Diodes for Large Rectifiers

Application Note

High Power Rectifier Diodes

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Application Note

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1 Introduction

ABB Switzerland Ltd, Semiconductors (ABB) has a long history of producing high power rectifier diodes for applications such as high current rectifiers, mainly for aluminium smelting and other metal refining applications, and input rectifiers for large AC-drives. When designing with high power rectifier diodes, there are certain issues to be considered, the most important of these are addressed in this application note.

2 Rectifier Diode product range from ABB

The ABB Switzerland Ltd, Semiconductors standard rectifier diode product range is presented in Table 1 and outline drawings for the devices are presented in Figure 1.

Type and ordering number	V_{RSM}	V_{RRM}	I_{FAVM}	I_{FSM}		V_{F0}	r_F	T_{VJM}	R_{thJC}	R_{thCH}	F_m	Housing
			T_c = 85°C	8.3 ms T_{VJM}	10 ms T_{VJM}	T_{VJM}						
	V	V	A	kA	kA	V	MΩ	°C	K/kW	K/kW	kN	
5SDD 11D2800	3000	2800	1285	16.2	15	0.93	0.242	160	32	7.5	11	D
5SDD 08D5000	5200	5000	1030	12.8	12	0.89	0.487	160	32	7.5	11	D
5SDD 07D6000	6200	6000	685	11.5	11	0.92	0.920	150	32	7.5	11	D
5SDD 24F2800	3000	2800	2600	32.0	30	0.91	0.135	160	15	4	22	F
5SDD 20F5000	5200	5000	1980	25.4	24	0.94	0.284	160	15	4	22	F
5SDD 10F6000	6200	6000	1235	17.0	16	1.05	0.450	150	15	4	22	F
5SDD 40H4000	4000	4000	3930	49.0	46	0.885	0.135	160	8	2.5	40	H
5SDD 38H5000	5000	5000	3810	48.1	45	0.903	0.136	160	8	2.5	40	H
5SDD 31H6000	6000	6000	3080	42.7	40	1.016	0.175	150	8	2.5	40	H
5SDD 51L2800	2800	2000	5765	70.0	65	0.77	0.082	175	7	1.5	70	L
5SDD 33L5500	5500	5000	3480	49.2	46	0.94	0.147	150	7	1.5	70	L
5SDD 60Q2800	2800	2000	7385	95.0	87	0.80	0.050	160	5	1	90	Q
5SDD 60N2800	2800	2000	6830	95.0	87	0.80	0.050	160	5.7	1	90	N
5SDD 54N4000	4000	3600	5200	90.0	85	0.80	0.086	150	5.7	1	90	N
5SDD 50N5500	5500	5000	4700	80.0	73	0.80	0.107	150	5.7	1	90	N

Table 1 The rectifier diode range from ABB Switzerland Ltd, Semiconductors.

