



## **Application Note**

### **Thyristor Power Electronics Teaching System**

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## I.About the SEMIKRON Thyristor Power Electronics Teaching System

The primary function of the thyristor power electronics teaching system is to give students a clear idea on the working of the basic power electronic circuits with a high safety level.

The main features of the system:

- Achieve all the basic thyristor industrial configurations with simple "banana" connections: single and three phase rectifiers and AC controllers.
- Due to the transparent protective cover, one can see the different components and visualise the different parts of such systems: the power modules, heatsinks, cooling fans, triggering circuits etc.
- An IP2x level of protection to ensure the safety of the personnel operating the system at all times.

## II.Precautions

1. Before switching ON the system, make sure of the following:
  - a. The cooling fan is connected to a 230V supply and is switched ON.
  - b. The system is grounded with through the two grounding terminals on the case to avoid the danger of electrical shocks.
2. The current in the system is limited to 30A due to the the connectors used.
3. When switching the minidip from B6C to W3C position or vice versa make sure that the system is switched OFF and the power supply is disconnected.
4. No fuses or other protection systems have been integrated on the stack. SEMIKRON strongly recommends the usage fast fuses on the input line side to protect the thyristors from damage due to short circuits.
5. The thermal trip included in the system is meant only as an indicator of the maximum heatsink temperature permissible. It can be integrated in a separate circuit designed by the user to give an indication of a temperature overshoot of the heatsink, for e.g. through the use of LEDs as warning indicators. It is **not** to be integrated directly in the power circuit, but intended to be a temperature overshoot indication feature.

### III. The different components of your thyristor teaching system

#### 1. The heatsink and the fan

The axial fan is defined by the curve shown below. It can work on a 50 Hz or a 60Hz power supply, but the performance would vary a bit as shown.

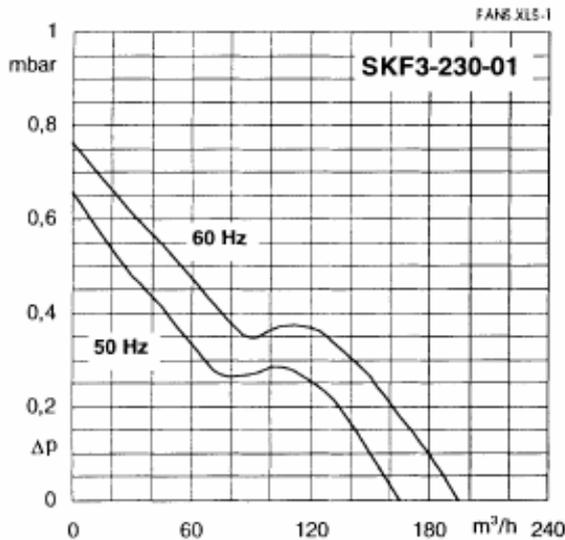


Fig 1: Air pressure drop vs. volume of airflow per hour for Fan SKF3-230-01 at 50 Hz / 60 Hz

