)C}$	Cathode-side cooled F_m = 36...46 kN			24	K/kW
Thermal resistance case to heatsink	$R_{th(c-h)}$	Double-side cooled F_m = 36...46 kN			3	K/kW
Thermal resistance case to heatsink	$R_{th(c-h)}$	Single-side cooled F_m = 36...46 kN			6	K/kW

Analytical function for transient thermal impedance:

$$Z_{th(j-c)}(t) = \sum_{i=1}^{n} R_{th\,i}(1 - e^{-t/\tau_i})$$

i	1	2	3	4
$R_{th\,i}$(K/kW)	7.705	2.748	1.009	0.539
τ_i(s)	0.5244	0.0633	0.0065	0.0015

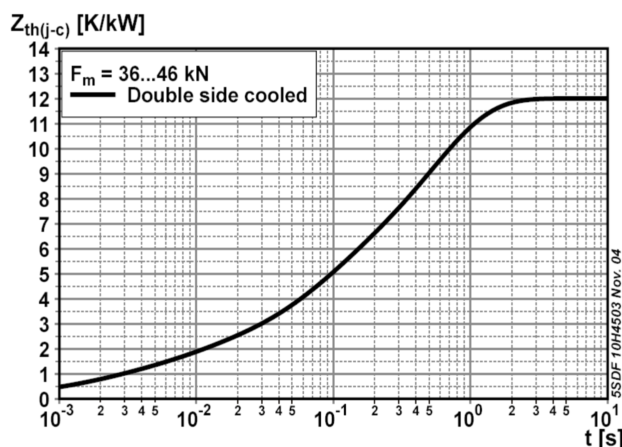

Fig. 1: Transient thermal impedance junction-to-case

T_{vj}: The operating junction temperature range gives the limits within which the silicon of the diode should be used. If the limits are exceeded, the ratings for the device are no longer valid and there is a risk of catastrophic failure.
T_{stg}: The temperature interval within which the diode must be stored to ensure that it will be operational at a later use. $T_{stg-min}$ and $T_{stg-max}$ are the extreme temperatures and are not recommended for long time storage. For long time storage please refer to Specification 5SZK 9104 «Specification of environmental class for pressure contact Diodes, PCTs and GTOs – STORAGE»
The thermal resistance junction to case, $R_{th(j-c)}$, and the thermal resistance case to heat sink, $R_{th(c-h)}$, are measures of how well the power losses can be transferred to the cooling system. The values are given both for double-sided cooling, where the device is clamped between two heat sinks, and single-sided cooling, where the device is clamped to only one heat sink. The values are valid for a homogeneously applied clamping force over the whole contact area of the diode. The temperature rise of the «virtual junction» (the silicon wafer inside the diode) in relation to the heat sink is calculated using Equation 1. $R_{th(j-c)}$ and $R_{th(c-h)}$ should be as low as possible since the temperature of the silicon determines the current capability of the diode. Furthermore the temperature excursion of the silicon wafer determines the load-cycling capability and thus the life expectancy of the diode.

$$\Delta T_{JH} = P_{loss} * \left(R_{th(j-c)} + R_{th(c-h)}\right) \quad [K] \qquad \text{Eqn 1}$$

where ΔT_{JH} is the temperature difference between the silicon wafer and the heat sink.

The transient thermal impedance emulates the rise of junction temperature versus time when a constant power is dissipated in the junction. This function can either be specified as a curve or as an analytic function with the superposition of four exponential terms. The analytic expression is particularly useful for computer calculations.

Max. on-state characteristic model:

$$V_{F25} = A_{Tvj} + B_{Tvj} \cdot I_F + C_{Tvj} \cdot \ln(I_F + 1) + D_{Tvj} \cdot \sqrt{I_F}$$

Valid for I_F = 300 – 30000 A

A_{25}	B_{25}	C_{25}	D_{25}
-79.52×10^{-6}	83.80×10^{-6}	99.41×10^{-3}	1.09×10^{-3}

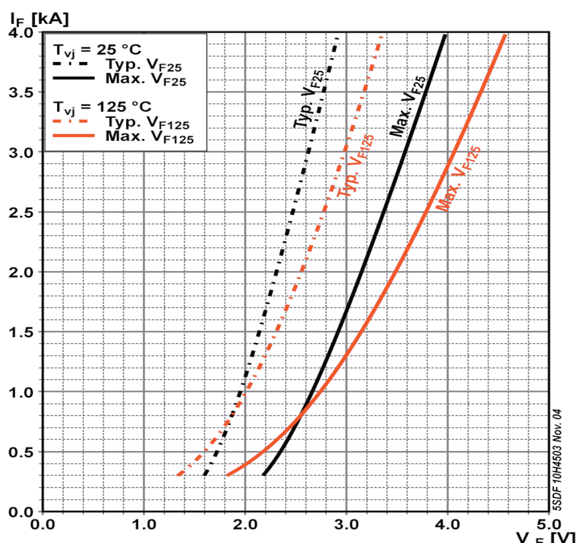

Fig. 2: Max. on-state voltage characteristics

The model (Fig. 2) gives a mathematical expression for the maximum on-state voltage at T_{vj} = 25 °C for the given current interval which is much greater than the interval given for the simple linear model given by $V_{(T0)}$ and r_T.
On-state voltage drop of the diode as a function of the on-state current at the given temperatures for normal operation current levels.

