Application Note 5SYA 2049-01

Voltage definitions for phase control and bi-directionally controlled thyristors

High power thyristors have a number of voltage ratings which need to be clearly understood for their optimal application. This application note will explain the definitions and the practical meanings of these various voltages.

Power and productivity
for a better world™

Contents

1 Voltage definitions for phase control and bi-directionally controlled thyristors

1.1 Parameter definitions

Several blocking voltages are defined in the data sheets of high power semiconductors. The differences between the various ratings are explained in this section. The definitions are, of course, standardised and can be found in various international standards such as IEC 60747.
It is important to distinguish between repetitive over-voltages V_{DR}/V_{RR} (commutation over-voltages that appear at line frequency) and non-repetitive over-voltage surges V_{DS}/V_{RS} that appear randomly (e.g. because of lightning and network transients).
Too high a single voltage surge will lead to an avalanche break-down of the semiconductor and too high a repetitive voltage peak may lead to thermal «runaway» even if the amplitude of these repetitive voltages is below the avalanche break-down limit.

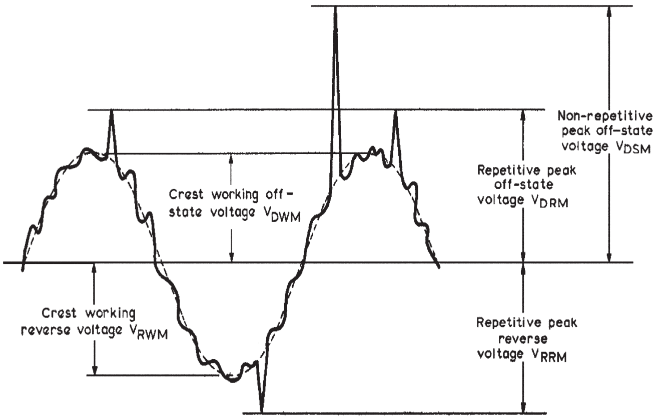


Fig. 1: Definition of repetitive, non-repetitive and normal operating voltages

V_{DWM}, V_{RWM}: Maximum crest working forward and reverse voltages. This is the maximum working voltage at line frequency. For safe operation, the device rated V_{DWM} (or V_{RWM}) must be equal to or higher than, that depicted in Fig. 1.

V_{DSM}, V_{RSM}: Maximum surge peak forward and reverse blocking voltage. This is the absolute maximum single-pulse voltage that the devices can instantaneously block. If a voltage spike above this level is applied, the semiconductor will fail. ABB measures this parameter with 10 ms half-sine pulses and a repetition rate of 5 hertz For safe operation, the device's rated V_{DSM}/V_{RSM} must be higher than the surge peak voltage depicted in Fig. 1.

V_{DRM}, V_{RRM}: Maximum repetitive peak forward and reverse blocking voltage. This is the maximum voltage that the device can block repetitively. Above this level the device may thermally «run-away» and fail. This parameter is measured with a pulse width and repetition rate defined in the device specification as explained later in this application note. For safe operation the device's rated V_{DRM}/V_{DRM} must be higher than that depicted in Fig. 1.

1.2 Repetitive voltage ratings for ABB high voltage thyristors

The definition of «high voltage» for a thyristor is somewhat arbitrary but has been set, at ABB at about 4500 volts (V) for reasons discussed in the following.
The Device Under Test (DUT) must have a stable and well-defined temperature during the blocking measurement and this is achieved by «passive» heating (heat supplied to the whole device) through heated connections (e.g., a hydraulic press).
The press applies the correct clamping force to the DUT and also provides the electrical connections. Since there is no temperature gradient in this measurement system, the problem of «thermal runaway» arises during testing.
Since the early beginnings of semiconductor devices, thermal runaway has been a well-known problem. Thermal runaway occurs when the power dissipation of a device increases rapidly with temperature. A classic example is thermal runaway during blocking, whereby the applied voltage generates a «leakage» current and the V x I product heats the device. As the device gets hotter, leakage current increases exponentially and so, therefore, does the heating. If the cooling of the device is not adequate, the device will get progressively hotter and will ultimately fail.
The development of high-voltage thyristors has lead to increased values of dissipated power in the off-state, due to the higher blocking voltages, even if the leakage currents themselves have remained at similar levels to those of earlier, lower voltage, devices. This causes problems when such devices are characterised and are measured in outgoing inspection at elevated temperatures (e.g. 125 °C). In such cases, the entire measurement system is heated to a constant temperature and no temperature gradient exists to sink the heat generated by the measurement itself. This is in stark contrast to real-world applications where the junction temperature may indeed reach 125 °C but the case temperature never exceeds, say, 110 °C, allowing leakage current losses to be cooled away across the temperature gradient between junction and case.
Since thermal runaway initiates only at or above a certain starting temperature, ABB traditionally quoted two different repetitive voltage ratings specified at two different temperatures. As an example, thyristor 5STP 26N6500 was rated $V_{DRM} = V_{RRM} = 6500$ V for junction temperatures up to 110 °C and 5600 V for temperatures up to 125 °C. In both cases, these voltages were specified using half-sine waves with $t_p = 10$ ms and f = 50 Hz.
Because of their lower power losses, lower voltage devices are less prone to thermal run-away and are therefore rated and tested with the same V_{DRM} and V_{RRM} throughout the rated temperature range, thus simplifying test procedures.
A more realistic method of measuring power semiconductors is achieved by forcing the test condition to emulate the definition of these different voltages as shown in Fig. 1. This is done by using a sinusoidal 50 or 60 Hz wave of peak value V_{DWM}/V_{RWM} and superimposing a narrow pulse of amplitude V_{DRM} per Fig. 2.
This pulse corresponds to repetitive voltage peaks as might be caused by commutation over-voltages. [Such over-voltages, which should never exceed V_{DRM} and V_{RRM}, are partly determined

