RECTIFIER / THYRISTOR
Modules
Applications and Technical Data Book

POWEREX

Ratings and Characteristics

Application Information

SCR/GTO/Diode POW-R-BLOK™ Modules Ratings and Characteristics

1.0 POW-R-BLOK™ Module Construction

Powerex POW-R-BLOK™ modules are hybrid assemblies consisting of various combinations of diodes and Silicon Controlled Rectifiers (SCRs). The metal baseplate of a POW-R-BLOK™ module is electrically isolated from the power devices. The isolated baseplate construction allows a number of POW-R-BLOK™ modules to be mounted on a common heatsink, greatly simplifying equipment assembly.

Chips are mounted to the baseplate within the package in two different ways. In lower power modules, the power chip is soldered to molybdenum discs. The molybdenum discs alleviate thermal stress on the chip due to the nearly equivalent thermal expansion coefficients of molybdenum and silicon. Both surfaces of this assembly are next soldered to the power terminals. The higher power modules use a pressure contact system to hold the chip against the power terminals.

Isolation of the power chips from the baseplate is achieved with various materials. The lower power modules typically utilize aluminum oxide, while the higher power modules utilize beryllium oxide (BeO). BeO has superior thermal conductivity, but it is more expensive and can be a personal health hazard. POW-R-BLOK™ modules which may contain BeO have the following caution printed on their data sheet:

WARNING:
Internal insulation used is Beryllium Oxide. User should avoid grinding, crushing or abrading these portions. Care must be exercised in properly disposing of unwanted modules.

The isolation materials used are selected to withstand 2000 to 2500 volts from live parts to the baseplate without significantly adding to the device's thermal resistance.

Many of the POW-R-BLOK™ modules have been tested and recognized by Underwriters Laboratories (QQQX2 Power Switching Semiconductors). UL Recognition is an on-going process for POW-R-BLOK™ modules. Please contact your local Powerex sales representative for the latest information on UL Recognition of POW-R-BLOK™ modules.

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SCR/GTO/Diode
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1.1 SCR/GTO/Diode POW-R-BLOK™ Module Configurations

The schematic symbol, terminal designations, and output current-voltage characteristic for diodes and SCRs are shown in Figures 1.1 and 1.2 respectively. The GTO is a special case of the SCR which can be turned off with a sufficiently high pulse of reverse gate current. Diodes are often also called rectifiers. Either term may be used interchangeably. SCRs are a member of the thyristor family of devices. The term thyristor defines any semiconductor switch whose bistable action depends upon p-n-p-n regenerative feedback. The SCR is classified as a reverse blocking triode thyristor.

Figure 1.1 Schematic Symbol, Terminal Designations and Current Voltage Characteristics of a Diode (Rectifier).

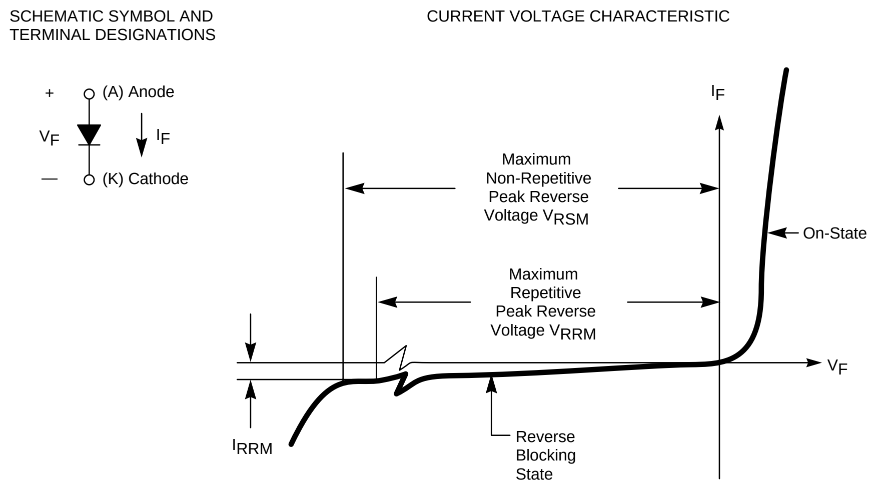
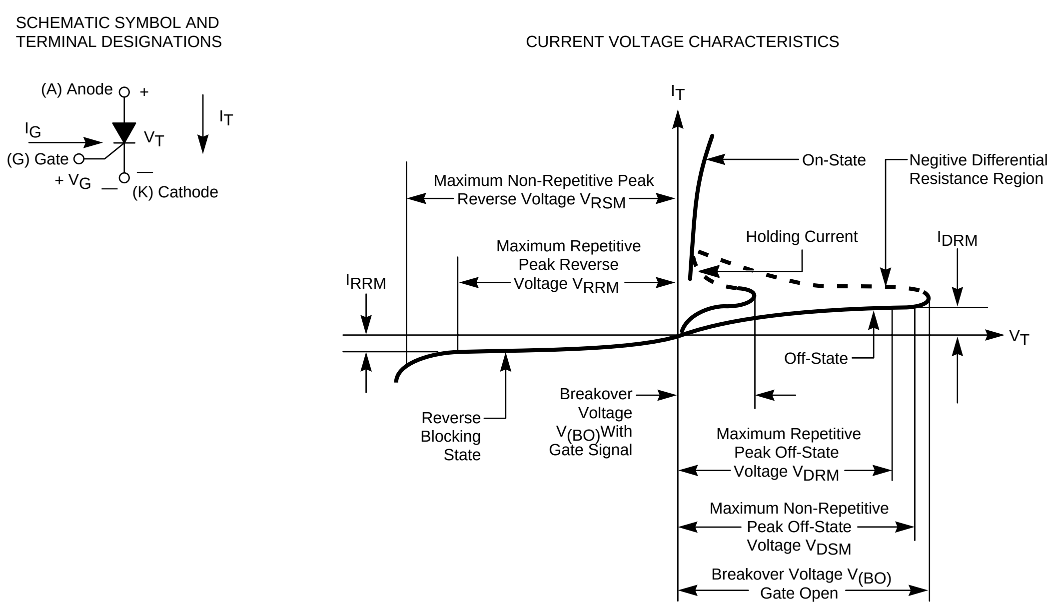


Figure 1.2 Schematic Symbol, Terminal Designations and Current Voltage Characteristics of an SCR.



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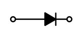
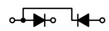
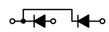
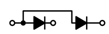
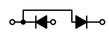
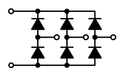
1.2 Typical Applications

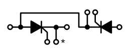
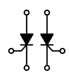
Some of the typical applications for POW-R-BLOK™ modules are: UPS, inverters, lighting controls, induction heating, ultrasonic cleaning, battery chargers, AC and DC motor control, high frequency welding, and power supplies. To meet such a diverse range of applications, POW-R-BLOK™ modules are available in a wide range of circuit configurations, as illustrated by Table 1.1.

Table 1.1 POW-R-BLOK™ Module Circuit Configurations.

DIODE MODULES

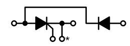
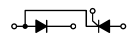
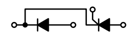
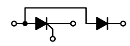
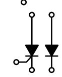
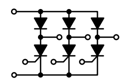
	Single	CS Series
	Dual	CD_1 Series ED_1 Series
	Common Anode	CC Series EC Series
	Common Cathode	CN Series EN Series
	Reverse Dual	CD_9 Series
	Three Phase Bridge	ME Series

DUAL SCR (FULL CONTROL) MODULES

	Dual SCR	CM_3 Series CD_3 Series ED_3 Series CD_A Series
	Split Dual SCR	CT_3 Series

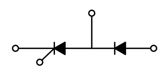
*Auxiliary Cathode Terminal Not Available On All Module Types

SCR/DIODE (HALF CONTROL) MODULES

	SCR/Diode	CM_2 Series CD_2 Series ED_2 Series CD_B Series
	Diode/SCR	CD_7 Series ED_7 Series CD_C Series
	Diode/SCR Center Tap	CC_2 Series EC_2 Series
	SCR/Diode Center Tap	CN_7 Series EN_7 Series
	Split SCR/Diode	CT_2 Series
	SCR/Diode Three-Phase Bridge	CE_2 Series

*Auxiliary Cathode Terminal Not Available On All Module Types

GTO BRIK



1.3 The Device Data Sheet

The proper application of power semiconductors requires an understanding of their maximum ratings and electrical characteristics, information which is presented within the device data sheet. Good design practice employs data sheet limits and not information obtained from small sample lots.

A *rating* is a maximum or minimum value that sets a limit on device capability. Operation in excess of a rating can result in irreversible degration or device failure. Maximum ratings represent extreme capabilities of a device. They are not to be used as design conditions.

A *characteristic* is a measure of device performance under specified operating conditions expressed by minimum, typical, and/or maximum values, or shown graphically.

Table 1.2 Major Ratings and Characteristics of a Typical POW-R-BLOK™ Module.

Absolute Maximum Ratings

Characteristics	Symbol	CM421290	CM421690	Units
Peak Forward Blocking Voltage	V_{DRM}	1200	1600	Volts
Transient Peak Forward Blocking Voltage (Non-Repetitive), t < 5ms	V_{DSM}	1350	1700	Volts
DC Forward Blocking Voltage	$V_{D(DC)}$	960	1280	Volts
Peak Reverse Blocking Voltage	V_{RRM}	1200	1600	Volts
Transient Peak Reverse Blocking Voltage (Non-Repetitive), t < 5ms	V_{RSM}	1350	1700	Volts
DC Reverse Blocking Voltage	$V_{R(DC)}$	960	1280	Volts
RMS On-State Current	$I_{T(RMS)}$, $I_{F(RMS)}$	140	190	Amperes
Average On-State Current, T_C = 82°C	$I_{T(AV)}$, $I_{F(AV)}$	90	90	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (60Hz)	I_{TSM}, $I_{F(TSM)}$	1800	1800	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (50Hz)	I_{TSM}, $I_{F(TSM)}$	1730	1730	Amperes
I^2t (for Fusing), 8.3 milliseconds	I^2t	15000	15000	A^2sec
Critical Rate-of-Rise of On-State Current*	di/dt	100	100	Amperes/μs
Peak Gate Power Dissipation	P_{GM}	5.0	5.0	Watts
Average Gate Power Dissipation	$P_{G(AV)}$	0.5	0.5	Watts
Peak Forward Gate Voltage	V_{GFM}	10	10	Volts
Peak Reverse Gate Voltage	V_{GRM}	5.0	5.0	Volts
Peak Forward Gate Current	I_{GFM}	2.0	2.0	Amperes
Storage Temperature	T_{STG}	-40 to 125	-40 to 125	°C
Operating Temperature	T_j	-40 to 125	-40 to 125	°C
Maximum Mounting Torque M6 Mounting Screw	—	26	26	lb.-in.
Maximum Mounting Torque M5 Terminal Screw	—	17	17	lb.-in.
Module Weight (Typical)	—	160	160	Grams
V Isolation	V_{RMS}	2500	2500	Volts

*T_j = 125°C, I_G = 1.0A, V_D = 1/2 V_{DRM}

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Table 1.2 illustrates the major ratings and characteristics of a typical Powerex POW-R- BLOK™ SCR/Diode Module. Table 1.3 lists the symbols and definitions of the major device parameters for diodes, SCRs, and GTOs.