Max. on-state characteristic model:

$$V_{F125} = A_{Tvj} + B_{Tvj} \cdot I_F + C_{Tvj} \cdot \ln(I_F + 1) + D_{Tvj} \cdot \sqrt{I_F}$$

Valid for I_F = 300 – 30000 A

A_{125}	B_{125}	C_{125}	D_{125}
-79.52×10^{-6}	83.80×10^{-6}	99.41×10^{-3}	1.09×10^{-3}

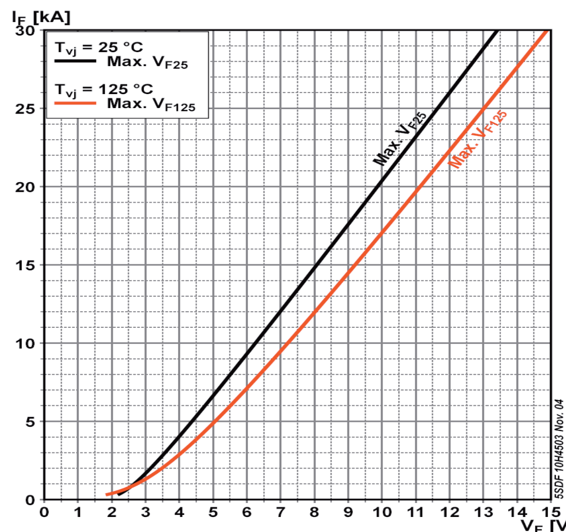

Fig. 3: Max. on-state voltage characteristics

The model (Fig. 3) gives a mathematical expression for the maximum on-state voltage at T_{vj} = 25 °C for the given current interval which is much greater than the interval given for the simple linear model given by $V_{(T0)}$ and r_T.
On-state voltage drop of the diode as a function of the on-state current at the given temperatures for the extended current levels up to the magnitude of IFSM. The curves are calculated with above mathematical expressions.

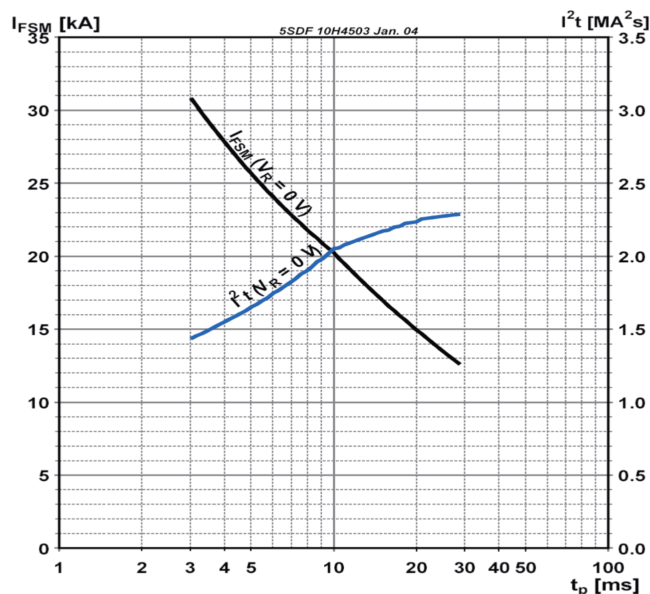

Fig. 4: Surge on-state current vs. pulse length. Half-sine wave

Surge current limit and surge current integral for half-sine pulses of different pulse widths with no reapplied voltage (Fig. 4). The curves are given for a starting temperature of T_{vj-max}.

