

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.



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 breakdown 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 breakdown limit.

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 figure 1.

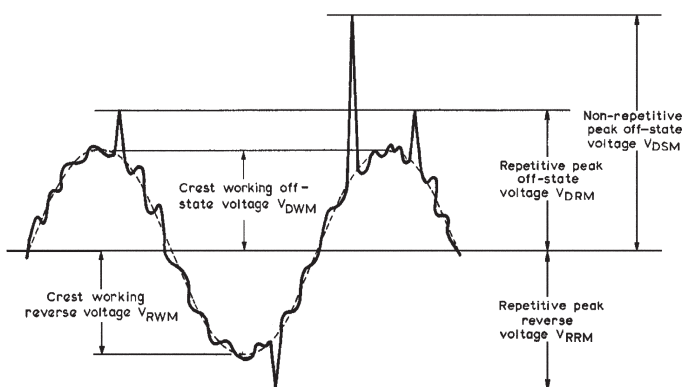
V_{DSM}, V_{RSM} : Maximum surge peak forward and reverse blocking voltage. This is the absolute maximum single-pulse voltage that the devices can instantaneously block. If a voltage spike above this level is applied, the semiconductor will fail. Hitachi Energy measures this parameter with 10 ms half-sine 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 figure 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_{RRM} must be higher than that depicted in figure 1.

1.2. Repetitive voltage ratings for Hitachi Energy high voltage thyristors

The definition of «high voltage» for a thyristor is somewhat arbitrary but has been set, at Hitachi Energy 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).



01 Definition of repetitive, non-repetitive and normal operating voltages

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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 run-away» arises during testing.

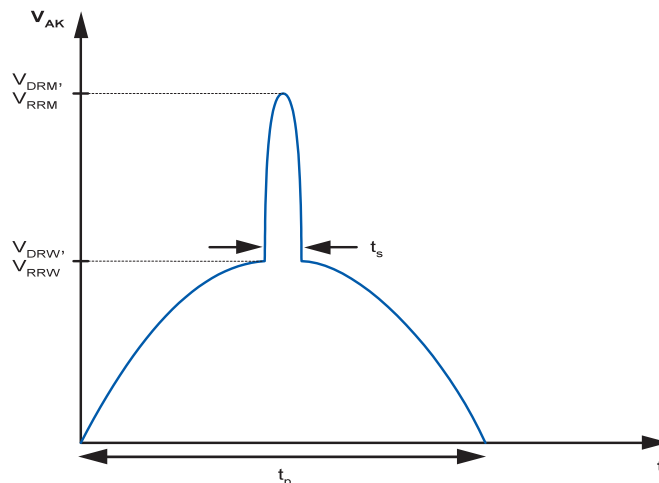
Since the early beginnings of semiconductor devices, thermal runaway has been a well-known problem. Thermal runaway occurs when the power dissipation of a device increases rapidly with temperature. A classic example is thermal runaway during blocking, whereby the applied voltage generates a «leakage» current and the $V \times I$ 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 led 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, Hitachi Energy 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 figure 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 figure 2.



02 Waveform for repetitive high voltage testing

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

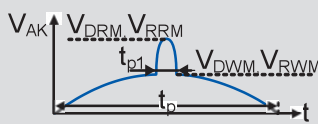
Hitachi Energy has introduced this test method on thyristors rated above 4500 V in compliance with both application conditions and standards definitions while avoiding thermal runaway at final test. V_{DWM} and V_{RWM} have been set to the maximum expected working voltage for the device's repetitive peak blocking voltage according to the guidelines found in the application note 5SYA2051. A voltage peak of pulse width $t_s = 250$ 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 table 1.

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 Hitachi Energy 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 table 1.

BlockingMaximum rated values ¹⁾

Parameter	Symbol	Conditions	5STP 12K6500	Unit
Max. surge peak forward and reverse blocking voltage	V_{DSM}, V_{RSM}	$t_p = 10 \text{ ms}, f = 5 \text{ Hz}$ $T_{vj} = 5 \dots 125 \text{ }^\circ\text{C}$, Note 1	6500	V
Max repetitive peak forward and reverse blocking voltage	V_{DRM}, V_{RRM}	$f = 50 \text{ Hz}, t_p = 10 \text{ ms}, t_{p1} = 250 \text{ } \mu\text{s}$, $T_{vj} = 5 \dots 125 \text{ }^\circ\text{C}$, 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, $T_{vj} = 125 \text{ }^\circ\text{C}$	2000	V/ μs

Characteristic values

Parameter	Symbol	Conditions	min	typ	max	Unit
Forward leakage current	I_{DRM}	$V_{DRM}, T_{vj} = 125 \text{ }^\circ\text{C}$			600	mA

Table 1 Voltage ratings in the data sheet for device 5STP 12K6500

Note 1: Voltage de-rating factor of 0.11% per $^\circ\text{C}$ is applicable for T_{vj} below $+5 \text{ }^\circ\text{C}$ 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 V_{WM}, V_{RM} and

V_{SM} are used for the working voltage, the repetitive peak voltage and the non-repetitive peak (surge) voltages respectively as can be seen in table 2.

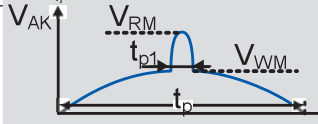
Parameter	Symbol	Conditions	5STP 12K6500	Unit
Max. surge peak forward and reverse blocking voltage	V_{SM}	$t_p = 10 \text{ ms}, f = 5 \text{ Hz}$	6500	V
Max repetitive peak forward and reverse blocking voltage	V_{RM}	$T_{vj} = 5 \dots 125 \text{ }^\circ\text{C}$, Note 1 $f = 50 \text{ Hz}, t_p = 10 \text{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

Table 2 Detail from the voltage ratings in the data sheet for device 5STB 13N6500

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.hitachienergy.com/semiconductors

3. Revision history

Version	Change	Authors
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