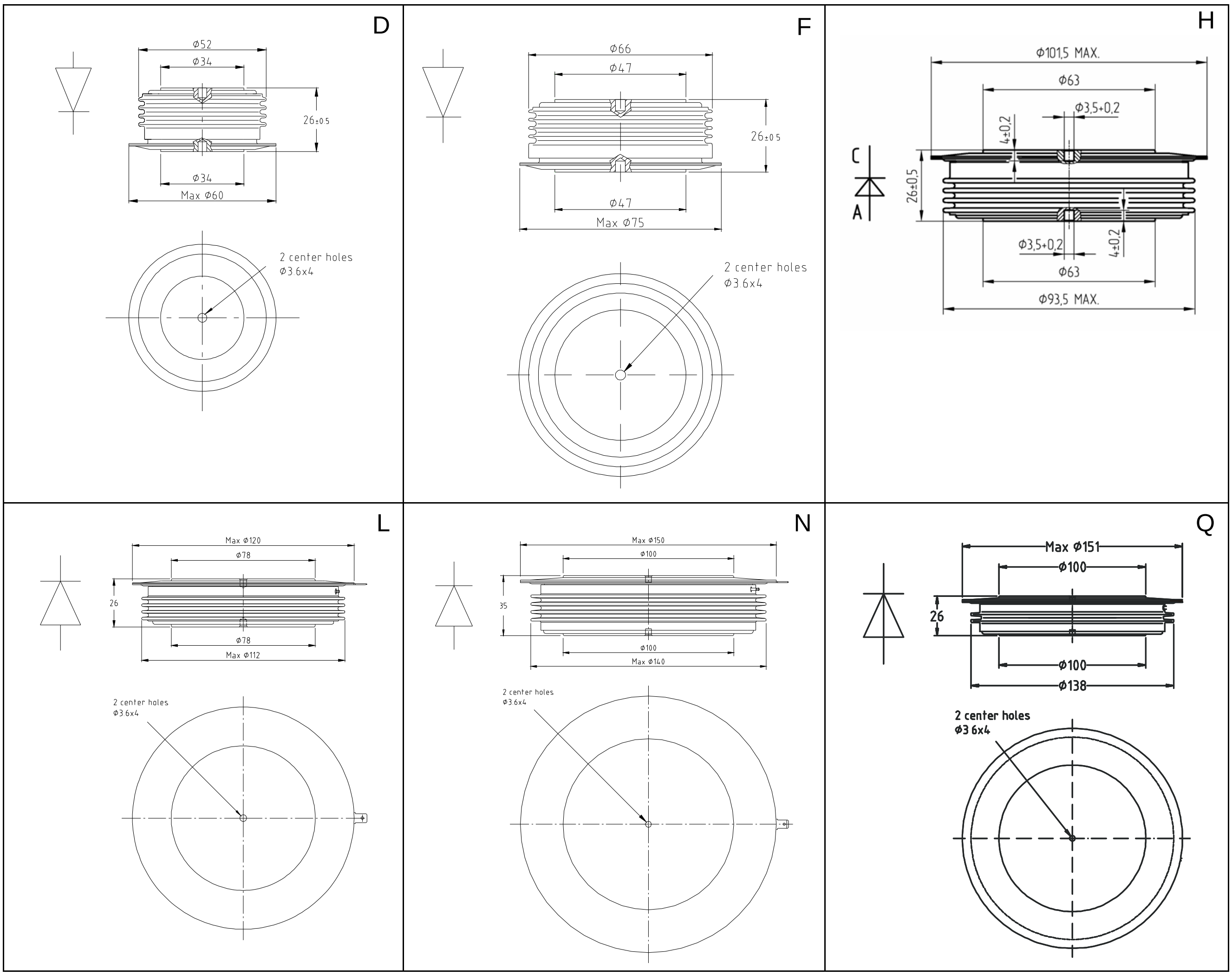


Fig. 1 Diode housing outline drawings. All dimensions are in millimeters.

3 Data sheet users guide

This section is a detailed guide to the proper understanding of a rectifier diode data sheet. Parameters and ratings are defined and illustrated by figures where appropriate while following the sequence in which parameters appear in the data sheet. For explanation purposes, data and diagrams associated with 5SDD 50N5500 have been used, however this guide is applicable to all rectifier diodes. The parameters are defined according to standard IEC 60747.

Rectifier Diode

5SDD 50N5500

V_{RSM} = 5500 V
$I_{F(AV)M}$ = 4700 A
$I_{F(RMS)}$ = 7390 A
I_{FSM} = $73×10^3$ A
V_{F0} = 0.8 V
r_F = 0.107 mW

- **Patented free-floating silicon technology**
- **Very low on-state losses**
- **Optimum power handling capability**

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 Note 1

Parameter	Symbol	Conditions	Value	Unit
Repetitive peak reverse voltage	V_{RRM}	f = 50 Hz, t_p = 10ms, T_j = 0...150°C	5000	V
Non-repetitive peak reverse voltage	V_{RSM}	f = 5 Hz, t_p = 10ms, T_j = 0...150°C	5500	V

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Max. (reverse) leakage current	I_{RRM}	V_{RRM}, Tj = 150°C			400	mA

V_{RRM}: Maximum voltage that the device can block repetitively. Above this level the device will thermally "run-away" and become a short circuit. This parameter is measured with 10 ms half-sine pulses with a repetition frequency of 50 Hz.

V_{RSM}: Absolute maximum single-pulse voltage that the device can block. If a voltage spike above this level is applied, the diode will fail and become a short circuit. This parameter is measured with 10 ms half-sine pulses with a repetition frequency of 5 Hz.

I_{RRM}: This is the maximum leakage current at the given conditions.

Mechanical data

Maximum rated values Note 1

Parameter	Symbol	Conditions	min	typ	max	Unit
Mounting force	F_M		81	90	108	kN
Acceleration	a	Device unclamped			50	m/s^2
Acceleration	a	Device clamped			100	m/s^2

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Weight	m				2.8	kg
Housing thickness	H	F_M = 90 kN, T_a = 25 °C	34.1		35.9	mm
Surface creepage distance	D_S		56			mm
Air strike distance	D_a		22			mm

Note 1 Maximum rated values indicate limits beyond which damage to the device may occur

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.

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 [Note 1]

Parameter	Symbol	Conditions	min	typ	max	Unit
Max. average on-state current	$I_{F(AV)M}$	50 Hz, Half sine wave, $T_C = 90$ °C			4700	A
Max. RMS on-state current	$I_{F(RMS)}$				7390	A
Max. peak non-repetitive surge current	I_{FSM}	$t_p = 10$ ms, $T_j = 150$°C, $V_R = 0$ V			73×10^3	A
Limiting load integral	I^2t				27.5×10^6	A^2s
Max. peak non-repetitive surge current	I_{FSM}	$t_p = 8.3$ ms, $T_j = 150$°C, $V_R = 0$ V			80×10^3	A
Limiting load integral	I^2t				26.7×10^6	A^2s

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
On-state voltage	V_F	$I_F = 5000$ A, $T_j = 150$°C			1.34	V
Threshold voltage	$V_{(T0)}$	$T_j = 150$°C $I_T = 2500...8000$ A			0.8	V
Slope resistance	r_T				0.107	mΩ

$I_{F(AV)M}$: The maximum average forward current and **$I_{F(RMS)}$:** are the maximum allowable average and rms device currents defined for 180 ° sine wave pulses of 50% duty cycle at a case temperature of 85 °C. The definitions are arbitrary but standard thus allowing device comparisons.