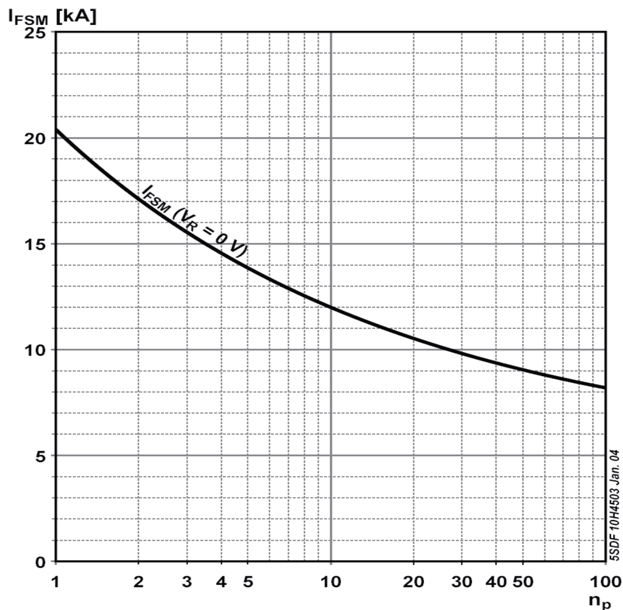

Fig. 5: Surge on-state current vs. number of pulses, half-sine wave, 10 ms, 50Hz

Surge current limit with no reapplied voltage as a function of the number of applied 10 ms half-sine pulses with a repetition rate of 50 Hz for a starting temperature of $T_{vj\text{-}max}$ (Fig. 5).

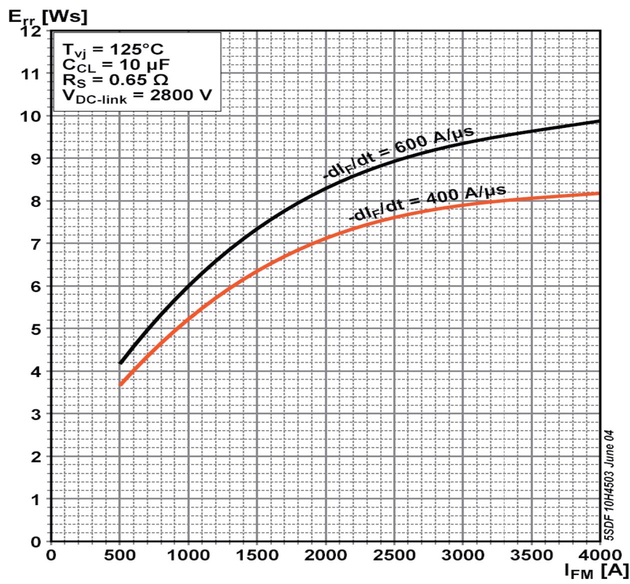

Fig. 6: Upper scatter range of turn-off energy per pulse vs. turn-off current

Maximum turn-off energy at the given conditions as a function of the on-state current I_F before the commutation. See figure 12 for definitions (Fig. 6).

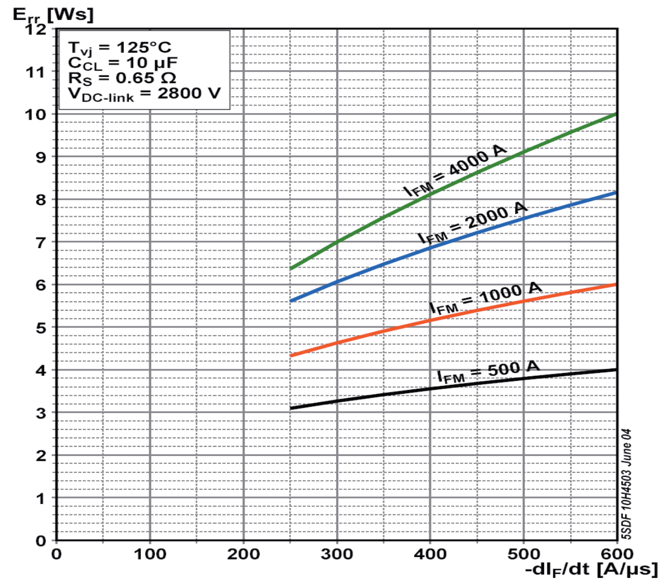

Fig. 7: Upper scatter range of turn-off energy per pulse vs. reverse current rise rate

Maximum turn-off energy at the given conditions as a function of the rate of decline of current before the commutation (Fig. 7). See figure 12 for definitions.

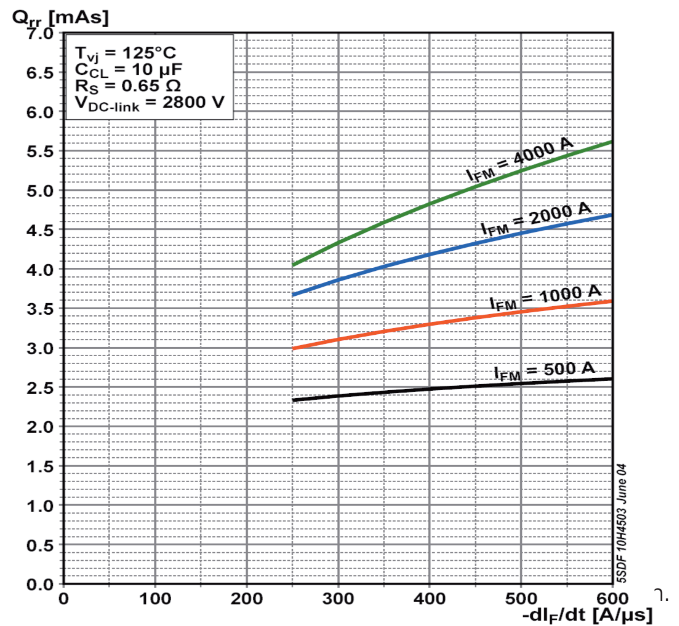

Fig. 8: Upper scatter range of repetitive reverse recovery charge vs. reverse current rise rate.