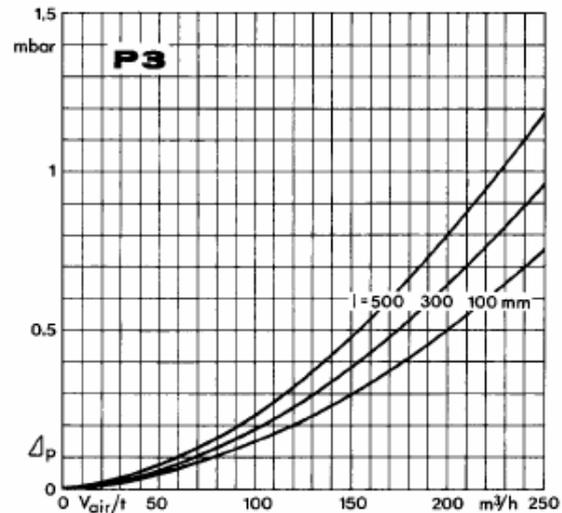
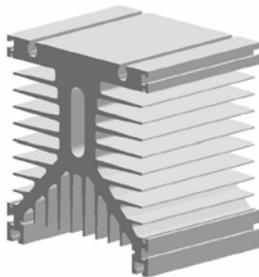
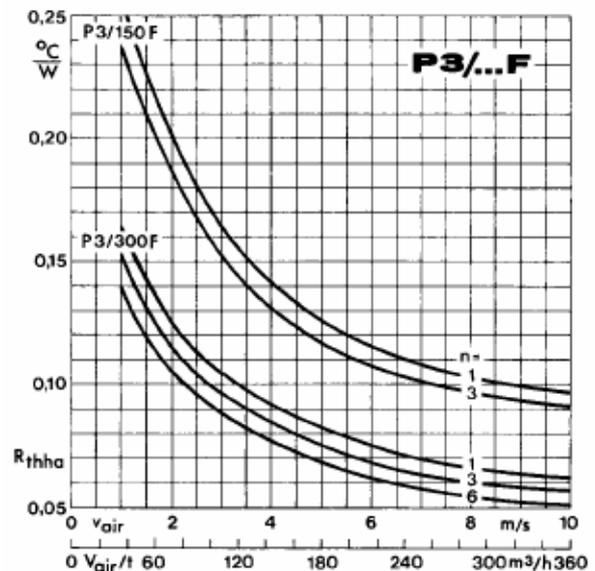


Fig 2: Air pressure drop vs. volume of airflow per hour for different lengths of heatsink P3

The heatsink is a 250mm long P3 profile (P3/250). One can determine the functioning point of the fan by crossing the above two curves (fig 1 + 2). The intersection gives the airflow inside the fins of the heatsink.



The figure alongside gives the thermal resistance vs. the number of modules on the heatsink depending upon the rate of air flow through the fins of the heatsink. One should note that a higher number of modules increases the conduction surface and so makes the heat conduction easier.

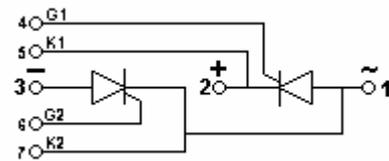


#### 2. The thermal trip

The thermal trip included in the system is of a normally closed (NC) type, meant for integration by the user in a **separate** circuit just for the indication of an overshoot in heatsink temperature for e.g. through the use of LED indicators. It is **not** meant to be integrated into the main power circuit.

### **3.The thyristor power module SKKT 57/12**

The unit consists of 5 thyristor half-bridge modules which can be used to achieve the different circuit configurations (explained later). The thyristors may be appropriately triggered to get the required firing angles.



One module SKKT 57/12

#### **Main parameters of the SKKT 57/12**

##### **Non-repetitive peak reverse voltage $V_{RSM}$**

Maximum allowable peak value of reverse voltage which should not be exceeded by short term transients.

For SKKT 57/12,  
 $V_{RSM} = 1300V$

##### **Repetitive peak off-state and reverse voltages $V_{DRM}$ and $V_{RRM}$**

Maximum allowable peak values of repetitive transient offstate and reverse voltages.

For SKKT 57/12,  
 $V_{DRM}, V_{RRM} = 1200V$

##### **Mean on-state current $I_{TAV}$**

Absolute maximum value of continuous on-state current of the diodes or thyristors for a set of given conditions with no margins allowed for overload.

For SKKT 57/12,  
 $I_{TAV} = 55A @T_c = 85^\circ C ; \sin 180$

##### **RMS on-state current $I_{TRMS}$**

Absolute maximum allowable value of rms current for continuous operation at the required conduction angle, current waveform and cooling conditions. It should never be exceeded in continuous operation even with very good cooling.

For SKKT 57/12,  
 $I_{TRMS} = 95A$

##### **Surge on-state current $I_{TSM}$**

Maximum peak value of a single half sinewave current surge of 10 ms duration.