I_{FSM} and **$\int I^2dt$:** The maximum peak forward surge current and the integral of the square of the current over one period are defined for a 10 ms wide, half sine-wave current pulse without reapplied voltage. Above this value, the device will fail short-circuit. These parameters are required for protection co-ordination. The values are given for two pulse lengths corresponding to line frequencies 50 and 60 Hz.

V_{FM}: 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 to calculate conduction losses. For a given current, the conduction losses are calculated using Equation 1. $V_{(T0)}$ and r_T should be as low as possible to minimise losses.

$$P_{loss} = V_{(T0)} * I_{FAV} + r_T * I_{Frms}^2 \qquad E^{qn}\ 1$$

where P_{loss} is the power loss, I_{FAV} is the average value of the current through the diode and I_{Frms} is the root mean square value of the current through the diode. Note that the linearisation is only valid within given current limits. Outside these limits, other models are preferable since the linear model is an approximation.

Switching

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Recovery charge	Q_{rr}	$di_F/dt = -10$ A/µs, $V_R = 200$ V $I_{FRM} = 4000$ A, $T_j = 150$°C			18000	µAs

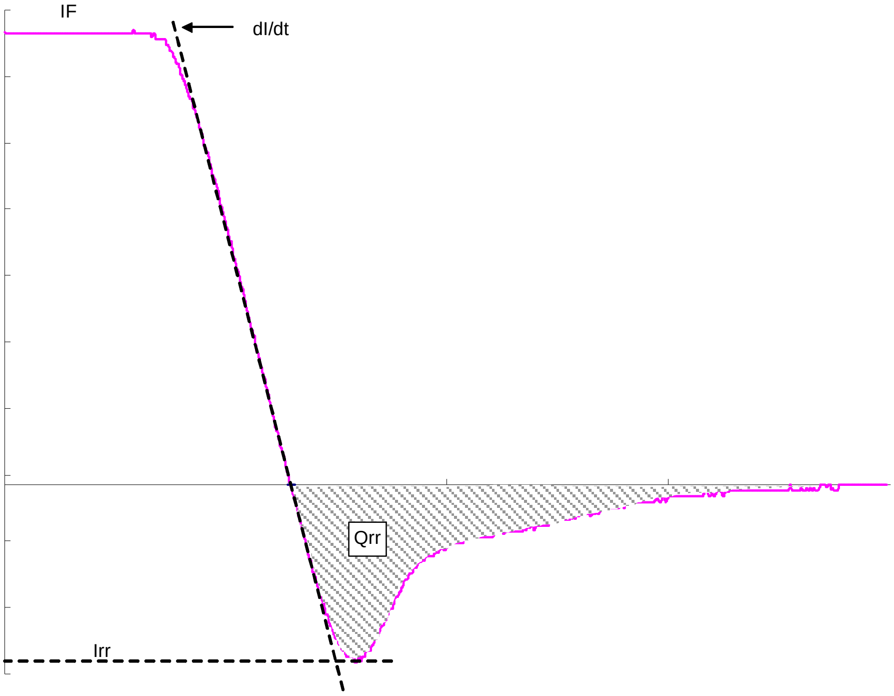


Fig. 2 Definitions for the turn-off parameters for the Diode.

Q_{rr}: *Reverse recovery charge.* This is the integral over time of the reverse current during commutation at the given conditions starting at the 0-crossing of the reverse current and ending when the reverse current goes back to 0 including the tail-current. See figure 2.

Thermal

Maximum rated values Note 1

Parameter	Symbol	Conditions	min	typ	max	Unit
Operating junction temperature range	T_{vj}		0		150	°C
Storage temperature range	T_{stg}		-40		150	°C

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Thermal resistance junction to case	$R_{th(j-c)}$	Double-side cooled $F_m = 81...108$ kN			5.7	K/kW
	$R_{th(j-c)A}$	Anode-side cooled $F_m = 81...108$ kN			11.4	K/kW
	$R_{th(j-c)C}$	Cathode-side cooled $F_m = 81...108$ kN			11.4	K/kW
Thermal resistance case to heatsink	$R_{th(c-h)}$	Double-side cooled $F_m = 81...108$ kN			1	K/kW
	$R_{th(c-h)}$	Single-side cooled $F_m = 81...108$ kN			2	K/kW

Analytical function for transient thermal impedance:

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

i	1	2	3	4
$R_{th\,i}$(K/kW)	3.709	1.262	0.475	0.251
τ_i(s)	0.8296	0.1107	0.0114	0.0024

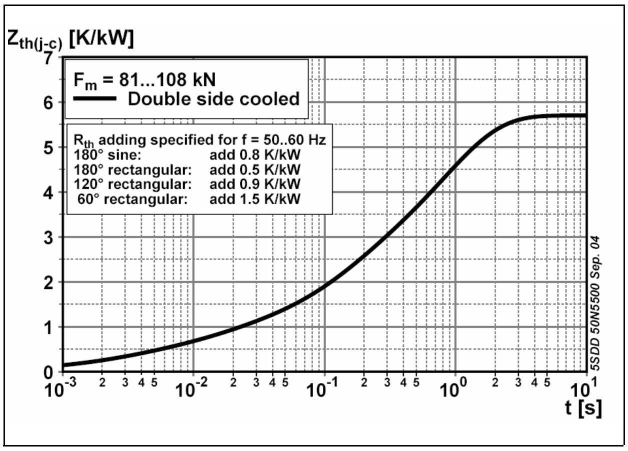


Fig. 1 Transient thermal impedance junction-to-case

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 the diode will be operational at a later use.