Maximum reverse recovery current at the given conditions as a function of the rate of decline of current before the commutation (Fig. 8). See figure 12 for definitions.

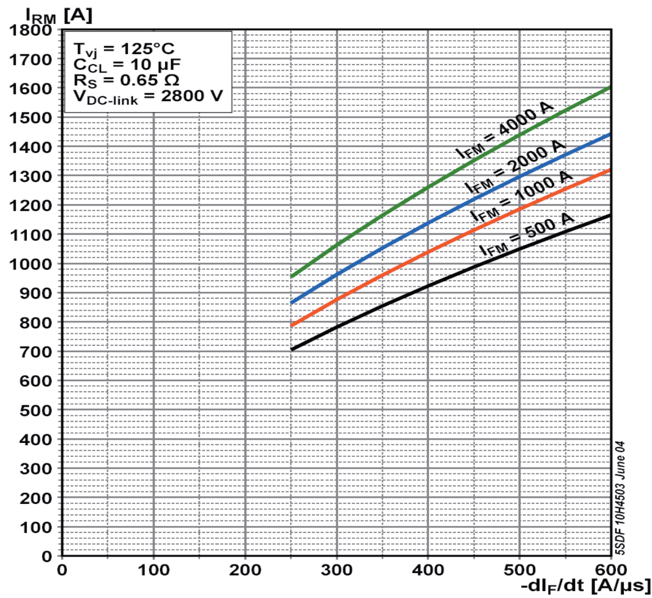

Fig. 9: Upper scatter range of reverse recovery current vs. reverse current rise rate

Maximum reverse recovery current at the given conditions as a function of the rate of decline of current before the commutation (Fig. 9). See figure 12 for definitions.

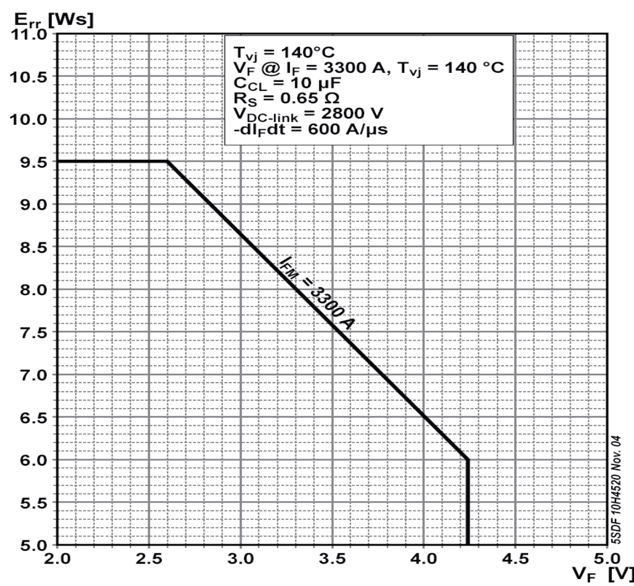

Fig. 10: Max. turn-off energy per pulse vs. on-state voltage.

Maximum turn-off switching energy depending on the on-state of the diode at the given conditions (Fig. 10). The curve represents the upper scatter range of E_{rr} of the production distribution.

Fig. 11: Diode Safe Operating Area

Safe operating area at the given conditions (Fig. 11). See figure 12 for definitions. Use of the diode outside these operation conditions could lead to catastrophic failures and should therefore be avoided.

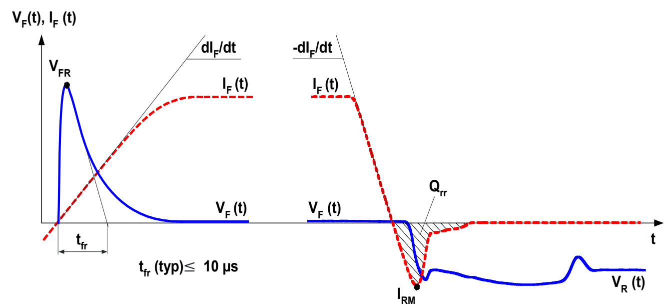

Fig. 12: General current and voltage waveforms

Electrical circuit used when determining the turn-on and turn-off data sheet ratings. C_{CL}, D_{CL}, R_S and L_{CL} represent the clamp circuit to limit switching over-voltages. L_{CL} is a stray inductance and restricts the switching capability of the circuit. It should be designed as small as possible in an application.
The turn-off parameters Err and Q_{rr} are only specified on the DUT position as a freewheeling diode. The reason is that on clamp position (D_{CL}) turn-off losses are typically not the limiting criteria.