For SKKT 57/12,  
 $I_{TSM} = 1500A @T_{vj} = 25^\circ C ; I_{TSM} = 1250A @T_{vj} = 125^\circ C$

##### **$i^2t$ value**

The  $i^2t$  value is given to assist in the selection of suitable fuses to protect against damage due to short circuits. The  $i^2t$  value of the fuse over the specified time interval for the input voltage used must be less than the value for the thyristor/diode. As the  $i^2t$  value of the fuse falls more rapidly than that of the thyristor/diode with increasing operating temperature it is usually sufficient to take the  $i^2t$  value of the semiconductor element at  $25^\circ C$  for comparison with that of the (un-loaded) fuse.

For SKKT 57/12,  
 $i^2t = 11000 @T_{vj} = 25^\circ C ; i^2t = 8000 @T_{vj} = 125^\circ C$

##### **Critical rate of rise of on-state current $(di/dt)_{cr}$**

Immediately after the triggering of the thyristor the onstate current flows only in the region of the gate connection, and to avoid excessive dissipation near this gate connection the rate of rise of this current must be limited to below a certain critical value.

For SKKT 57/12,  
 $(di/dt)_{cr} = \max 150 A/\mu s @T_{vj} = 125^\circ C$

##### **Critical rate of rise of off-state voltage $(dv/dt)_{cr}$**

For an exponential increase in off-state voltage higher than a certain critical rate, the thyristor may break over and self trigger.

For SKKT 57/12,  
 $(dv/dt)_{cr} = \max 1000 V/\mu s @T_{vj} = 125^\circ C$

**Holding current  $I_H$** 

The minimum anode current which will still hold the thyristor in its on-state. If the thyristor is switched on from cold at below 25 °C the value of holding current may initially be slightly higher.

For SKKT 57/12,

$$I_{Htyp} = 150 \text{ mA} @ T_{vj} = 25^\circ\text{C}$$

**Latching current  $I_L$** 

The minimum anode current which will hold the thyristor in its on-state immediately after triggering with a 10  $\mu\text{s}$  gate pulse.

For SKKT 57/12,

$$I_{Ltyp} = 300 \text{ mA} @ T_{vj} = 25^\circ\text{C}$$

**Minimum gate trigger voltage  $V_{GT}$  and trigger current  $I_{GT}$** 

These are the lowest values of gate voltage and current with a 100  $\mu\text{s}$  pulse and anode voltage of 6 V which will ensure firing. These figures are increased by a factor of 1,5 to 2 for 10  $\mu\text{s}$  trigger pulses. Triggering circuits should provide pulses which exceed  $I_{GT}$  four to five times.

For SKKT 57/12,

$$V_{GT} = \text{min } 3\text{V} @ T_{vj} = 25^\circ\text{C}$$

$$I_{GT} = \text{min } 150 \text{ mA} @ T_{vj} = 25^\circ\text{C}$$

**Maximum gate non-trigger voltage  $V_{GD}$  and nontrigger current  $I_{GD}$** 

These are the highest values of gate voltage and current which will not cause the thyristor to fire. Interfering signals in the gate circuit must be restricted to amplitudes below these values.

For SKKT 57/12,

$$V_{GD} = \text{max } 0,25\text{V} @ T_{vj} = 125^\circ\text{C}$$

$$I_{GD} = \text{max } 6 \text{ mA} @ T_{vj} = 125^\circ\text{C}$$

**Insulation testing**

The insulation between the live parts and the baseplate of the SKKT module is tested for one second at 3600 V a.c and one minute at 3000 V. During the test all electrical terminals including the gate terminals must be connected with each other in order to avoid damage by inductively or capacitively induced voltage transients. The test voltage is applied between the connected terminals and the baseplate.

#### **4. Diode Module SKKD 46/12 : Main Parameters**

##### **Non-repetitive peak reverse voltage $V_{RSM}$**

Maximum allowable peak value of reverse voltage which should not be exceeded by short term transients.