The thermal resistance junction to case**,** **R_{thJC}**, and the thermal resistance case to heat sink, **R_{thCH}**, 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 temperature rise of the "virtual junction" (the silicon wafer inside the diode) in relation to the heat sink is calculated using Equation 2. R_{thJC} and R_{thCH} 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.

$$\Delta T_{JH} = P_{loss} * \left(R_{thjc} + R_{thch}\right) \qquad E^{qn}\ 2$$

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.

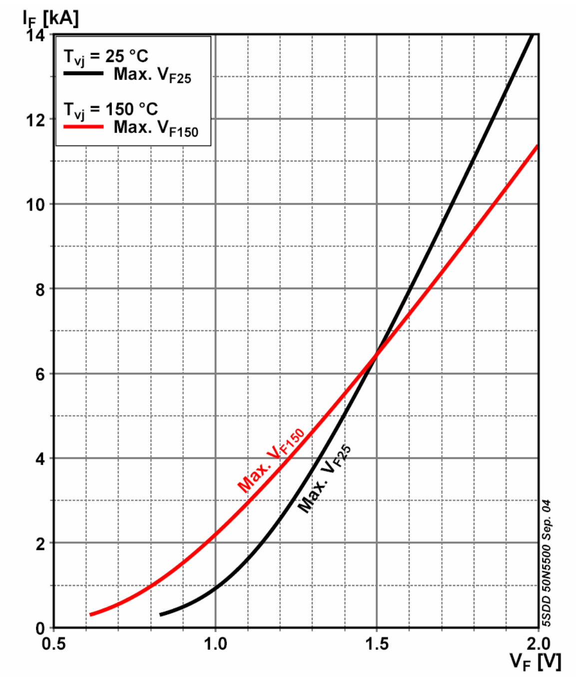
Max. on-state characteristic model:

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

Valid for I_F = 300 – 110000 A

A_{25}	B_{25}	C_{25}	D_{25}
2.32×10^{-6}	61.85×10^{-6}	149.9×10^{-3}	-2.67×10^{-3}

The model gives a mathematical expression for the maximum on-state voltage at T_{vj} = 25 °C for the given current interval which is much expanded compared with 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 temperature for normal operation current levels.

Fig. 3 Isothermal on-state characteristics.

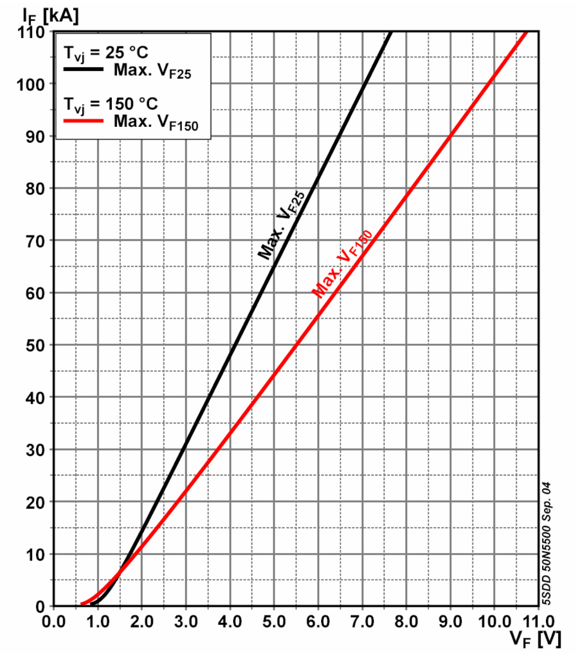
Max. on-state characteristic model:

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

Valid for I_F = 300 – 110000 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}

The model gives a mathematical expression for the maximum on-state voltage at T_{vj} = 25 °C for the given current interval which is much expanded compared with 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 temperature for the extended current levels up to the magnitude of I_{FSM}.

Fig. 4 Isothermal on-state characteristics.