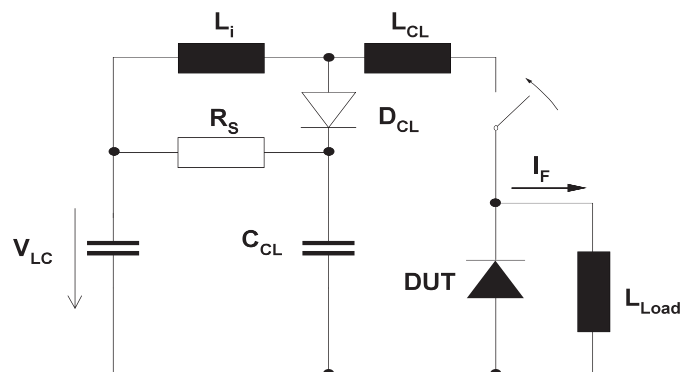

Fig. 13: Test circuit

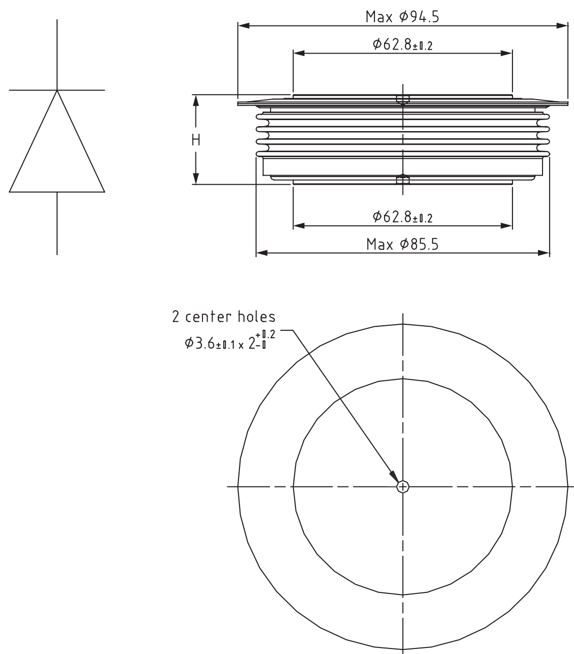

Fig. 14: Outline drawing, all dimensions are in millimeters and represent nominal values unless stated otherwise

Related documents:

Doc. Nr.	Titel
5SYA 2036	Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors
5SYA 2061	Failure rates of fast recovery diodes due to cosmic rays
5SZK 9104	Specification of environmental class for pressure contact diodes, PCTs and GTO, STORAGE. Available on request, please contact ABB's Application Support.
5SZK 9105	Specification of environmental class for pressure contact diodes, PCTs and GTO, TRANSPORTATION. Available on request, please contact ABB's Application Support.

Please refer to http://www.abb.com/semiconductors for current versions.

A list of applicable documents is included at the end of the data sheet.

4 Design recommendations

4.1 Determine the right diode for standard application conditions

If the application conditions are close to the specified conditions in the datasheets of the used GTO or IGCT ABB recommends the use of the following diodes. If several diodes are recommended by ABB, the decision should be made according to the needs of the application:

- High expected losses in the diode -> use the larger diode
- GTO/GCT and diodes in one combined mechanical clamp system -> use the diode with adequate mounting force
- Application conditions very close to the GTO/IGCT SOA limits -> use the larger diode

GTO applications:

GTO Type	Recommended freewheeling diodes	Recommended snubber diodes
5SGA 15F2502	5SDF 05D2505 5SDF 11F2501	5SDF 05D2501
5SGA 20H2501	5SDF 05D2505 5SDF 11F2501	5SDF 05D2501
5SGA 25H2501	5SDF 05D2505 5SDF 11F2501	5SDF 05D2501
5SGA 30J2501	5SDF 11F2501	5SDF 05D2501
5SGA 06D4502	5SDF 03D4501	5SDF 03D4501
5SGA 20H4502	5SDF 03D4501 5SDF 07F4501	5SDF 03D4501
5SGA 30J4502	5SDF 07F4501 5SDF 13H4501	5SDF 03D4501
5SGA 40L4501	5SDF 13H4501	5SDF 03D4501 5SDF 07H4501
5SGF 30J4502	5SDF 07F4501 5SDF 13H4501	5SDF 03D4501 5SDF 07H4501
5SGF 40L4502	5SDF 13H4501	5SDF 03D4501 5SDF 07H4501