The remainder of this section on ratings and characteristics will be specific to SCRs. However, much of the material is also applicable to diodes and GTOs.

Table 1.2 Major Ratings and Characteristics of a Typical POW-R-BLOK™ Module. (Continued)

Electrical and Thermal Characteristics, T_j = 25°C unless otherwise specified

Characteristics	Symbol	Test Conditions	CM421290/CM421690	Units
Blocking State Maximums				
Forward Leakage Current, Peak	I_{DRM}	T_j = 125°C, V_{DRM} = Rated	15	mA
Reverse Leakage Current, Peak	I_{RRM}	T_j = 125°C, V_{RRM} = Rated	15	mA
Conducting State Maximums				
Peak On-State Voltage	V_{FM}	I_{FM} = 270A, I_{TM} = 270A	1.4	Volts
Switching Minimums				
Critical Rate-of-Rise of Off-State Voltage	dv/dt	T_j = 125°C, V_D = 2/3 V_{DRM}	500	Volts/μs
Thermal Maximums				
Thermal Resistance, Junction-to-Case	$R_{\theta(J-C)}$	Per Module	0.3	°C/Watt
Thermal Resistance, Case-to-Sink (Lubricated)	$R_{\theta(C-S)}$	Per Module	0.2	°C/Watt
Gate Parameters Maximums				
Gate Current-to-Trigger	I_{GT}	V_D = 6V, R_L = 2Ω	100	mA
Gate Voltage-to-Trigger	V_{GT}	V_D = 6V, R_L = 2Ω	2.0	Volts
Non-Triggering Gate Voltage	V_{GDM}	T_j = 125°C, V_D = 1/2 V_{DRM}	0.25	Volts

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters

Power Semiconductor Devices, General Use

Symbol	Parameter	Definition/Description
R_θ	Thermal Resistance	Defined when junction power dissipation results in a balanced state of thermal flow. Specifies the degree of temperature rise per unit of power, measuring junction temperature from a specified external point.
$R_{\theta(J\text{-}A)}$	Junction-to-Ambient Thermal Resistance	The steady state thermal resistance between the junction and ambient.
$R_{\theta(J\text{-}C)}$	Junction-to-Case Thermal Resistance	The steady state thermal resistance between the junction and surface of the case.
$R_{\theta(J\text{-}S)}$	Junction-to-Sink Thermal Resistance	The steady state thermal resistance between the junction and the heatsink mounting surface.
$R_{\theta(C\text{-}S)}$	Contact Thermal Resistance	The steady state thermal resistance between the surface of the case and the heatsink mounting surface.
Z_θ	Transient Thermal Impedance	The change of temperature difference between two specified points or regions at the end of a time interval divided by the step function change in power dissipation at the beginning of the same interval causing the change of temperature difference.
$Z_{\theta(J\text{-}A)}$	Junction-to-Ambient Transient Thermal Impedance	The transient thermal impedance between the junction and ambient.
$Z_{\theta(J\text{-}C)}$	Junction-to-Case Transient Thermal Impedance	The transient thermal impedance between the junction and the surface of the case.
$Z_{\theta(J\text{-}S)}$	Junction-to-Sink Transient Thermal Impedance	The transient thermal impedance between the junction and the heatsink mounting surface.
T_A	Ambient Temperature	When used in the natural cooling or forced-air cooling it is the temperature of the surrounding atmosphere of a device which is dependent on geographical location and season, and is not influenced by heat dissipation of the device.
T_S	Sink Temperature	The temperature at a specified point on the device heatsink.
T_C	Case Temperature	The temperature at a specified point on the device case.
T_j	Junction Temperature Rating	The device junction temperature rating. Indicates the maximum and minimum allowable operation temperatures.
T_{STG}	Storage Temperature Rating	The device storage temperature (with no electrical connection). Indicates the maximum and minimum allowable temperatures.
—	Mounting Torque Mounting Screw	The maximum allowable torque specification for mounting a device to a heatsink with the specified mounting screw.
—	Mounting Torque Terminal Screw	The maximum allowable torque specification for tightening the specified electrical terminal screws.

SCR Modules

V_{RRM}	Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the repetitive peak reverse anode to cathode voltage applicable on each cycle.
V_{RSM}	Transient Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the non-repetitive peak reverse anode to cathode voltage applicable for time width equivalent to less than 5ms.
$V_{R(DC)}$	DC Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the maximum value for DC anore to cathode voltage applicable in the reverse direction.

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

SCR Modules (continued)

Symbol	Parameter	Definition/Description
V_{DRM}	Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the repetitive peak off-state anode to cathode voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive off-state voltage, but excludes non-repetitive transient off-state voltage.
V_{DSM}	Transient Peak Forward Blocking Voltage	Within the rated junction temperature range and when there is no signal between the gate and cathode, specifies the peak non-repetitive off-state anode to cathode voltage applicable for a time width equivalent to less than 5ms. Indicates the maximum instantaneous value for non-repetitive transient off-state voltage.
$V_{D(DC)}$	DC Forward Blocking Voltage	Within the rated junction temperature range and when there is no signal between the gate and cathode, specifies maximum value for DC anode to cathode voltage applicable in the forward direction.
dv/dt	Critical Rate-of-Rise of Off-State Voltage	At maximum rated junction temperature, and when there is no signal between the gate and cathode, specifies the maximum rate-of-rise of off-state voltage that will not drive the device from an off-state when an exponential off-state voltage of specified amplitude is applied to the device. $\frac{dv}{dt} = \frac{0.632V_D}{r}$ V_D: Specified Off-State Voltage r: Time constant for exponential waveform
V_{TM}	Peak On-State Voltage	At specified junction temperature, and when on-state current (commercial frequency, half sine wave of specified peak amplitude) is applied to the device, indicates peak-value for the resulting voltage drop.
$I_{T(RMS)}$	RMS On-State Current	At specified case temperature, indicates the RMS value for on-state current that can be continuously applied to the device.
$I_{T(AV)}$	Average On-State Current	At specified case temperature, and with the device connected to a resistive or inductive load, indicates the average value for forward-current (sine half wave, commercial frequency) that can be continuously applied to the device.
I_{TSM}	Peak On-State Current	Within the rated junction temperature range, indicates the peak-value for non-repetitive on-state current (sine half wave, commercial frequency). This value indicated for one cycle, or as a function of a number of cycles.
I^2t	Current-Squared Time	The maximum, on-state, non-repetitive short time-thermal capacity of the device and is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. This rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal wave form. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
di/dt	Critical Rate-of-Rise of On-State Current	At specified case (or point) temperature, specified off-state voltage, specified gate conditions, and at a frequency of less than 60Hz, indicates the maximum rate-of-rise of on-state current which the thyristor will withstand after switching from an off-state to an on-state, when using recommended gate drive.
I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for reverse-current flow when a voltage (sine half wave, commercial frequency, and having a peak value as specified for repetitive peak reverse-voltage rating) is applied in a reverse direction to the device.
I_{DRM}	Forward Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for off-state-current flow when a voltage (sine half wave, commercial frequency, and having a peak value for repetitive off-state voltage rating) is applied in a forward direction to the device.
P_{GM}	Peak Gate Power Dissipation	Within the rated junction temperature range, indicates the peak-value for maximum allowable power dissipation over a specified time period, when the device is in forward conduction between the gate and cathode.
$P_{G(AV)}$	Average Gate Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation when the device is forward-conducting between the gate and cathode.

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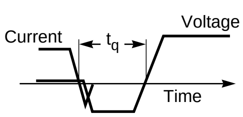
Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

SCR Modules (continued)

Symbol	Parameter	Definition/Description
I_{GFM}	Peak Forward Gate Current	Within the rated junction temperature range, indicates the peak-value for forward-current flow between the gate and cathode.
V_{GRM}	Peak Reverse Gate Voltage	Within the rated junction temperature range, indicates the peak-value for reverse-voltage applied between the gate and cathode.
V_{GFM}	Peak Forward Gate Voltage	Within the rated junction temperature range, indicates the peak-value for forward-voltage applied between the gate and cathode.
I_{GT}	Gate Current-to-Trigger	At a junction temperature of 25°C, and with a specified off-voltage, and a specified load resistance, indicates the minimum gate DC current required to switch the thyristor from an off-state to an on-state.
V_{GT}	Gate Voltage-to-Trigger	At a junction temperature of 25°C, and with a specified off-state voltage, and a specified load resistance, indicates the minimum gate DC voltage required to switch the thyristor from an off-state to an on-state.
V_{GDM}	Non-Triggering Gate Voltage	At maximum rated junction temperature, and with a specified off-state voltage applied to the device, indicates the maximum gate DC voltage which will not switch the device from an off-state to an on-state.
t_{on}	Turn-On Time	At specified junction temperature, and with a peak repetitive off-state voltage of half rated value, followed by device turn-on using specified gate-current, when specified on-state current of specified di/dt flows, indicated as the time required for the applied off-state voltage to drop to 10% of its initial value after gate current application. “Delay time” is the term used to define the time required for applied voltage to drop to 90% of its initial value following gate-current application, and the time required for level to drop from 90% to 10% is referred to as “rise time”. The sum of both these defines turn-on time.
t_q	Turn-Off Time 	Specified at maximum rated junction temperature. Device set up to conduct on-state current, followed by application of specified reverse-voltage to quench on-state current, and then increasing voltage at a specified rate-of-rise as determined by circuit conditions controlling the point where specified off-state voltage is reached. Turn-off time defines the minimum time which the device will hold its off-state, starting from the point on-state current reached zero, and after forward voltage is again applied.