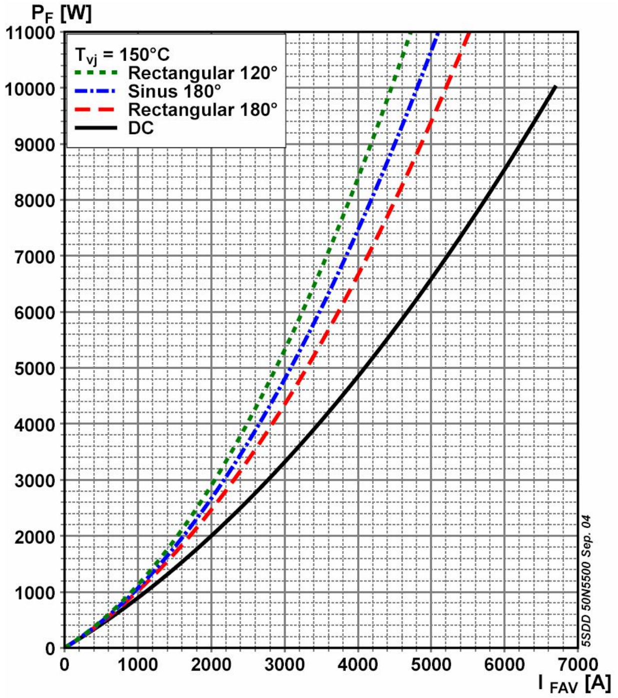


Fig. 5 On-state power losses vs. average on-state current.

On-state power loss as a function of the average current at T_{vj} = 150 °C for the most common current wave shapes.

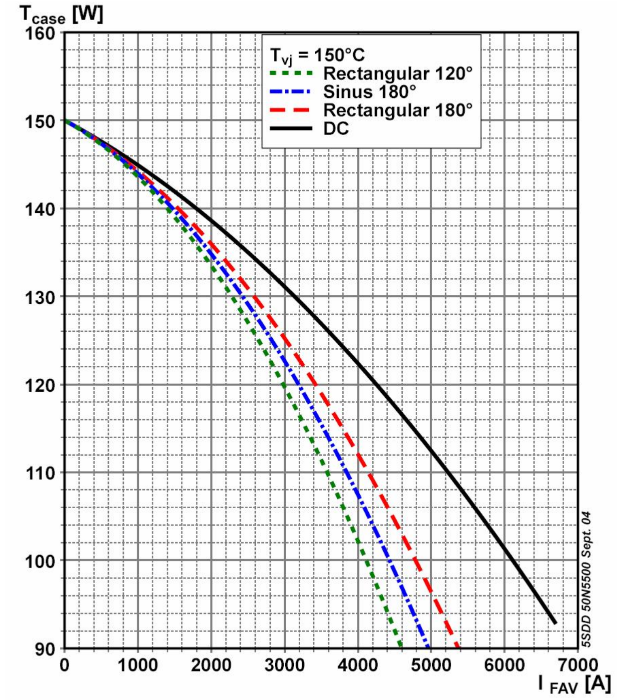


Fig. 6 Maximum permissible case temperature vs. average on-state current.

Maximum permissible case temperature as a function of the average current for the most common current wave shapes. Exceeding the average current at a given case temperature and current wave shape will lead to overheating of the device.

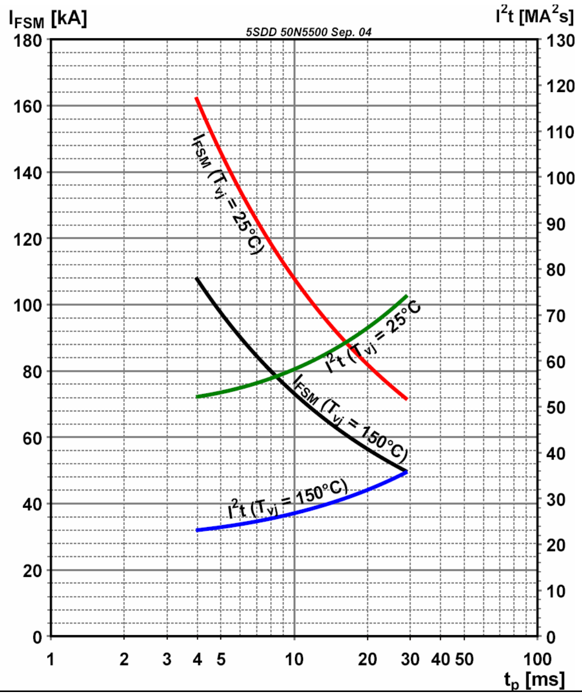


Fig. 7 Surge on-state current vs. pulse length, half-sine wave.

Surge current limit and the surge current integral for half-sine pulses of different pulse widths for starting temperatures of 25 and 150 °C.

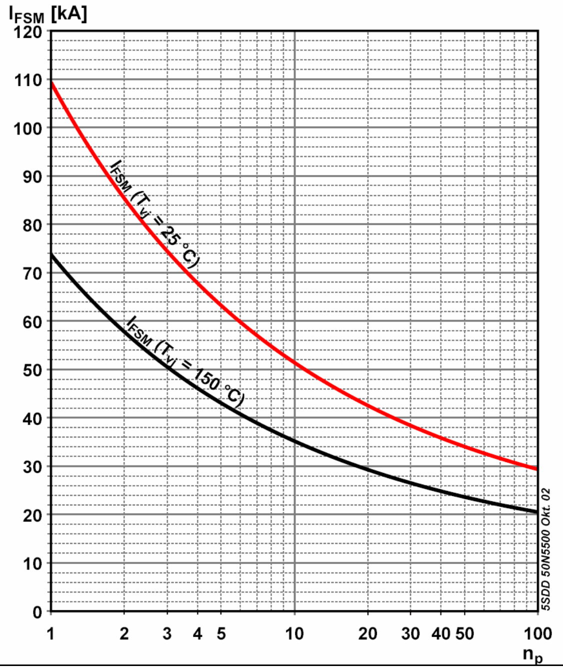


Fig. 8 Surge on-state current vs. number of pulses, half-sine wave, 10 ms, 50Hz.