Table 4: Recommended diodes for GTO applications

IGCT applications

GTO Type	Recommended freewheeling diodes	Recommended clamp diodes	Recommended NPC diodes**
5SHX 08F4510	Integrated	5SDF 03D4502	5SDF 03D4502
5SHX 14H4510	Integrated	5SDF 03D4502 5SDF 05F4502	5SDF 03D4502 5SDF 05F4502 5SDF 10H4503
5SHX 26L4510	Integrated	5SDF 03D4502 5SDF 05F4502	5SDF 05F4502 5SDF 10H4503 5SDF 10H4520
5SHX 06F6010	Integrated	5SDF 02D6004	5SDF 02D6004 5SDF 04F6004
5SHX 10H6010	Integrated	5SDF 02D6004 5SDF 04F6004	5SDF 04F6004 5SDF 08H6005
5SHX 19L6010	Integrated	5SDF 02D6004 5SDF 08H6005	5SDF 04F6004 5SDF 08H6005
5SHY 35L4510 5SHY 35L4511 5SHY 35L4512 5SHY 55L4500	5SDF 10H4503 5SDF 10H4520 5SDF 16L4503	5SDF 05F4502 5SDF 10H4503 5SDF 10H4520	5SDF 10H4503 5SDF 10H4520 5SDF 16L4503

Table 5: Recommended diodes for IGCT applications

** Note: NPC diodes stand for Neutral Point Clamp diodes. These diodes are typically used in 3-level inverters. The conditions to which these diodes are subjected are typically similar to the conditions of a freewheeling diode used in an IGCT inverter.

4.2 Determine the right diode for customized application conditions

If the application conditions differ from the specified conditions in the datasheet, the following parameters must be defined:

a) Diode type?
Freewheeling diode, dv/dt at turn-off < 700V/µs ⟶ GTO freewheeling diode

Freewheeling diode, dv/dt at turn-off > 700V/µs ⟶ IGCT diode

Snubber diode in a GTO-application, no dc-blocking operation ⟶ GTO snubber diode

Clamp diode in an IGCT-application ⟶ IGCT diode

b) Voltage class?
Diodes with higher blocking voltage typically show
- Higher forward recovery during turn-on
- Increased ruggedness and softness while turning off
- Higher on-state and switching losses
- Much lower cosmic radiation FIT rate at compared voltage. Please consider application notes 5SYA2051 «Voltage ratings of high power semiconductors» and 5SYA2061 «Cosmic ray on FRD»

c) Diode-diameter?
Diodes with larger diameter show
- Lower forward recovery during turn-on
- Increased ruggedness
- Lower on-state losses
- Proportional to the silicon area higher cosmic radiation FIT rate at compared voltage
- Lower thermal impedance
- The need for higher clamping force. From a mechanical point of view it is often preferable to clamp IGCT (GTO) und its related diodes in one single clamp system. If devices in one mechanical clamp have unequal pole-piece diameter, force spreaders have to be used. Please consider application note 5SYA2036 «Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors».

4.3 Diode switching and important parameters to consider

4.3.1 Diode turn-on

During turn-on of a diode the two parameters turn-on energy (E_{on}) and peak forward recovery voltage (V_{FRM}) are important to review regarding the specific needs of the application.

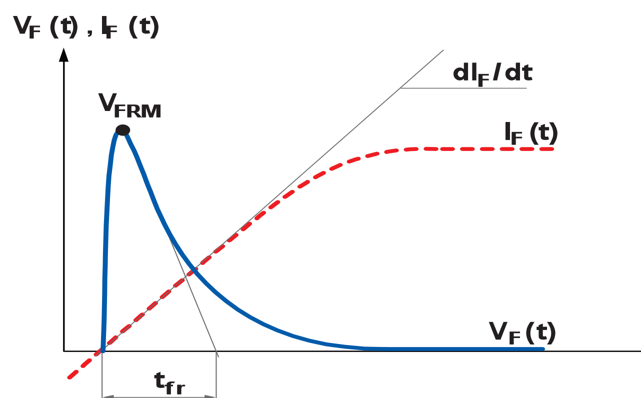

Fig. 15: Peak forward recovery voltage as a function of time

Fig. 15 shows the initial forward voltage overshoot V_{FRM}, when a diode turns on with a high di/dt. V_{FRM} is the peak voltage, and t_{fr} characterizes the decay of the overshoot. The voltage overshoot originates from the fact that conductivity of the diode is initially reduced, because the number of free charge carriers available is much lower than in the steady-state. The device needs time to build up the required electron and hole concentration, within the bulk of the silicon.

Measurements have shown that the V_{FRM} vs. di/dt characteristic is slightly digressive. V_{FRM} values at 125 °C are about double those at 25 °C. This behavior can be explained by reduced charge carrier mobility at elevated temperatures.