Diode Modules

V_{RRM}	Peak Reverse Blocking Voltage	Within the rated junction temperature range, specifies the repetitive peak reverse voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive transient reverse voltage, but excludes non-repetitive transient reverse-voltage.
V_{RSM}	Transient Peak Reverse Blocking Voltage	Within the rated junction temperature range, specifies the non-repetitive peak reverse voltage applicable for a time width equivalent to less than 5ms. Indicates the maximum instantaneous value for non-repetitive transient voltage.
$V_{R(DC)}$	DC Reverse Blocking Voltage	The maximum value for DC voltage applicable in the reverse direction, specified within the rated junction temperature range.
V_{FM}	Peak On-State Voltage	At specified junction temperature, and when forward-current (commercial frequency, sine wave of specified peak amplitude) is applied to the device, indicates peak-value for the resulting voltage drop.
$I_{F(RMS)}$	RMS On-State Current	At specified case temperature, indicates the RMS value for forward-current that can be continuously applied to the device.
$I_{F(AV)}$	Average On-State Current	At specified case temperature, and with the device connected to a resistive or inductive load, indicates the average value for forward-current (sine half wave, commercial frequency) that can be continuously applied to the device.
I_{FSM}	Peak Surge On-State Current	Within the rated junction temperature range, indicates the peak-value for non-repetitive forward-current (sine half wave, commercial frequency), this value is defined at one cycle or as a function of a number of cycles.

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

Diode Modules (continued)

Symbol	Parameter	Definition/Description
I^2t	Current-Squared Time	The maximum, on-state, non-repetitive short time-thermal capacity of the device and is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. This rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal wave form. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for reverse-current flow when a voltage (sine half wave, commercial frequency, and having a peak value as specified for repetitive peak reverse-voltage rating) is applied in a reverse direction to the device.
Q_{rr}	Reverse Recovery Charge	Indicates the total amount of reverse recovery charge. Specified at a certain junction temperature, and current which has decreased at a specified rate of decrease, from the forward state to reverse after a certain forward current was applied.

GTO Modules

Symbol	Parameter	Definition/Description
V_{RRM}	Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the peak repetitive reverse-voltage applicable on each cycle.
V_{RSM}	Transient Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the peak non-repetitive peak reverse voltage applicable for a time width equivalent to less than 5ms.
V_{DRM}	Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and cathode, specifies the peak repetitive off-state voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive transient off-state voltage, but excludes non-repetitive off-state voltage.
V_{DSM}	Transient Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and cathode, specifies the peak non-repetitive off-state voltage applicable for a time width equivalent to less than 5ms. Indicates the maximum instantaneous value for non-repetitive transient off-state voltage.
$V_{D(DC)}$	DC Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and cathode, specifies maximum value for DC voltage applicable in the forward direction.
dv/dt	Critical Rate-of-Rise of Off-State Voltage	At maximum rated junction temperature, and when there is a specified reverse voltage between the gate and cathode, specifies the maximum rate-of-rise of off-state voltage that will not drive the device from an off-state to an on-state when an exponential off-state voltage of specified amplitude is applied to the device. $\frac{dv}{dt} = \frac{0.632V_D}{r}$ V_D: Specified Off-State Voltage; r: Time constant for exponential waveform
V_{TM}	Peak On-State Voltage	At specified junction temperature, and when on-state current (commercial frequency, half sine wave of specified peak amplitude) is applied to the device, indicates peak-value for the resulting voltage drop.
$I_{T(RMS)}$	RMS On-State Current	At specified case temperature, indicates the RMS value for on-state current that can be continuously applied to the device.
$I_{T(AV)}$	Average On-State Current	At specified case temperature, and with the device connected to a resistive or inductive load, indicates the average value for forward-current (sine half wave, commercial frequency) that can be continuously applied to the device.
I_{TSM}	Peak Surge On-State Current	Within the rated junction temperature range, indicates the peak-value for non-repetitive on-state current (sine half wave, commercial frequency). This value indicated for one cycle, or as a function of a number of cycles.

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Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

GTO Modules (continued)

Symbol	Parameter	Definition/Description
I^2t	Current-Squared Time	The maximum, on-state, non-repetitive short time-thermal capacity of the device and is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. This rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal wave form. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
di/dt	Critical Rate-of-Rise of On-State Current	At specified case (or point) temperature, specified off-state voltage, specified gate conditions, and at a frequency of less than 60Hz, indicates the maximum rate-of-rise of on-state current which the GTO will withstand after switching from an off-state to an on-state, when using recommended gate drive.
I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for reverse-current flow when a voltage (a half sine wave, commercial frequency, and having a peak value as specified for repetitive peak reverse-voltage rating) is applied in a reverse direction to the device.
I_{DRM}	Forward Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for off-state-current flow when a voltage (sine half wave, commercial frequency, and having a peak value as specified for repetitive off-state voltage rating) is applied in a forward direction to the device. Tested with a specified reverse voltage between the gate and cathode.
P_{GFM}	Peak Gate Forward Power Dissipation	Within the rated junction temperature range, indicates the peak-value for maximum allowable power dissipation over a specified time period, when the device is forward conducting between the gate and cathode.
$P_{G(AV)}$	Average Gate Forward Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation when the device is forward-conducting between the gate and cathode.
I_{GFM}	Peak Forward Gate Current	Within the rated junction temperature range, indicates the peak-value for forward-current flow between the gate and cathode.
V_{GRM}	Peak Reverse Gate Voltage	Within the rated junction temperature range, indicates the peak-value for reverse-voltage applied between the gate and cathode.
V_{GFM}	Peak Forward Gate Voltage	Within the rated junction temperature range, indicates the peak-value for forward-voltage applied between the gate and cathode.
I_{GT}	Gate Current-to-Trigger	At a junction temperature of 25°C, and with a specified off-voltage, and a specified load resistance, indicates the minimum gate DC current required to switch the GTO from an off-state to an on-state.
V_{GT}	Gate Voltage-to-Trigger	At a junction temperature of 25°C, and with a specified off-state voltage, and a specified load resistance, indicates the minimum gate DC voltage required to switch the GTO from an off-state to an on-state.
P_{GRM}	Peak Gate Reverse Power Dissipation	Within the rated junction temperature range, indicates the peak-value for maximum allowable power dissipation in the reverse direction between the gate and cathode, over a specified time period.
$P_{GR(AV)}$	Average Gate Reverse Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation in the reverse direction between the gate and cathode.
I_{GRM}	Peak Reverse Gate Current	Within the rated junction temperature range, indicates peak-value for reverse-current that can be conducted between the gate and cathode.
I_{TGQ}	Gate Controlled Turn-off Current	Under specified conditions, indicates the instantaneous value for on-current usable in gate control, specified immediately prior to device turn-off.
t_{gt}	Turn-On Time	When applying forward-current to the gate, indicates the time required to switch the GTO from an off-state to an on-state.
t_{gq}	Turn-Off Time	When applying reverse-current to the gate, indicates the time required to switch the GTO from an on-state to an off-state.

1.4 Voltage Ratings

The specified voltages are defined by the maximum rating voltages which can be applied between anode and cathode in the forward, (anode positive with respect to the cathode), and the reverse directions. *The maximum voltage ratings should never be exceeded.* Exceeding the maximum voltage ratings can be detrimental to the device, resulting in instant failure or a decrease in the life of the device.

The repetitive peak sinusoidal forward voltage which can be applied to an SCR or a GTO in the off-state is specified by the Peak Forward Blocking Voltage, V_{DRM}. The forward voltage applicable for sine pulses of less than 5 milliseconds duration which can be applied on a non-repetitive basis to an SCR or a GTO in the off-state is specified by the Transient Peak Forward Blocking Voltage, V_{DSM}. The maximum forward DC voltage rating for an SCR or a GTO is specified by the DC Forward Blocking Voltage, $V_{D(DC)}$. Similar parameters exist with respect to the reverse direction, i.e. Peak Reverse Blocking Voltage, V_{RRM}; Transient Peak Reverse Blocking Voltage, V_{RSM}; and DC Reverse Blocking Voltage, $V_{R(DC)}$. The reverse parameters are applicable to diodes in addition to SCRs and GTOs.

Voltage ratings are specified at the maximum rated junction temperature and are applicable over the entire operating temperature range. For most SCRs, voltage ratings are specified with the gate terminal open. Of particular caution, users should avoid applying positive gate voltage during periods when an SCR is blocking reverse voltage. Positive gate bias during reverse anode to cathode voltage results in a significant increase in SCR power dissipation which must be accounted for to insure reliable operation. For GTOs, voltage ratings are specified with a stipulated value of reverse gate to cathode voltage. SCRs are normally assigned the same voltage rating in both the forward and reverse directions. In practice, most SCRs exhibit a slightly higher reverse breakdown voltage, and the forward breakdown voltage sets the device rating.

Leakage currents are specified at the device forward and reverse voltage ratings. Leakage currents are strongly temperature dependent. At high junction temperatures, it is possible to have regenerative thermal runaway of the device if the case to ambient thermal resistance is at or above a critical value. This potential high power dissipation, particularly with poor or no heatsinking is one reason why it is not recommended to measure blocking voltages of diodes, SCRs, or GTOs with DC tests.

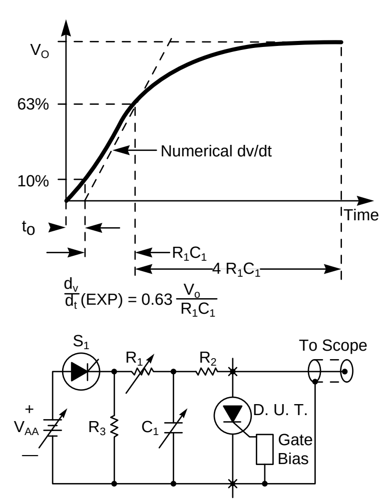
Exceeding the forward blocking voltage of an SCR will result in triggering the device into conduction. Voltage breakover is generally not damaging providing the allowable di/dt rating under this condition is not exceeded. The breakover voltage of an SCR is highly temperature dependent, decreasing rapidly above rated junction temperature. It is not recommended to trigger SCRs by voltage breakover, rather a zener diode or equivalent network should be connected from anode to gate so that the device is triggered by gate drive.