Surge current limit as a function of the number of applied 10 ms half-sine pulses with a repetition rate of 50 Ht for starting temperatures of 25 and 150 °C.

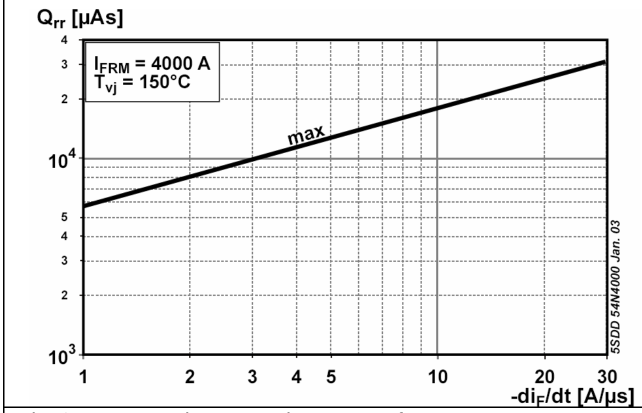


Fig. 9 Recovery charge vs. decay rate of on-state current.

Maximum reverse recovery charge as a function of the rate of decline of current before the commutation at the given conditions. See figure 2 for definitions.

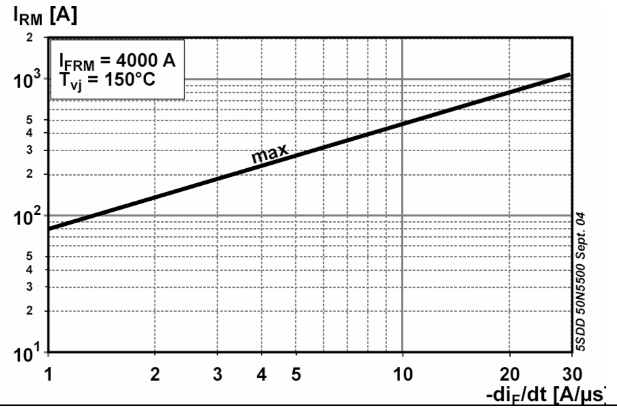


Fig. 10 Peak reverse recovery current vs. decay rate of on-state current.

Maximum reverse recovery current as a function of the rate of decline of current before the commutation at the given conditions. See figure 2 for definitions.