Comparing V_{FRM} values between diodes of different thickness, it is obvious that dynamic forward voltage increases exponentially with device thickness. This is explicable by the difficulty in achieving steady-state carrier concentration in a thick device within a few µs. Fig. 16 shows typical V_{FRM} values relating to the active wafer area of ABB diodes. The red and orange curves belong to 6 kV IGCT diodes and 5.5 kV IGCT diodes at T_{vj} = 125 °C, 80 °C and 25 °C while the blue colored curve is applicable for 4.5 kV diodes at T_{vj} = 125 °C. To estimate typical V_{FRM} values of ABB diodes at a specific di_F/dt the «di/dt per wafer area» of Fig. 16 has to be multiplied by the active wafer area of the diode. The active area of the different diodes correspond to the housing type which is listed in tables 1-3 where

D - housing corresponds to an active area of 24.3 cm^2
F - housing corresponds to an active area of 33.8 cm^2
H - housing corresponds to an active area of 46.3 cm^2
L - housing corresponds to an active area of 65.2 cm^2

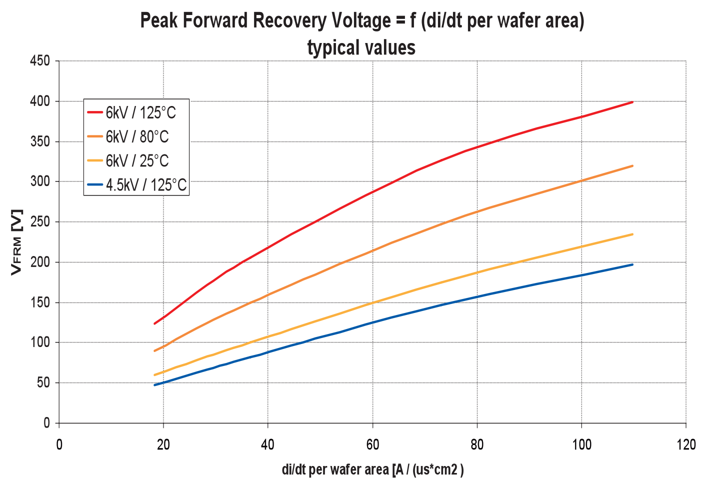

Fig. 16: Peak forward recovery voltage as a function of di/dt per wafer area

To estimate turn-on losses of a diode equation 2 can be taken to calculate the order of magnitude of E_{on}.

$$E_{on_typ} \approx 1/6 * V_{FRM} * di_F/dt * t_{fr}^2 \quad [Ws] \qquad \text{Eqn 2}$$

Where E_{on_typ} are the estimated typical turn-on losses, di_F/dt is the applied turn-on di/dt, V_{FRM} is the peak forward recovery voltage at di_F/dt and t_{fr} is the time constant of V_{FRM}. T_{fr} depends on different parameter but can be chosen as 5 µs for this raw calculation.

Example 1:
5SDF 10H4503, 4.5 kV IGCT diode in L-housing on freewheeling position, di_F/dt = 600 A/µs, T_{vj} = 125 °C

⇒ di/dt per wafer area = 600 A/µs / 46.3 cm^2 = 13 A/(µs*cm^2)
⇒ V_{FRM} ≈ 40 V
⇒ E_{on_typ} ≈ 1/6 * 40 V * 600 A/µs * 5µs^2 = 0.1 Ws

Example 2:
5SDF 02D6004, 6 kV IGCT diode in D-housing on clamp position,

di_F/dt = 2500 A/µs, T_{vj} = 125 °C

⇒ di/dt per wafer area = 2000 A/µs / 24.3 cm^2 = 82 A/µs*cm^2
⇒ V_{FRM} ≈ 350 V
⇒ E_{on_ty} ≈ 1/6 * 350 V * 2000 A/µs * $5µs^2$ = 2.9 Ws

It is obvious that turn-on losses of a diode on a freewheeling position are in most cases negligible since the diode typically has a large diameter and the di_F/dt is in the range below 1000 A/µs. On a clamp position or on a snubber position the turn-on losses can become relevant. di_F/dt is equal to the turn-off di/dt of the Switch (GTO or IGCT) and can be much higher than on a free-wheeling position. Typical diF/dt that can be expected are in the range of the turn-off current of the switch per 1µs. E.g. turn-off of 3000 A leads to a diF/dt in the range of 3000 A/µs.

As a further effect V_{FRM} of diodes on a GTO-snubber position or on an IGCT freewheeling- or clamp-position increases the dynamic commutation voltage of the Switch (GTO, IGCT with its freewheeling diode). This so called spike voltage V_{DSP} is specified in the GTO and IGCT datasheets under «general current and voltage waveforms». High values of this spike voltage reduce the switching capability of the switch. Because of this a larger snubber diode or IGCT diode increases the turn-off capability of the switch and vice versa. In terms of turn-off capability of the switch it is also recommended not to use too high voltage diodes. Typically snubber, clamp and freewheeling diodes are of the same voltage class as the related GTO or IGCT. It only makes sense to choose diodes of a higher voltage class if ruggedness in terms of turn-off switching of the diode itself is critical.