1.5 dv/dt Rating

A high rate of off-state anode-to-cathode voltage, dv/dt, may cause an SCR to turn-on. The static dv/dt test circuit and standard waveforms are shown in Figure 1.3.

Static dv/dt capability is an inverse function of junction temperature. Reverse biasing the gate with respect to the cathode may increase dv/dt withstand capability for medium and low current SCRs. Often the circuit designer will need to add a snubber network across the SCR to limit the maximum dv/dt applied to an SCR.

Figure 1.3 Exponential dv/dt Test Circuit and Waveform



S_1 = Mercury Wetted Reed Relay or SCR
R_1 = Noninducive Resistor
R_2 = Current Limiting Resistor

1.6 Power Dissipation

The power generated in an SCR consists of the following components:

1. Turn-on switching
2. Conduction
3. Turn-off switching or commutation
4. Blocking
5. Gate Circuit

On-state conduction losses are the major source of junction heating for normal duty cycles and power frequencies. For very high di/dt current waveforms or high operating frequencies, turn-on switching loss can become significant.

Figure 1.4 illustrates a typical curve of on-state power dissipation in average watts for an SCR as a function of average current in amperes for various conduction angles for operation up to 400 Hz. These curves are based on a current waveform which is the remainder of a half sine wave which results from delayed angle triggering in a single phase resistive load circuit. Similar curves are provided for rectangular current waveforms. These curves represent the integrated product of the instantaneous anode current and on-state voltage drop, and the integration of the appropriate reverse blocking losses. Pulse triggering is assumed and hence gate losses are neglected.

1.7 Average and RMS Current Ratings

Average current rating versus case temperature as it appears in a typical curve for an SCR is shown in Figure 1.5. These curves specify the maximum allowable average anode current ratings of the SCR as a function of case temperature and conduction angle for a resistive load operating up to 400 Hz. Points on this curve are selected so that the junction temperature does not exceed the maximum allowable value. These curves have definite end points for the various conduction angles. These end points represent the RMS rating of the device. The RMS current rating is necessary to prevent excessive heating of the resistive elements of the SCR, such as joints, leads, interfaces, etc. The relationship between the RMS value and the average value of a current waveform is dependent upon the wave shape. For the data sheet rating standard half wave sinusoidal waveform, the ratio of RMS to average values is 1.57. For low duty cycle waveforms, the average value can be well within device ratings but the high peak currents can result in the allowable RMS rating being exceeded. Similar curves are provided for rectangular current waveforms, typical highly inductive loads.

1.8 POW-R-BLOK™ Rating Curves

In addition to the standard sine and square wave information, there are also families of curves for assemblies of AC switches, single and three-phase bridges. This latter group takes the designer one step closer in selecting a heatsink to satisfy his systems needs.

The set of curves shown in Figure 1.6 for the single phase AC switch will be used to demonstrate how the curves were constructed. This set of curves is for one (1) CD43_ _60 module mounted on a heatsink. The left hand vertical axis is for total average power, the right hand vertical is for maximum allowable case temperature, the

Figure 1.4 On-State Power Dissipation vs. Average Current Characteristic Curve

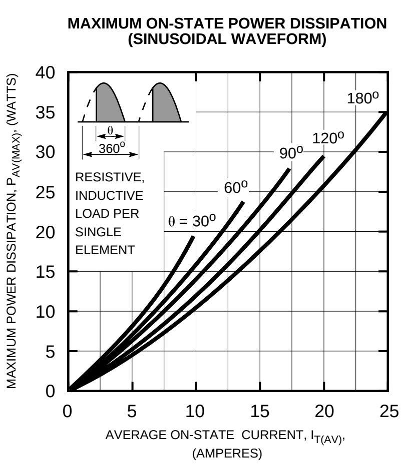


Figure 1.5 Average Current vs. Case Temperature Characteristic Curve

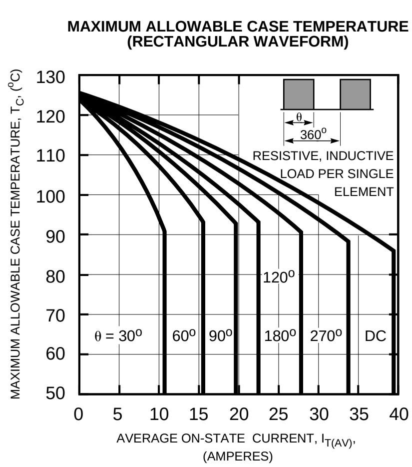
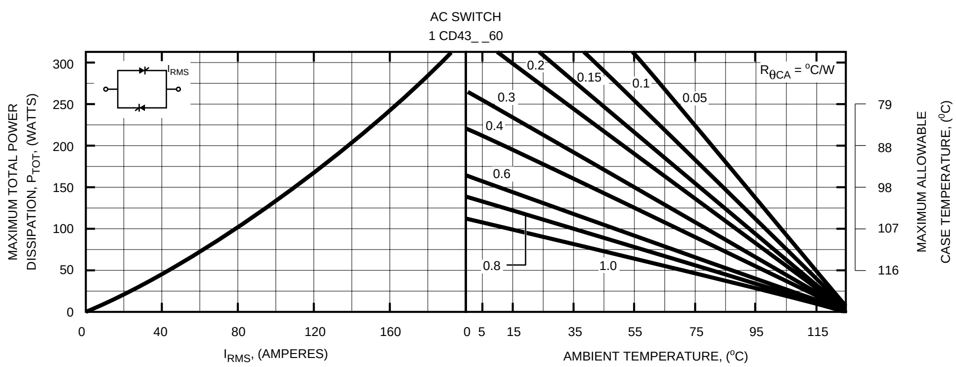


Figure 1.6 Maximum Total Power Dissipation and Maximum Ambient Temperature Curve for AC Switch Application



horizontal axis is split between current and ambient temperature.

The first step is to plot the left hand half of the curve. This information is available from the more familiar average power versus average current curve. In this case, only the 180° sine data is plotted. First the average current is changed to RMS by the 2.22 factor. The 2.22 factor takes current rating from average SCR current to RMS switch current for 180° sine. Then the average power for the AC switch is plotted as a function of RMS switch current. The formula

$$T_C = T_j - P_{AVG} R_{\theta(J\text{-}C)}$$

is used to determine the maximum allowable case temperature while maintaining the junction temperature rating of 125°C. Three or four power levels were selected to do the calculations to determine case temperature limits. For instance, at 108A RMS, the power dissipation is 150 watts. $R_{\theta(J\text{-}C)}$ is determined again from average power and case temperature curves both a function of current. The value for the CD43_ _60 is 0.183°C/W, based on the complete module and 180° sine. This yields

$$T_C = 125°C - 150W \times 0.183°C/W$$

$$T_C = 98°C$$

A horizontal line is drawn from the 150 watt level and it intersects the right hand vertical axis at 98°C. This process is continued until the maximum allowable case temperature axis is sufficiently filled.

The next step is to label the right hand horizontal axis with ambient temperatures up to 125°C which corresponds to the maximum permitted junction temperature. The formula

$$T_A = T_C - P_{TOT} \times R_{\theta(C\text{-}A)}$$

is used to generate case-to-ambient thermal impedance lines where:

T_A = Ambient temperature

T_C = Maximum allowable case temperature from above

P_{TOT} = Total power dissipation

NOTE: If 3 modules were used as in three-phase AC switch, P_{TOT} would be the total power of all three modules.

and

$R_{\theta(C\text{-}A)}$ = Thermal impedance case-to-ambient.

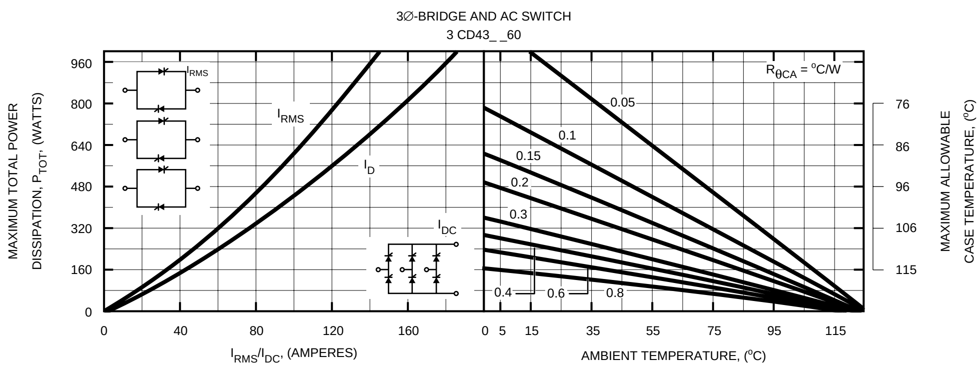
The procedure is to take an average power dissipation and its corresponding maximum allowable case temperature and arbitrarily select $R_{\theta(c\text{-}a)}$ values to calculate maximum ambients. For example

$$T_A = 98°C - 150W \times 0.1°C/W$$

$$T_A = 83°C$$

The intersection of the 83°C ambient and 98°C case temperature becomes a point on the 0.1°C/W $R_{\theta(C\text{-}A)}$ line. The line may be drawn through this point and the 125°C ambient which is a common point to all $R_{\theta(C\text{-}A)}$ lines. Another $R_{\theta(C\text{-}A)}$ is chosen and the procedure is repeated. If

Figure 1.7 Maximum Total Power Dissipation and Maximum Ambient Temperature Curve for Three-Phase Bridge Application.



negative ambients are found, choose other values of average power and case temperature and continue the process until sufficient $R_{\theta(c\text{-}a)}$ lines are drawn.