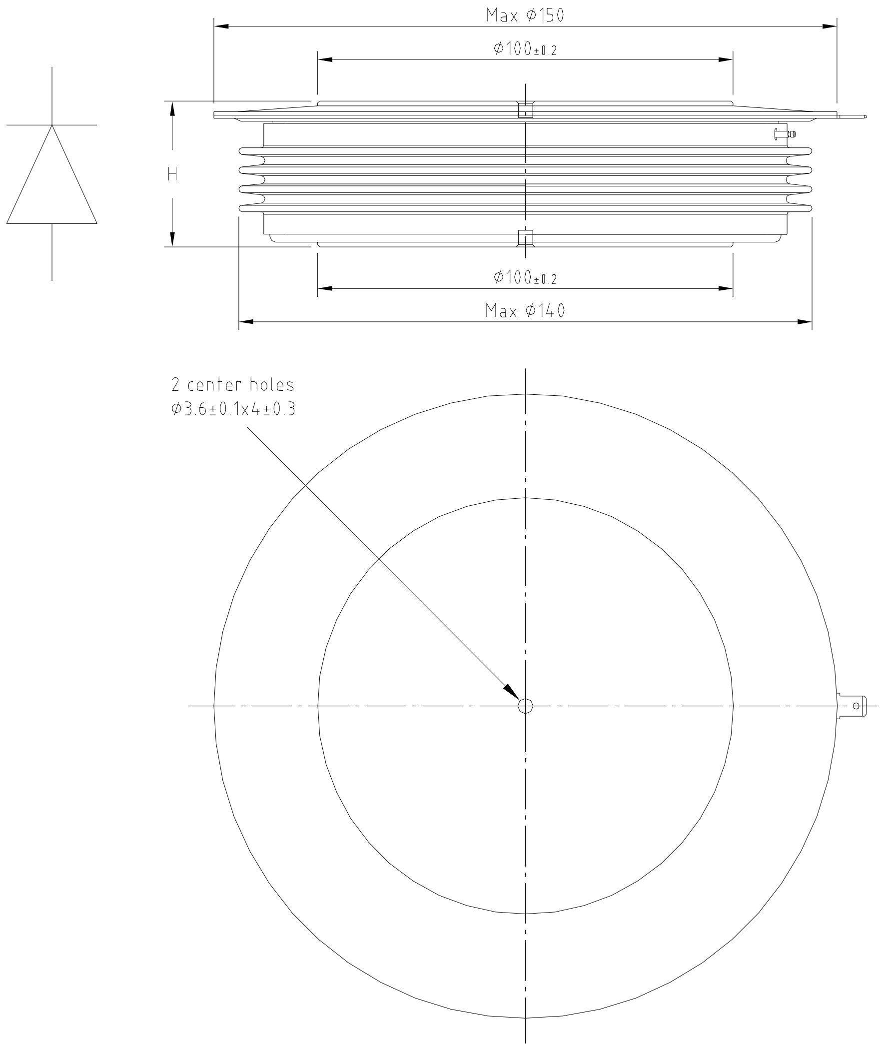


Fig. 11 Outline drawing; all dimensions are in millimeters and represent nominal values unless stated otherwise. The height is given in the table for mechanical data.

Related documents

5SYA 2020	Design of RC-Snubbers for Phase Control Applications
5SYA 2029	Designing Large Rectifiers with High Power Diodes
5SYA 2036	Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors

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

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

4 Design recommendations

4.1 Determining the required Diode voltage rating

Due to the over-voltage transients that occur on a supply network, especially in an industrial environment, the diode must be carefully chosen to handle most over-voltages without the need of expensive external over-voltage protection. For detailed explanations about the voltage dimensioning and the recommended device voltages for a given supply voltage see document 5SYA2051.

4.2 Current sharing issues at paralleling of devices

In the following text a position is defined as follows:

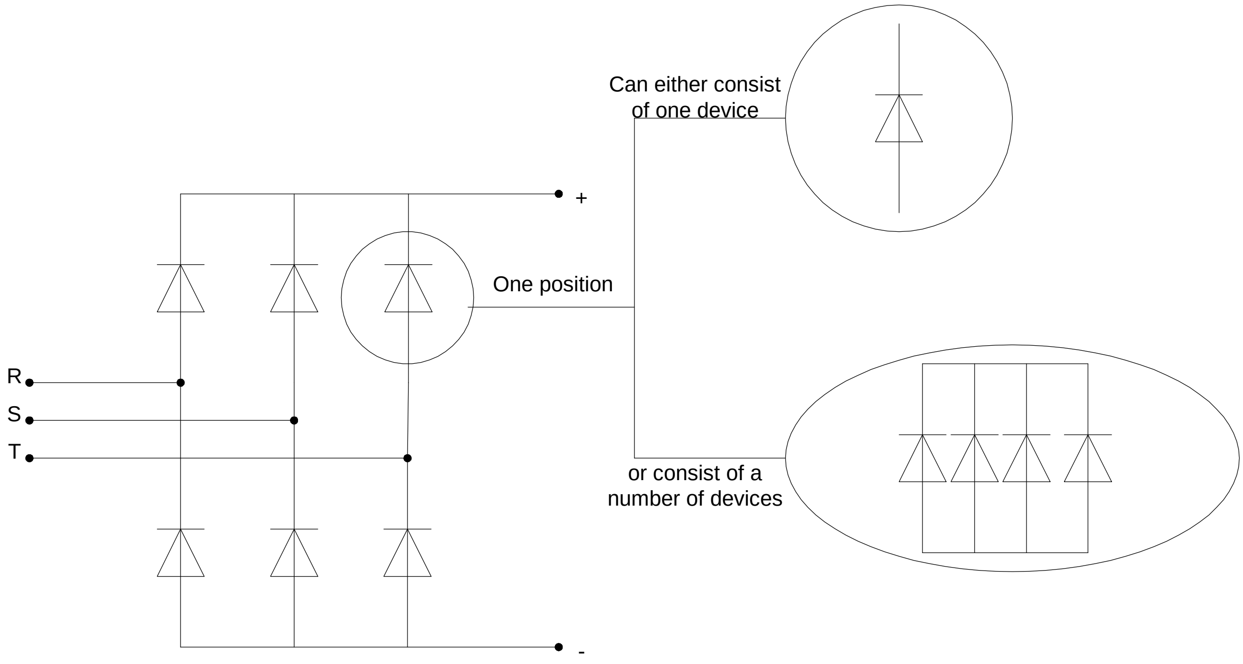


Fig. 12 Definition of position.

When the required output current is so high that paralleling of devices is needed, a number of actions must be taken to avoid poor current sharing, which in turn leads either to device failure or to an uneconomical solution with excessive margins.

The main objective is to achieve similar resistance and inductance values in all parallel current paths. Differences in the current paths will lead to uneven current sharing forcing one or more diodes to operate at a higher temperature than the rest. This in turn can lead to diode destruction due to overheating or to an uneconomical solution since the other parallel-connected diode will be underrated. Switching device differences can be compensated with an appropriate control scheme but for diodes, careful mechanical design and component selection are the only means of balancing the current.

The assembly should be designed so that busbars, heat sinks and other current-carrying components have equal current path lengths and are arranged symmetrically to obtain equal inductances. Also a mechanically sound assembly is essential: badly assembled devices can have high contact resistances towards the heat-sink, causing voltage drops higher than the actual spread among the diodes, thus impeding a good current sharing.