For SKKD 46/12,  
 $V_{RSM} = 1300V$

##### **Repetitive peak reverse voltage $V_{RRM}$**

Maximum allowable peak value of repetitive reverse voltage.

For SKKD 46/12,  
 $V_{RRM} = 1200V$

##### **Mean on-state current $I_{FAV}$**

Absolute maximum value of continuous on-state current of the diodes or thyristors for a set of given conditions with no margins allowed for overload.

For SKKD 46/12,  
 $I_{FAV} = 47A @T_c = 85^\circ C; \sin 180$

##### **RMS on-state current $I_{FRMS}$**

Absolute maximum allowable value of rms current for continuous operation at the required conduction angle, current waveform and cooling conditions. It should never be exceeded in continuous operation even with very good cooling.

For SKKD 46/12,  
 $I_{FRMS} = 90A$

##### **Surge on-state current $I_{FSM}$**

Maximum peak value of a single half sinewave current surge of 10 ms duration.

For SKKD 46/12,  
 $I_{FSM} = 700A @T_{vj} = 25^\circ C ; I_{FSM} = 600A @T_{vj} = 125^\circ C$

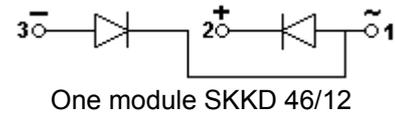
##### **$i^2t$ value**

The  $i^2t$  value is given to assist in the selection of suitable fuses to protect against damage due to short circuits. The  $i^2t$  value of the fuse over the specified time interval for the input voltage used must be less than the value for the thyristor/diode. As the  $i^2t$  value of the fuse falls more rapidly than that of the thyristor/diode with increasing operating temperature it is usually sufficient to take the  $i^2t$  value of the semiconductor element at  $25^\circ C$  for comparison with that of the (un-loaded) fuse.

For SKKD 46/12,  
 $i^2t = 2450 @T_{vj} = 25^\circ C ; i^2t = 1800 @T_{vj} = 125^\circ C$

##### **Insulation testing**

The insulation between the live parts and the baseplate of the SKKT module is tested for one second at 3600 V a.c and one minute at 3000 V. During the test all electrical terminals including the gate terminals must be connected with each other in order to avoid damage by inductively or capacitively induced voltage transients. The test voltage is applied between the connected terminals and the baseplate.



## 5. Single phase thyristor trigger module RT380MU B2C

### Features

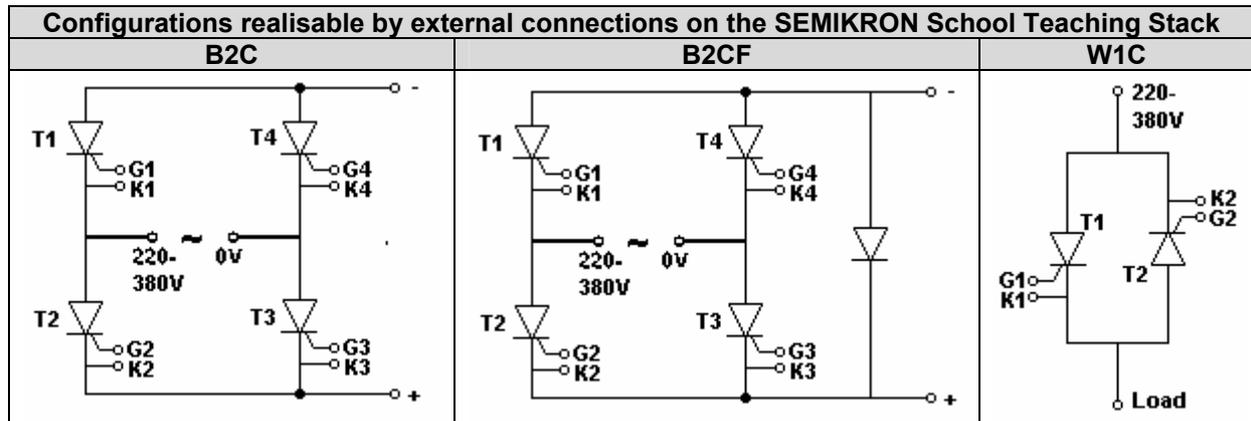
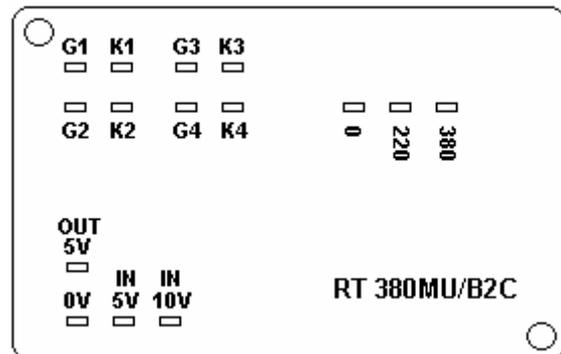
- 220/380 V bi-tension supply (230V supply connected in the school teaching stack)
- Perfect operation with inductive loads
- Control voltage selectable 0-5 V / 0-10 V (0-5 V connected in the school teaching stack)
- Auxilliary 5 V supply for the control voltage
- 4000 V galvanic insulation