4.3.2 Diode turn-off

Fig 17 shows the turn off of an IGCT diode on a freewheeling position. The forward current, I_F, is switched off with a certain di_F/dt (determined by the driving voltage and the di/dt limiting inductance), and continues to flow in the reverse direction until the pn junction is able to block reverse voltage. At this time, the reverse recovery current has reached its peak value I_{RM}. The subsequent decay of the current and rise in reverse voltage are mainly determined by the diode itself and the applied voltage as a function of time. The applied voltage shape depends on the circuit of the application

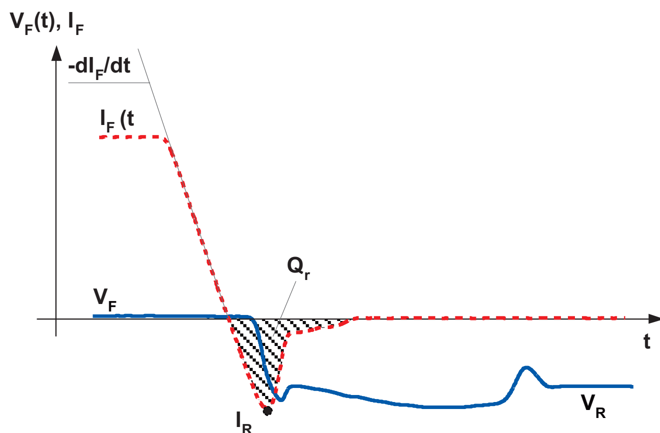

Fig. 17: Turn-off of an IGCT freewheeling diode

It is the goal of the diode design engineer to ensure that the tail current decays in a «soft» manner, meaning without ringing or overshoot provoking «snap», and that tail current and tail time are so small as to not contribute much to turn-off losses, despite reverse voltage being already high at this time. The application specific $V_R(t)$ is one of the main reasons that different diode designs are recommended for application conditions such as GTO-snubber diode, GTO-freewheeling diode or IGCT free-wheeling- NPC- and clamp-diode. It is not recommended to use diodes above the maximum values specified in the data sheets. Especially the use of diodes in IGCT applications without dv/dt limitation is very sensitive regarding $V_{DC\text{-}Link}$ and L_{CL}.

4.3.3 Surge current rating

I_{FSM} is the maximum allowed, non-repetitive and pulse-width dependent peak value of a half-sinusoidal surge current, applied at an instant when the diode is operating at its maximum junction temperature T_{vjm}. Although, in practice, the case temperature prior to a surge is always below T_{vjm}, both the junction and the housing are heated to T_{vjm} when the surge current limit is established. This worst-case test condition provides an additional margin to the real stress in an application.
During a surge, the junction heats up to a temperature well above its rated maximum value. Therefore, the diode is no longer able to block rated voltage, so the I_{FSM} values are valid only for V_R = 0 V after the surge, i.e. without reapplied voltage. Although a single surge does not cause any irreversible damage to the silicon wafer, it should not be allowed to occur too frequently.
I^2t is an abbreviation and stands for $\int I_F^2\,dt$. This value is derived from the I_{FSM} value discussed above, according to equation 3:

$$I^2t = \int_0^{t_p} I_F^{\,2}(t)dt = \frac{I_{FSM}^{\;2} \cdot t_p}{2} \qquad \text{Eqn 3}$$

(for half-sinusoidal waveforms) [A^2s]

To protect the diode, the I^2t of a semiconductor fuse must be lower than the maximum I^2t of the diode. The caveat for I_{FSM} applies similarly to I^2t.

The shape of I_{FSM} of applications depends on the protection concept and the electrical circuit and is therefore individual. The sinusoidal waveforms described in the datasheets typically don't appear in applications with fast switching diodes. I_{FSM} is a standardised value that enables comparison of datasheets of different devices and even of different manufacturers. When I_{FSM} is expected to be close to the diode capability, ABB is able to simulate the stress that occurs under application conditions.
As input data for the simulation i(t), starting values of T_{case} and $T_{junction}$ and the mounting force F_m are needed. I(t) should be available in a numerical form such as ASCII or Excel.

5 References

1) IEC 60747 «Semiconductor Devices»
2) 5SYA2036 «Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors»
3) 5SYA2051 «Voltage ratings of high power semiconductors»
4) 5SYA2061 «Failure rates of fast recovery diodes due to cosmic rays»
5) 5SZK9104 «Specification of environmental class for pressure contact diodes, PCTs and GTO, STORAGE»
6) 5SZK9105 «Specification of environmental class for pressure contact diodes, PCTs and GTO, TRANSPORTATION»

The application notes, Reference 2 - 4, are available at www.abb.com/semiconductors

The environmental specifications 5 – 6 are available on request; please contact ABB's Application Support

6 Revision history

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01		Thomas Setz

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