1.9 Sample Problem

Assume one is trying to select a device to use on a 50hp direct current machine. A current of 90 amperes is required from a three-phase 480 volt AC line with the motor running at base speed. This assumes a 90% efficiency. Figure 1.7 is very useful in determining what heatsink rating is required for a given ambient. A horizontal line can be drawn from the 90 amp point on the I_D curve. This line intersects with the case-to-heatsink curves on the right hand side of the illustration. Assuming a 40°C ambient an interpolation is needed between the 0.2°C/W and 0.3°C/W $R_{\theta(C\text{-}A)}$ lines. This results in an $R_{\theta(C\text{-}A)}$ of 0.266°C/W. With three (3) POW-R-BLOK's mounted on a common heatsink, the following formula may be used to determine the actual heatsink rating required.

$$R_{\theta(S\text{-}A)} = R_{\theta(C\text{-}A)} - \frac{R_{\theta(C\text{-}S)}}{N}$$

where

$R_{\theta(S\text{-}A)}$ = Sink-to-ambient thermal impedance

$R_{\theta(C\text{-}A)}$ = Case-to-ambient thermal impedance

$R_{\theta(C\text{-}S)}$ = Case-to-sink thermal impedance for a module, i.e. 0.1°C/W

and

N = The quantity of POW-R-BLOK's on the common sink.

The sink-to-ambient thermal impedance is

$$R_{\theta(S\text{-}A)} = 0.266°\text{C/W} - \frac{0.1°\text{C/W}}{3}$$

$$R_{\theta(S\text{-}A)} = 0.23°\text{C/W}$$

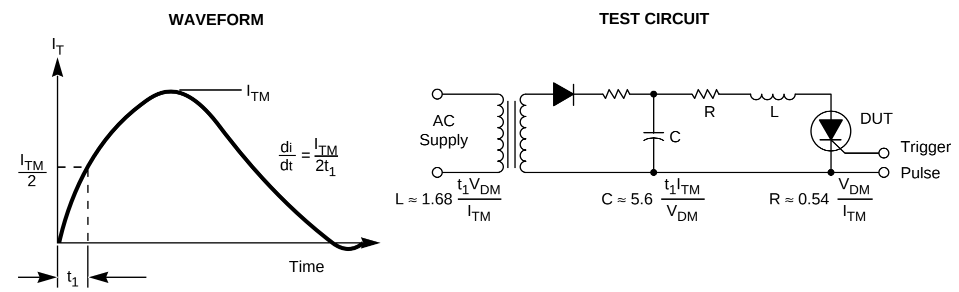
This value of thermal impedance, however, only guarantees the junction temperature will not exceed 125°C. This is not normally the approach taken by designers. A safety margin is normally applied to keep the junction to a lower value and provide added system reliability. A simple method to use with the curves at hand is to add the desired safety margin onto the actual maximum ambient. If 20° margin on junction temperature is desired in a 40°C ambient, extend the existing horizontal line so that it intersects with the vertical 60°C line. This intersection lies on another $R_{\theta(C\text{-}A)}$ line which is 0.2°C/W. This translates into a 0.17°C/W heatsink to ambient thermal impedance. This heatsink would guarantee that even with worst case device parameters, the peak junction temperature will not exceed 105°C.

Similar problems may be solved with any of the other sets of curves for AC switch or single phase bridge configurations.

1.10 Surge and I^2t Ratings

For non-recurrent current overloads, the rated junction

Figure 1.8 di/dt Test Circuit and Waveform



Test Parameter	Recommended Values
I_{TM}	≥ Twice Device Current Rating
t_1	≥ lμs
Test REP Rate	≥ 60PPS
Test Temperature	Maximum Rated Value
Off-State Voltage	Rated Value
Gate Trigger Pulse	20V/20Ω, t_r = lμs, t_r = 3μs
Test Duration	≥ 1000 Hours

temperature can be exceeded for a brief instant as indicated by the surge and I^2t ratings. Non-recurrent ratings apply only when they are not repeated before the peak junction temperature has returned to its maximum rated value or less. Non-recurrent ratings apply to situations that occur no more than a limited, typically 100, number of times over the life of the device. In determining the surge current rating, the device is assumed to be at its rated junction temperature prior to application of the overload. Many of the device parameters are not specified or guaranteed immediately following the surge current. Surge current ratings are provided for one, three, or ten half cycles of sinusoidal current at 60 Hz. The I^2t rating is derived from the single cycle surge current rating. The "I" in I^2t rating is the RMS value of the surge current, while it is a peak value in the surge current rating. The I^2t rating is useful in coordinating fuses to protect the SCR or diode.

1.11 di/dt Ratings

When the rate of rise of anode current (di/dt) is very rapid compared to the spreading velocity of the turn-on process across the junctions, local "hot spot" heating will occur. These "hot spots" may lead to localized excessive temperatures that can destroy the device.

The di/dt test circuit and standard waveform are shown in Figure 1.8. The di/dt rating guarantees that the device will block voltage but does not guarantee maintenance of device dynamic characteristics such as turn-off time and dv/dt capability.

The circuit designer must consider all current sources when assessing di/dt. In particular, the discharge current from a snubber network must be included in determining the application di/dt.

1.12 Reverse Recovery Characteristics

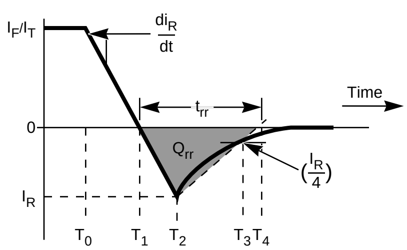
During commutation from forward conduction to the off-state, SCRs and diodes display a transient reverse current that far exceeds the maximum rated blocking current. This reverse current is called reverse recovery current and its time integral is the recovered charge, Q_{rr}. Figure 1.9 illustrates a typical reverse recovery waveform and includes the definition of reverse recovery time, t_{rr}.

Both Q_{rr} and t_{rr} are strongly circuit dependent as well as device dependent. The peak on-state forward current prior to commutation as well as the commutation di/dt are significant circuit variables. Recovered charge has a positive temperature coefficient. Diodes are available in power modules in standard, fast, and super fast recovery times. With the exception of the ED Series, POW-R-BRIK™ and OPEN-BRIK™ modules, the SCRs used in POW-R-BLOK™ modules have standard recovery times typical of power line frequency applications.

1.13 Thermal Resistance

Temperature calculations are simplified by using thermal resistance concepts. The flow of heat through a thermal path as a result of power dissipation is analogous to the flow of current through a conductive path as a

Figure 1.9 Reverse Recovery Waveform and Parameter Definitions



result of a voltage source. Hence, knowing the power being dissipated in a device, and the ambient temperature, the resulting junction temperature can be calculated using the total thermal resistance and the following equation.

$$T_j = T_A + PT^* R_{\theta(J\text{-}A)}$$

where:

$R_{\theta(J\text{-}A)}$ = Total thermal resistance junction-to-ambient (°C/W)

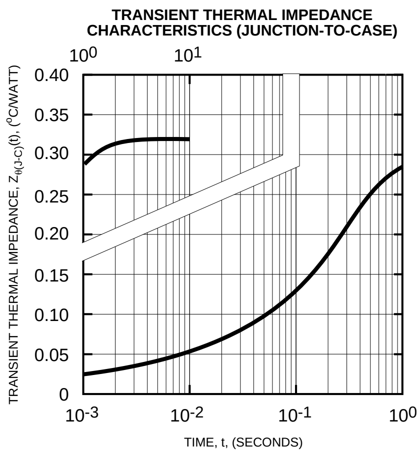
P_T = Total power dissipation (W)

T_j, T_A = Junction, ambient temperature

The total thermal resistance is given by:

$$R_{\theta(J\text{-}A)} = R_{\theta J\text{-}C)} + R_{\theta(C\text{-}S)} + R_{\theta(S\text{-}A)}$$

Figure 1.10 Transient Thermal Impedance Characteristic Curve



where:

$R_{\theta(J\text{-}C)}$ = Junction-to-case thermal resistance specified on data sheet (°C/W)

$R_{\theta(C\text{-}S)}$ = Lubricated case-to-sink thermal resistance specified on data sheet (°C/W)

$R_{\theta(S\text{-}A)}$ = Sink-to-ambient thermal resistance (°C/W)

The thermal resistance ($R_{\theta(J\text{-}C)}$) specified for a device is always a maximum value, with a safety margin included to allow for production variations from lot to lot. The interface case-to-sink thermal resistance ($R_{\theta(C\text{-}S)}$) can be significant and the data sheet value specified is for a baseplate properly lubricated with thermal compound.

1.14 Transient Thermal Impedance

For short or low duty cycle power pulses, using the steady state thermal resistance will give conservative junction temperatures. In addition, using the average value of power dissipation will underestimate the peak junction temperature. The solution is use of the transient thermal impedance curves (Figure 1.10 illustrates a typical transient thermal impedance curve). For a power device subjected to single or very low duty cycle, short duration power pulses, the maximum allowable power dissipation during the transient period can be substantially greater than the steady state dissipation capability.

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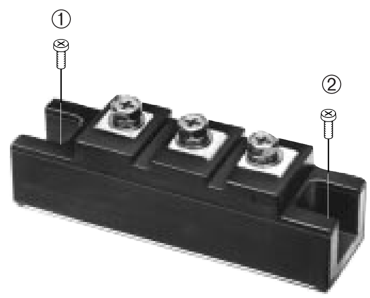
2.0 POW-R-BLOK™ Module Mounting

When mounting POW-R-BLOK™ modules to a heatsink, care should be taken to avoid applying uneven torque to the baseplate due to one sided tightening. It is recommended that the mounting screws be tightened in the fashion shown in Figure 2.1. The device data sheet lists the maximum torque rating for both the mounting screws and, where applicable, the terminal screws.

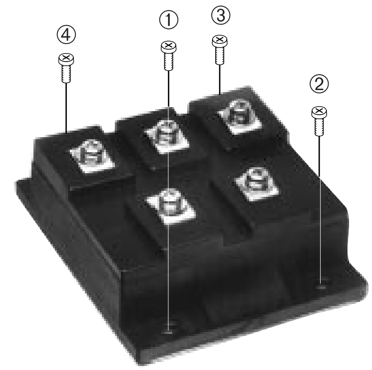
The use of thermal compounds when mounting POW-R-BLOK™ modules to heatsinks is highly recommended to prevent hot spots due to voids between the package and the heatsink surface. It is important to select a thermal compound which has a stable characteristic over the operating temperature range and the lifetime of the equipment.

The compound should be applied in a very thin layer, applying a thin coating with a spatula or lintless brush and wiping lightly to remove excess material. Another method is to place a predetermined minimal amount at or along the center of the contact area. Then in mounting, rotation and pressure will force the compound over the contact area and experience will indicate whether the quantity is sufficient as excess will appear around the edges of the contact area. Excess compound may be wiped away using a cloth wetted with acetone or alcohol. The use of thick consistency thermal compounds should be avoided, particularly with larger modules, since it may

Figure 2.1 Mounting Screw Fastening Pattern



Two-point mounting type
temporary tightening ① → ②
final tightening ② → ①



Four-point mounting type
temporary tightening ① → ② → ③ → ④
final tightening ④ → ③ → ② → ①

not compress evenly when the module is torqued.