The selection of the diode for improved current sharing is also recommended. A V_F-band of 50 mV, normally measured at T_{jm} and a current close to I_{Fav}, is recommended for good current sharing. Since this may be difficult for the supplier to deliver without increased cost, a solution with 2 or 3 overlapping V_F-bands where only one band is used per position but where different positions may have different bands, may be the most economical approach. Note that any banding of devices will not compensate for a bad mechanical solution and/or bad assembly.

Since diode characteristics over the whole operating temperature range are rarely very similar for diodes from different suppliers, mixing diodes from different suppliers is not recommended or even mixing old and new devices from the same supplier. When the need for replacement parts occurs, one position should be changed completely. Any old but good devices remaining from the replaced position can subsequently be used as spare parts for devices in other positions.

To illustrate the importance of good matching some examples are given below. For simplification we will use the following circuit with definitions as per figure 13 only considering differences in the diode itself assuming that the mechanical lay-out and the assembly is equal for the two devices. To express the forward voltage drop we use the linear approximation in equation 3:

$$V_F = V_{F0} + r_F \times I_F \qquad \text{E}^{\text{qn}}\ 3$$

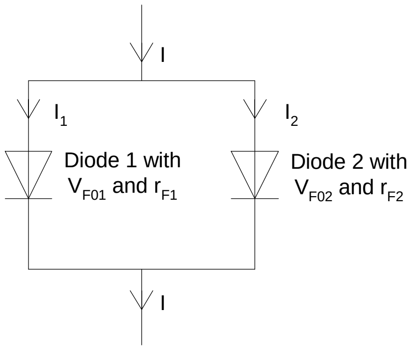


Fig. 13 Definitions for the example calculations below.

Example 1:
2 diodes, one with V_{F01} = 0.80 V and r_{F1} = 0.050 mΩ, V_F (I_F = 6000A) = 1.1 V and one with V_{F02} = 0.85 V and r_{F2} = 0.065 mΩ, V_F (I_F = 6000A) = 1.24 V are parallel connected and should together conduct I = 10000 A. Using Kirchoffs laws:

$$10000 = I_1 + I_2$$

$$0.80 + 0.00005 \times I_1 = 0.85 + 0.000065 \times I_2$$

resulting in:

$$I_1 = 6090A$$

$$I_2 = 3910A$$

The current unbalance, in this case, is 54 %

Compare this with:
Example 2:
2 diodes, one with V_{F01} = 0.80 V and r_{F1} = 0.050 mΩ, V_F (I_F = 6000A) = 1.1 V and one with V_{F02} = 0.82 V and r_{F2} = 0.040 mΩ, V_F (I_F = 6000A) = 1.06 V are parallel connected and should together conduct I = 10000 A. In this case:

$$10000 = I_1 + I_2$$

$$0.80 + 0.00005 \times I_1 = 0.82 + 0.00004 \times I_2$$

resulting in:

$$I_1 = 4670A$$

$$I_2 = 5330A$$

The current unbalance, in this case, is 14 %.

4.3 Correct Diode Installation

The mechanical design of the rectifier is crucial for its performance and reliability. As an example inhomogeneous pressure distribution is a common cause of diode failure. For recommendations on mechanical design and assembly please refer to application note 5SYA2036 “Recommendations regarding mechanical clamping of press-pack high power semiconductors”.

4.4 Over-voltage protection through RC-snubbers

To protect the diode from over-voltages at commutation RC-snubbers are often used. For recommendations on the design of RC-snubbers please refer to application note 5SYA2020 “Design of RC-snubbers for phase control applications”.

5 Additional notes

5.1 Further considerations

For protection of the converter and to disconnect faulty diodes in the case of parallel connection, thus enabling continuation of equipment operation if sufficient redundancy is built into the system, fuses are often connected in series to each diode. Since these fuses often have to carry large currents and have to interrupt the full short-circuit current it may not always be possible to protect the semiconductor from failure. For protection of the assembly and the environment however, the fuses should be selected to at least avoid a semiconductor explosion in a fault situation. This generally imposes the use of a special fast fuse, normally referred to as semiconductor fuse. Application support for protection co-ordination is available from the fuse manufacturers. Commonly used are fuses from suppliers Bussmann, www.bussmann.dk, and Ferraz-Shawmut, www.ferrazshawmut.com. For the largest diode sizes ABB have an optional solution for so called “enhanced explosion rating” that allows for higher energies without catastrophic failures during fault conditions. For more information about this option please contact your nearest sales office.

5.2 References

1) IEC 60747 “Semiconductor Devices”

2) 5SYA2020 “Design of RC-snubbers for phase control applications”

3) 5SYA2036 “Recommendations regarding mechanical clamping of high power press-pack semiconductors”

4) 5SYA2051 “Voltage ratings of high power semiconductors”

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

5.3 Application support

For further information please contact:

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Data sheets for the devices and your nearest sales office can be found at the ABB Switzerland Ltd, Semiconductors internet web site:
http:// www.abb.com/semiconductors