The RT380MU B2C is designed to trigger 4 thyristors in B2C configuration and can also be used with only 2 thyristors, with a variable delay over the zero-crossing of the mains alternating voltage. In this way, the power allowed through to the load by the thyristors is regulated.

The triggering unit can be used to realise the following circuit configurations:

- B2C
- B2CF
- W1C
- B2HZ (not realisable with teaching stack external jumper connections)
- B2HKF(not realisable with teaching stack external jumper connections)

The load may be supplied with a variable alternating voltage if both thyristors are connected in anti-parallel, or with a variable voltage if both are connected in a controlled DC rectifier assembly.



### Technical specifications

Parameter	Value
Supply voltage	230/380 V <sub>AC</sub> +10% / -15%
Power drain	3W
Input control voltages	0-5 V IN 0-10V IN
Auxilliary output voltage	+5V OUT
Trigger current	5V 100 mA max 300 mA @ V <sub>GK</sub> = 5V
Isolation	4000Vac inlet/outlet
Working frequency	47 - 53 Hz
Working temperature	0 - 50°C
Terminals	faston 2.8 x 0.8 mm
Mounting holes	M4 screws
Weight	0.5 kg

## 6. Analog three-phase thyristor trigger module RT380T

### Features:

- 230/380 V bi-tension supply (380V supply connected in the school teaching stack)
- Perfect operation with inductive loads upto  $\cos\phi = 0,2$
- Control voltage selectable 0-5 V / 0-10 V (0-5 V connected in the school teaching stack)
- External inhibit input
- 4000V galvanic insulation

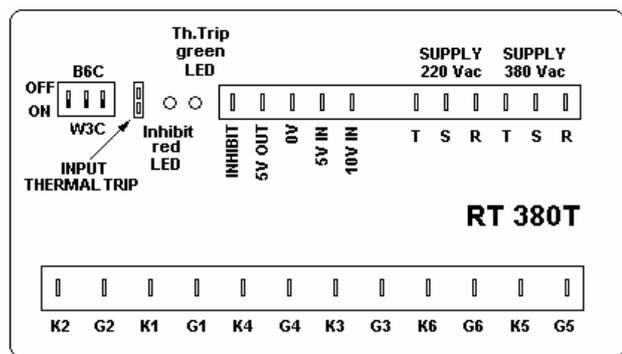
This module has been designed for triggering 6 thyristors with phase regulation in order to control the power on the load. (Use of external snubbers is recommended to protect the thyristors and to facilitate triggering).

The load may be supplied with a variable alternating voltage if the thyristors are connected in antiparallel W3C, or with a variable direct voltage if they are connected in B6C, B6HK or B6HKF.