A number of manufacturers supply a wide variety of thermal grease and fluid type compounds. Among these are Wakefield, Dow-Corning, Alcoa, and Thermalloy. In addtion, some manufacturers offer alternative thermal interface pads which avoid the application problems of greases. These materials, such as THERMSTRATE™, are often available in pre-cut shapes that accommodate many POW-R-BLOK™, module packages.

It is recommended that heatsink surfaces be flat within ±1 mil/inch over the mounting area and have a surface finish of less than 64 microinches. It is also important to properly prepare the heatsink mounting surface just prior to module mounting. The heatsink surface should be thoroughly cleaned to remove any foreign material, oxides, or films. A satisfactory cleaning technique is to polish the mounting area with No. 000 fine steel wool, followed by an alcohol or acetone rinse.

2.1 Gate Drive Recommendations

SCRs have extraordinarily high power gain. For example, a 90 Ampere, 1000 Volt SCR is guaranteed to turn on if a 100 mA, 3 Volt gate drive is applied. This is a power gain of 3 x 10^5. The power gain is further magnified as the required gate controlled signal is a pulse only a few microseconds wide.

To achieve reliable performance of the SCR, a gate drive signal greater than the minimum specified I_{GT} and V_{GT} values is required. Because of the diverse range of SCR applications, a DC gate test condition with a resistive load was established for the basic gate parameters, I_{GT} and V_{GT}, found on a typical data sheet.

These DC gate trigger parameters are not intended to reflect operational application requirements.

The reason for the gate overdrive requirement is the finite time required to achieve full area conduction in the SCR. This di/dt problem, is especially critical in the first few microseconds of turn-on, when only a very small percentage of the total device area will be in conduction. The initial conduction area is highly dependent upon gate-to-cathode geometry and the amount of gate current overdrive.

Most POW-R-BLOK™ modules utilize SCRs with di-namic gate designs. The di-namic gate design provides an integrated pilot SCR connected from anode to gate of the main SCR. The pilot SCR provides rapid turn on of a significant portion of the main SCR section of the device. Di-namic gate devices allow the use of soft gate drive for most applications. However, applications still exist even with di-namic gate devices which require hard gate drive.

Figure 2.2 illustrates soft and hard gate drive waveforms and provides recommended gate current and voltage levels. Note that gatetrigger parameters are temperature dependent, with the required gate parameters increasing in magnitude as temperature decreases. Thus, the selection of drive levels should be made for the lowest operating temperature anticipated for the equipment. Hard gate drive is required for high repetitive di/dt applications typical of capacitive loads, heavy industrial phase control operation with inductive load, and systems where electrical noise is troublesome requiring gate signal suppression circuitry.

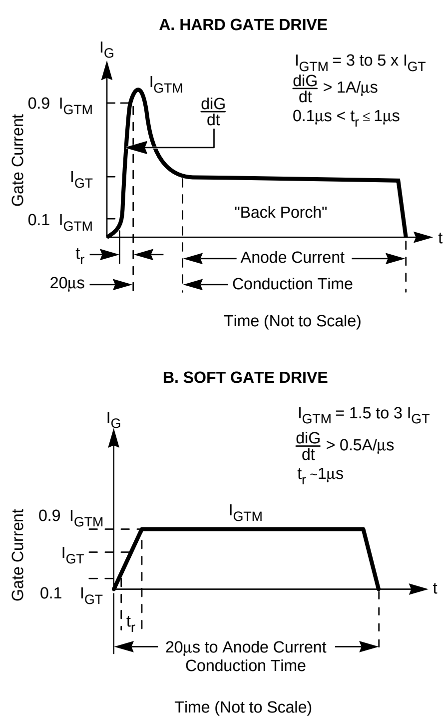
It is also necessary to increase the gate drive amplitude for pulse width less than 20 microseconds. This is due to the need for the SCR to receive a finite amount of charge to turn-on. Additional gate drive recommendations and precautions are enumerated here:

A. GENERAL CONSIDERATIONS

- Gate the SCR when the anode voltage is positive. Allowing a positive gate while the SCR becomes reverse biased limits device reliability.

- Design the gate firing sequence such that the snubber network across the SCR is charged prior to gate triggering. This gives good di-namic gate action.

Figure 2.2 Hard and Soft Gate Drive Waveforms

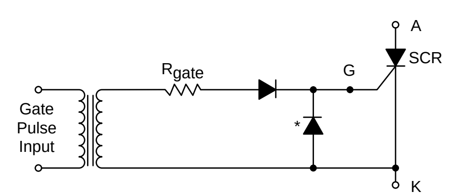


- If a DC gate signal is used in a multi-phase system a soft gate drive signal does not give good di-namic gate action. No snubber discharge is possible after time zero which results in poor di-namic gate action. In addition, POW-R-BLOK™ modules have high noise immunity characteristics, meaning they do not false trigger at very low gate currents. For this particular application, hard gate drive is required.

- The gate drive circuitry should have a 1 to 2 Amp average. 100 Volt diode in series with the gate and across the gate to cathode terminals as shown in Figure 2.3. These will eliminate two possible SCR failure modes. The diode in series will prevent negative gate current flow while the diode across the gate-to-cathode limits the reverse gate voltage by clamping.
- Minimize average gate power dissipation. Do not use excessive gate drive or excessively long gate pulses.

- Remember that SCRs require more gate current to trigger under narrow pulse width and

Figure 2.3 Diode Protected Gate Circuit



*May also employ a zener diode of appropriate rating to provide protection against excessive forward gate voltage transients in addition to the reverse voltage protection.

low junction temperature operating conditions, refer to Figure 2.4.

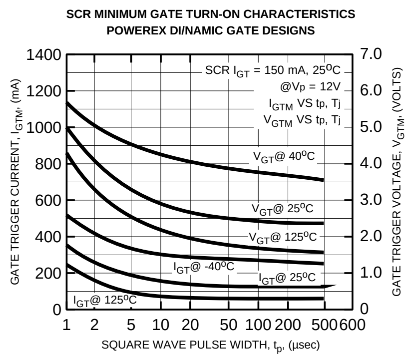
- Both excessive overdrive or weak underdrive can defeat the operation of the di-namic amplifying gate.

- Inductive loads can be troublesome if the gate drive is insufficient in amplitude or width. Recommended practice is the use of “picket fence” or hard gate drive. A picket fence is a high frequency gate signal varying from 1 to 15kHz, 20 to 50 microseconds wide, within a 60Hz envelope such that the SCR is continuously gated. The average gate current rating is maintained within device rating. In hard gate drive circuits, the “back porch” anticipates worse case power factor; making the gate pulse width wide enough to insure SCR latching and holding.

- Prevent noise pickup in the gate signal connections twisting together the gate and the cathode potential leads to the SCR and use either twisted pair wire from the gate pulse amplifier or a coax type shielded cable. Locate the gate wires as close as possible to the SCR but away from magnetics and high current carrying members of the power circuits. Of course, the gate signal leads should be as short as possible.

- Minimize delta delay time between SCRs using hard gate drive with as high a gate current rise time, (di_G/dt), as possible.

Figure 2.4 Minimum Pulsed Gate Trigger Parameters for a Typical SCR



- Always use a resistor in series with each gate lead if triggering more than the SCR from the same source. Generally, 10 to 25 ohms is used to diminish input gate cathode impedance variations.

- Use single point triggering if gating more than one device from the same source.

B. HIGH di/dt OPERATION

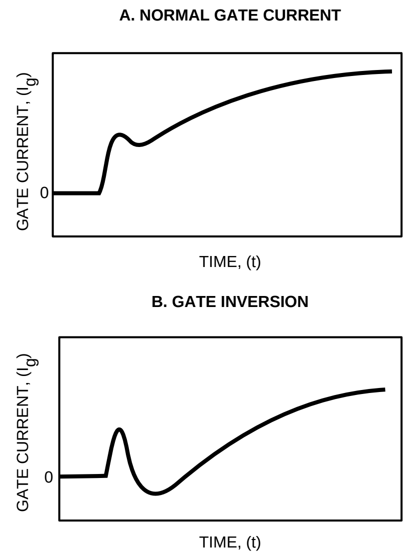
- Design for worst case di/dt and include all capacitance and snubber discharge currents in determining the SCR di/dt stress level.

- Treat SCR data sheet di/dt ratings like voltage ratings. Good engineering application practice dictates a 2 to 1 safety factor for reliable operation.

- Minimize gate drive rise time.

- Minimize or eliminate shunt capacitance and series inductance in the gate circuit

Figure 2.5 Normal Gate Current and Gate Inversion Waveforms



to prevent gate current inversion and resultant di/dt stress.

- Be aware that high di/dt can require open circuit gate source voltage upward of 40 Volts to prevent gate cur-rent inversion and assure reli-able operation. Gate current inversion or gate drive extinction occurs when high anode di/dt causes the instantaneous gate cathode voltage to exceed the gate-to-source voltage. Refer to Figure 2.5.

C. LOW di/dt OPERATION

- Use DC gate drive when possible to minimize turn-on delay time.

- When using repetitive pulse/picket fence gate drive, maximize duty cycle to reduce turn-on delay time and latching current effects.

D. VERY LOW ANODE VOLTAGE OPERATION

- Be aware that the SCR amplifying gate structure may not function at very low anode voltage. Observe turn-on behavior if anode voltage is less than 10 Volts.

- Assure adequate trigger current by driving with peak gate current in excess of five times the I_{GT} specification of the SCR.

2.2 Determining Power Losses

Proper application of SCRs, GTOs, and diodes requires that users determine device power losses and provide adequate cooling to keep junction temperatures within rated values.

For standard phase control applications, this process is greatly simplified by using the data sheet curves of power dissipation and maximum allowable case temperature versus average current. Use of these curves and explanations of the components of device power dissipation were explained in the Ratings and Characteristics section.

It is often required to calculate the root mean square (RMS) and/or average value of a waveform from peak currents, pulse widths, phase angles, etc., in order to determine device power losses. Figure 2.6 provides definitions and formulas for calculating RMS and average values of typical power control waveforms.