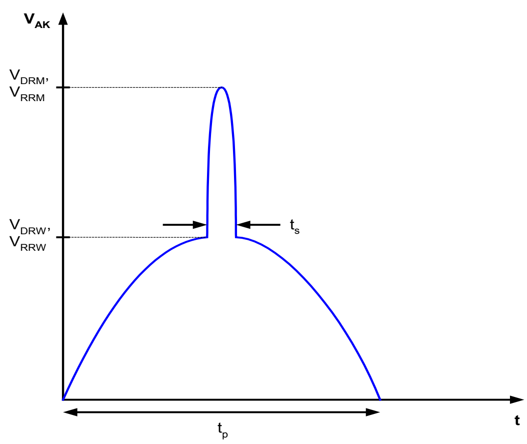
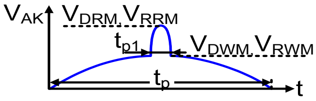


Fig. 2: Waveform for repetitive high voltage testing

Blocking

Maximum rated values 1)

Parameter	Symbol	Conditions	5STP 12K6500	Unit
Max. surge peak forward and reverse blocking voltage	V_{DSM}, V_{RSM}	t_p = 10 ms, f = 5 Hz T_{vj} = 5…125°C, Note 1	6500	V
Max repetitive peak forward and reverse blocking voltage	V_{DRM}, V_{RRM}	f = 50 Hz, t_p = 10 ms, t_{p1} = 250 µs, Tvj = 5…125°C, Note 1, Note 2	6500	V
Max crest working forward and reverse voltages	V_{DWM}, V_{RWM}		3300	V
Critical rate of rise of commutating voltage	dv/dt_{crit}	Exp. to 3750 V, T_{vj} = 125°C	2000	V/µs

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Forward leakage current	I_{DRM}	V_{DRM}, T_{vj} = 125°C			600	mA
Reverse leakage current	I_{RRM}	V_{RRM}, T_{vj} = 125°C			600	mA

Fig. 3 : Voltage ratings in the data sheet for device 5STP 12K6500.

Note 1: Voltage de-rating factor of 0.11% per °C is applicable for T_{vj} below +5 °C

Note 2: Recommended minimum ratio of V_{DRM} / V_{DWM} or V_{RRM} / V_{RWM} = 2. See App. Note 5SYA 2051.

Due to the absence of a “forward” or “reverse” direction in the case of Bi-directionally Controlled Thyristors (BCTs) the terms VWM, VRM and VSM are used for the working voltage, the repetitive peak voltage and the non-repetitive peak (surge) voltages respectively as can be seen in Fig. 4.

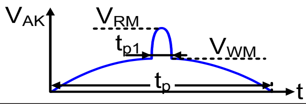
Parameter	Symbol	Conditions	5STP 12K6500	Unit
Max. surge peak forward and reverse blocking voltage	V_{SM}	t_p = 10 ms, f = 5 Hz T_{vj} = 5…125°C, Note 1	6500	V
Max repetitive peak forward and reverse blocking voltage	V_{RM}	f = 50 Hz, t_p = 10 ms, t_{p1} = 250 µs, T_{vj} = 5…125°C, Note 1, Note 2	6500	V
Max crest working forward and reverse voltages	V_{WM}		3300	V

Fig. 4: Detail from the voltage ratings in the data sheet for device 5STB 13N6500.

by «snubbers» (RC-circuits). See Application Note 5SYA2020 for snubber design]. By using the test method of Fig. 2, voltage capability will be tested at application-like conditions in accordance with international standards and without risk of thermal runaway during testing.

ABB has introduced this test method on thyristors rated above 4500 V in compliance with both application conditions and standards definitions while avoiding thermal runaway at final test.

V_{DWM} and V_{RVM} have been set to the maximum expected working voltage for the device’s repetitive peak blocking voltage according to the guidelines found in Application Note 5SYA2051. A voltage peak of pulse width ts = 250 microsecond is added to the working voltage crest such that the sum corresponds to V_{DRM} or V_{RRM}. How these new ratings are presented in the data sheet can be seen in Fig. 3.

Note that the given V_{DWM} is both a rating and a device test condition and that the supply voltage in a given application should not exceed it. For the selection of rated voltage for a given supply voltage, see Application Note 5SYA 2051.

1.3 Voltage ratings for ABB thyristors at low temperatures

At low temperatures thermal runaway is not an issue but there is a limitation of the blocking voltage due to the temperature dependence of the avalanche breakdown voltage. The avalanche breakdown voltage decreases with decreasing temperature at a rate of about 0.11 percent/K. This means that a de-rating of V_{DRM} and V_{DSM} for the device is needed when operating at low temperatures. As can be seen on the device data sheets, this is applicable to temperatures below 5 °C and is explained in the

data sheet in Note 1 of Fig. 3.

2 References

1) IEC 60747 «Semiconductor Devices»
2) 5SYA2020 «Design of RC Snubbers for Phase Control Applications»
3) 5SYA2051 «Voltage ratings of high power semiconductors»

The application notes, References 2 and 3, are available at www.abb.com/semiconductors

3 Revision history

Version	Change	Authors
01		Björn Backlund
		Thomas Setz

Contact us

ABB Switzerland Ltd
Semiconductors
Fabrikstrasse 3
CH-5600 Lenzburg
Switzerland
Tel: +41 58 586 14 19
Fax: +41 58 586 13 06
E-Mail: abbsem@ch.abb.com
www.abb.com/semiconductors
m.abb.com

Application note 5SYA 2049-01 27.08.2013

Power and productivity
for a better world™