In some practical applications, the power waveform is a short pulse at a low duty cycle or some other irregular shape. In many of these situations it is not adequate to determine the average power dissipation and average junction temperature. Proper application requires that the peak operating junction temperature does not exceed the maximum allowable junction temperature.

The procedure for determining the peak junction temperature is to plot device power dissipation versus time by multiplying instantaneous current values by corresponding forward voltage values obtained from the device data sheet on-state current voltage characteristic curve. The peak junction temperature is then calculated using the transient thermal impedance curve.

For irregular waveforms, this procedure is tedious. For the purpose of calculating peak junction temperature, the irregular power waveshape can be approximated by a rectangular waveshape having an identical value of peak power and with a pulse width such that the average power is also identical. Figure 2.7 illustrates this square wave approximation technique. Translation into rectangular power pulses of power ensures a worst case approximation since a rectangular waveform will always have an equal or greater effect on temperature as an arbitrary waveform of equal peak and average values. After determination of the equivalent rectangular power waveform, the transient thermal impedance curve can be used along with the equations presented in Figure 2.8 to determine the peak junction temperature.

2.3 Voltage Ratings and Overvoltage Suppression

The voltage rating of an SCR, GTO, or diode must be selected high enough to withstand anticipated voltage transients as well as the repetitive peak forward and reverse voltages imposed upon the device by the application circuit. It is common practice with SCRs and diodes to provide a voltage safety factor of two times the maximum high line condition circuit voltage. Table 2.1 provides device voltage rating recommendations for common circuit voltages.

Table 2.1 Recommended Device Voltage Ratings

Supply Voltage ($V_{AC(RMS)}$)	Recommended Device Voltage Rating (V_{RRM}, V_{DRM})
120	400
240	800
480	1600
575	2000

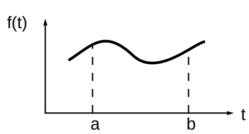
Unanticipated voltage transients which exceed the blocking voltage ratings are probably the most frequent failure mode for SCRs and diodes. Because voltage breakdown tends to occur at the surface of the device, the energy required to cause damage can be quite small. Techniques to protect against voltage transients include:

1. Redesign the circuit operation and/or physical layout to remove or minimize the source of the transient.
2. Suppress the transient by absorbing the energy in an appropriately designed RC snubber circuit located across the device or across the source of the transient. Design of a snubber for a specific device and application involves trade offs between many conflicting requirements. Figure 2.9 illustrates an RC snubber used with an SCR and provides general recommended snubber component values. Care must be taken in selecting the actual RC snubber component values to insure their capability to handle peak currents without overheating or adding additional transients to the circuit.
3. Use nonlinear resistive elements such as selenium transient suppressors, zener diodes, or metal oxide varistors (MOVs) in shunt with the device being protected. Maintain short leads between the transient suppressor and the device.
4. Occasional severe transients can sometimes be best limited by a solid-state crowbar circuit which shorts the line and absorbs the transient energy until a fuse or circuit breaker can be opened.

2.4 Typical Applications

POW-R-BLOK™ modules are utilized in a wide variety of applications. The circuit configurations and critical parameters for a number of common phase control applications are given Figure 2.10.

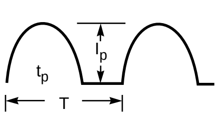
Figure 2.6 Definitions and Formulas for Calculating RMS and Average Values of Typical Power Control Waveforms



$$\text{Form Factor} = \frac{\text{RMS Value}}{\text{Average Value}}$$

$$\text{RMS Value} = \left[\frac{1}{b-a}\int_a^b f(t)^2 dt\right]^{1/2} \qquad \text{Average Value} = \frac{1}{b-a}\int_a^b f(t)dt$$

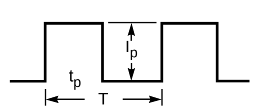
Half-Sine Waveform



$$(1)\ I_{AV} = \frac{2}{\pi} Ip \frac{t_p}{T} \qquad (3)\ I_{RMS} = I_P \sqrt{\frac{t_p}{2T}}$$

$$(2)\ I_{RMS} = \frac{1.57\ I_{AV}}{\sqrt{2\left[\frac{t_p}{T}\right]}}$$

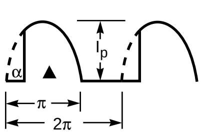
Square Waveform



$$(4)\ I_{AV} = \frac{t_p I_p}{T} \qquad (6)\ I_{RMS} = I_p \sqrt{\frac{t_p}{T}}$$

$$(5)\ I_{RMS} = \frac{I_{AV}}{\sqrt{\frac{t_p}{T}}}$$

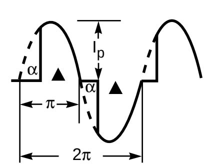
Phase Control Half-Sine Waveform



$$(7)\ I_{AV} = \frac{I_p}{2\pi}\left[1 + \cos\alpha\right]$$

$$(8)\ I_{RMS} = \frac{I_p}{2\pi}\sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}}$$

Phase Control Full-Wave Sine Waveform



$$(9)\ I_{AV} = \frac{I_p}{\pi}\left[1 + \cos\alpha\right]$$

$$(10)\ I_{RMS} = \frac{I_p}{\sqrt{2}}\sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}}$$

α = Triggering Angle
▲ = Conduction Angle

Figure 2.7 Square Wave Approximation of Irregular Power Waveforms

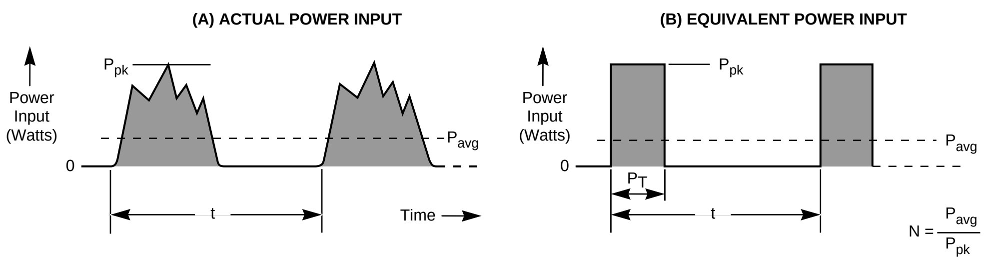


Figure 2.8 Basic Load Current Rating Equations

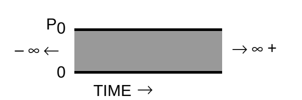
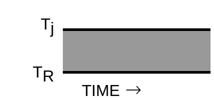
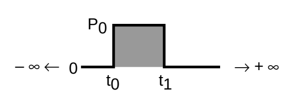
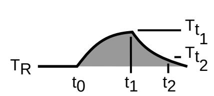
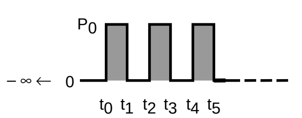
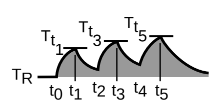
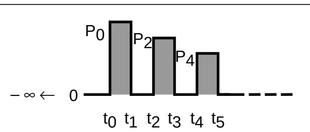
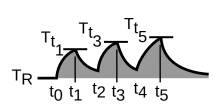
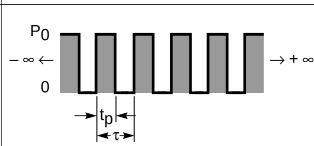
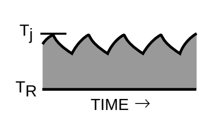
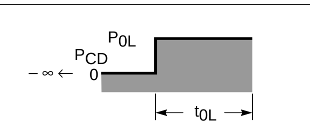
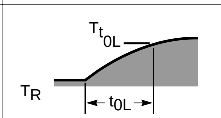
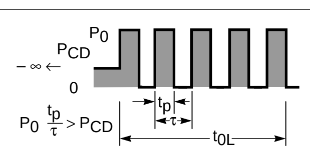
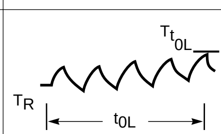
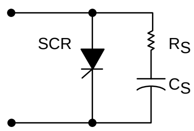
Load Condition	Waveform of Power Loss at Junction	Waveform of Junction Temperature Rise (T_R = Reference Temp.)	Solution for Juction Temperature R_θ = Steady-State Thermal Resistance $R_{\theta(t_1)}$ = Transient Thermal Impedance at Time t_1 $R_{\theta(t_2 - t_1)}$ = Transient Thermal Impedance at Time $(t_2 - t_1)$, etc.
Continuous Load			$T_j - T_R = P_0 R_\theta$ $P_0 = \frac{T_j - T_R}{R_\theta}$
Single Load Pulse			$T_{t_1} - T_R = P_0 Z_{\theta(t_1)}$ $T_{t_2} - T_R = P_0 [Z_{\theta(t_2)} - Z_{\theta(t_2 - t_1)}]$ $P_0 = \frac{T_{t_1} - T_R}{Z_{\theta(t_1)}}$
Short Train of Load Pulses (Equal Amplitude)			$T_{t_1} - T_R = P_0 Z_{\theta(t_1)}$ $T_{t_3} - T_R = P_0[Z_{\theta(t_3)} - Z_{\theta(t_3 - t_1)} + Z_{\theta(t_3 - t_2)}]$ $T_{t_5} - T_R = P_0[Z_{\theta(t_5)} - Z_{\theta(t_5 - t_1)} + Z_{\theta(t_5 - t_2)}]$, etc.
Train of Unequal Amplitude Load Pulses			$T_{t_1} - T_R = P_0 Z_{\theta(t_1)}$ $T_{t_3} - T_R = P_0 Z_{\theta(t_3)} - P_0 Z_{\theta(t_3 - t_1)} + P_2 Z_{\theta(t_3 - t_2)}$ $T_{t_5} - T_R = P_0 Z_{\theta(t_5)} - P_0 Z_{\theta(t_5 - t_1)} + P_2 Z_{\theta(t_5 - t_2)} - P_2 Z_{\theta(t_5 - t_3)} + P_4 Z_{\theta(t_5 - t_4)}$
Long Train of Equal Amplitude Load Pulses (Approx. Solution)			$T_j - T_R = P_0[\frac{t_p R_\theta}{\tau} + (l - \frac{t_p}{\tau}) Z_{\theta(\tau + t_p)} - Z_{\theta(\tau)} + Z_{\theta(t_p)}]$ $P_0 = \frac{T_j - T_R}{\frac{t_p R_\theta}{\tau} + (1 - \frac{t_p}{\tau}) Z_{\theta(\tau + t_p)} - Z_{\theta(\tau)} + Z_{\theta(t_p)}}$
Overload Following Continuous Duty (Non-Pulsed)			$T_{t_{OL}} - T_R = P_{CD} R_\theta + (P_{OL} - P_{CD}) Z_{\theta(t_{OL})}$ $P_{OL} = \frac{T_{t_{OL}} - T_R - P_{CD} R_\theta}{Z_{\theta(t_{OL})}} + P_{CD}$
Overload Following Continuous Duty (Pulsed) (Approx. Solution)			$T_{t_{OL}} - T_R = P_{CD} R_\theta + P_0 \left\{ [\frac{t_p}{\tau} - \frac{P_{CD}}{P_O}] Z_{\theta(t_{OL})} + (1 - \frac{t_p}{\tau}) Z_{\theta(\tau + t_p)} - Z_{\theta(\tau)} + Z_{\theta(t_p)} \right\}$ $P_0 = \frac{T_{t_{OL}} - T_R + P_{CD}(R_\theta - Z_{\theta(t_{OL})})}{\frac{t_p}{\tau} Z_{\theta(t_{OL})} + (1 - \frac{t_p}{\tau}) Z_{\theta(\tau + t_p)} - Z_{\theta(\tau)} + Z_{\theta(t_p)}}$

Figure 2.9 RC Snubber Circuit and Recommended Snubber Component Values



Recommended Snubber Circuit Values

Module Current Rating (A)	R_S (Ω)	C_S (μF)
25-60	10	0.1
90-130	10	0.2

Figure 2.10 Circuit Configurations and Critical Parameters for Common Phase Control Applications

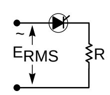
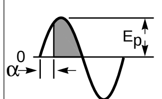
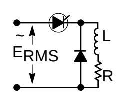
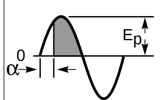
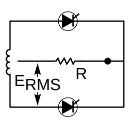
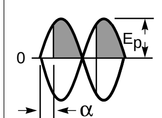
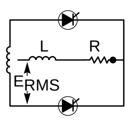
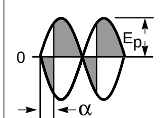
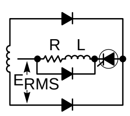
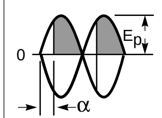
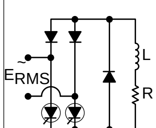
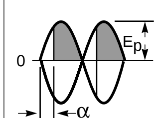
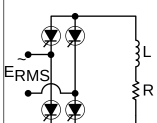
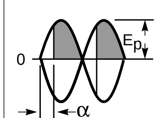
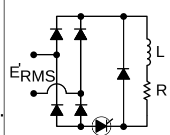
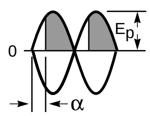
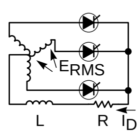
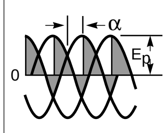
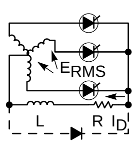
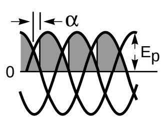
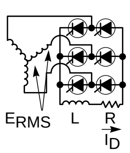
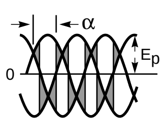
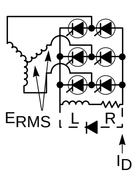
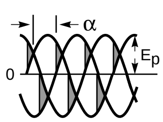
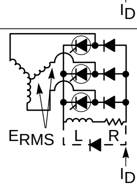
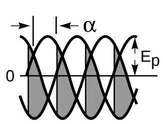
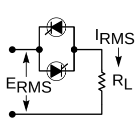
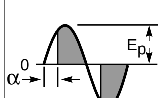
Circuit: Notation	Circuit: Schematic	Waveforms	Max. SCR Voltage	Peak Reverse Voltage: SCR	Peak Reverse Voltage: Diode	Max. Load Voltage E_d = Avg. E_a = RMS	Load Voltage with Delayed Firing	Max. Average SCR Current: Avg. Amps.	Max. Average SCR Current: Cont. Period	Max. Average Diode Current: Avg. Amps.	Max. Average Diode Current: Cont. Period
1-1-1-H			1.4 E_{RMS}	E_p	—	$E_d = \frac{E_p}{\pi}$ $E_a = \frac{E_p}{2}$	$E_d = \frac{E_p}{2\pi}(1 + \cos\alpha)$ $E_a = \frac{E_p}{2\sqrt{\pi}}\sqrt{(\pi - \alpha + 1/2 \sin 2\alpha)}$	$\frac{E_p}{\pi R}$	180°	—	—
1-1-1-H With Free-Wheeling Diode			1.4 E_{RMS}	E_p	E_p	$E_d = \frac{E_p}{\pi}$	$E_d = \frac{E_p}{2\pi}(1 + \cos\alpha)$	Very Ind. Load $\frac{E_p}{2\pi R}$ Conventional $\frac{E_p}{\pi R}$	180°	$0.54\frac{(E_p)}{pR}$	210°
2-1-1-C			2.8 E_{RMS}	2EP	—	$E_d = \frac{2E_p}{\pi}$	$E_d = \frac{E_p}{\pi}(1 + \cos\alpha)$	$\frac{E_p}{\pi R}$	180°	—	—
2-1-1-C			2.8 E_{RMS}	$2E_p$	—	$E_d = \frac{2E_p}{\pi}$	$E_d = \frac{E_p}{\pi}(1 + \cos\alpha)$ (I_{dc} = K)	$\frac{E_p}{\pi R}$	180°	—	—
2-1-1-C With Thyristor in D C Circuit			1.4 E_{RMS}	0	2.8 E_{RMS}	$E_d = \frac{2E_p}{\pi}$	$E_d = \frac{E_p}{\pi}(1 + \cos\alpha)$	$\frac{2E_p}{\pi R}$	360°	$\frac{E_p}{\pi R}$ for 2-1-1-C $\frac{0.5(E_p)}{\pi R}$	180° <180° FWD
Half Control 4-1-1-B and FWD			1.4 E_{RMS}	E_p	E_p	$E_d = \frac{2E_p}{\pi}$	$E_d = \frac{E_p}{\pi}(1 + \cos\alpha)$	$\frac{E_p}{\pi R}$	180°	$\frac{E_p}{\pi R}$ for 4-1-1-B $\frac{0.26(2E_p)}{\pi R}$	180° <180° FWD
Full Control 4-1-1-B			1.4 E_{RMS}	E_p	—	$E_d = \frac{2E_p}{\pi}$	$E_d = \frac{E_p}{\pi}(1 + \cos\alpha)$ (I_{dc} = K)	$\frac{E_p}{\pi R}$	180°	—	—

Figure 2.10 Circuit Configurations and Critical Parameters for Common Phase Control Applications (Continued)

Circuit: Notation	Circuit: Schematic	Waveforms	Max. SCR Voltage	Peak Reverse Voltage: SCR	Peak Reverse Voltage: Diode	Max. Load Voltage E_d = Avg. E_a = RMS	Load Voltage with Delayed Firing	Max. Average SCR Current: Avg. Amps.	Max. Average SCR Current: Cont. Period	Max. Average Diode Current: Avg. Amps.	Max. Average Diode Current: Cont. Period
4-1-1-B With Thyristor and FWD.			1.4 E_{RMS}	E_p	E_p	$E_d = \frac{2E_p}{\pi}$	$E_d = \frac{E_p}{\pi}(1 + \cos\alpha)$	$\frac{2E_p}{\pi R}$	360°	$\frac{E_p}{\pi pR}$ $\frac{.5E_p}{\pi R}$	180° <180°
3-1-1-Y			2.45 E_{RMS}	2.45 E_{RMS}	—	$E_d = \frac{3\sqrt{3E_p}}{2\pi}$	$E_d = \frac{3\sqrt{3E_p}}{2\pi}(\cos\alpha)$ $(I_{dc} = K)$	0.33 I_D	120°	—	—
3-1-1-Y With Free-Wheeling Diode			2.45 E_{RMS}	2.45 E_{RMS}	E_p	$E_d = \frac{3\sqrt{3E_p}}{2\pi}$	$E_d = \frac{3\sqrt{3E_p}}{2\pi}(\cos\alpha)$ $(0<\alpha<30°)$ $E_d = \frac{3E_p}{2\pi}[1 + \cos(\alpha + 30°)]$ $(30°<\alpha<150°)$	0.33 I_D	120°	Size to 0.33 I_D	<120° FWD
6-1-1-B With Full Control			2.45 E_{RMS}	2.45 E_{RMS}	—	$E_d = \frac{3\sqrt{3E_p}}{\pi}$	$E_d = \frac{3\sqrt{3E_p}}{\pi}(\cos\alpha)$	0.33I_D	120°	—	—
6-1-1-B With Full Control and FWD			2.45 E_{RMS}	2.45 E_{RMS}	2.45 E_{RMS}	$E_d = \frac{3\sqrt{3E_p}}{\pi}$	$E_d = \frac{3\sqrt{3E_p}}{\pi}(\cos\alpha)$ $(0<\alpha<60°)$ $E_d = \frac{3\sqrt{3E_p}}{2\pi}$ $(1+\frac{\cos\alpha}{2} - \frac{3}{2}\sin\alpha)$ $(60°<\alpha<120°)$	0.33 I_D	120°	Size to 0.33 I_D	<120° FWD
6-1-1-B Half Control and FWD			2.45 E_{RMS}	2.45 E_{RMS}	2.45 E_{RMS}	$E_d = \frac{3\sqrt{3E_p}}{\pi}$	$E_d = \frac{3\sqrt{3E_p}}{\pi}(1 + \cos\alpha)$	0.33 I_D	120°	0.33 I_D Size to 0.33 I_D	120° <120° FWD
AC Switch			1.4 E_{RMS}	E_p	—	$E_a = \frac{E_p}{1.4}$	$E_a = \frac{E_p}{\sqrt{2\pi}}\sqrt{(\pi - \alpha + 1/2\sin 2\alpha)}$	$\frac{E_p}{\pi R}$	180°	—	—