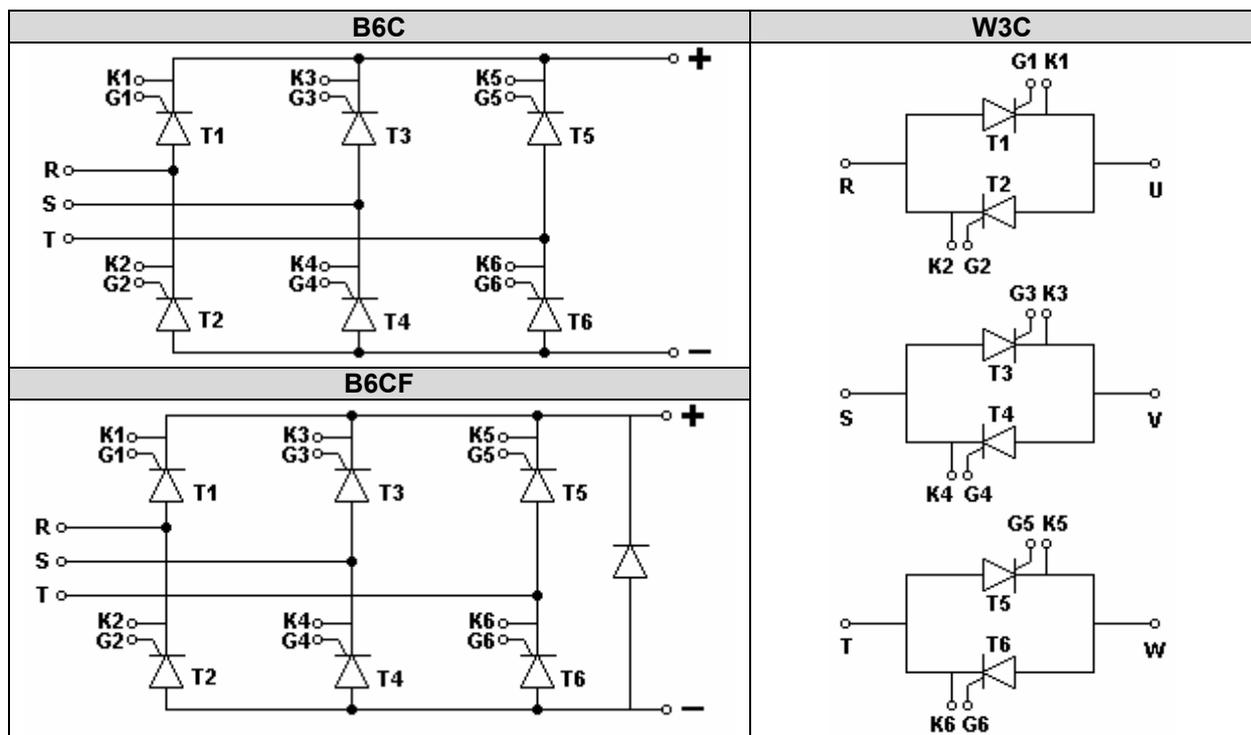
The external thermal trip has to be normally closed. If it opens, the module stops, the green LEDs goes off and the red LED lights.

The module has an automatic power-on delay of approx 1 sec. That means for the first second the output is inhibited (no pulse output).

To select the thyristor configuration W3C, the three minidips have to be in the ON position. For B6C, they have to be in the OFF position. This can be done through the hole provided for this purpose on the top of the stack-cover using a screwdriver .



An input of +12V (7 to 16V) in the input INHIBIT stops the output of the gate pulses and the red LED lights. This +12V can be external or using the internal auxiliary 12Vdc present at the thermal trip jumper. If the jumper of the thermal trip is connected, the module will be inhibited.



## Technical specifications

Parameter	Value
Supply voltage	230/380 V <sub>AC</sub> +10% / -15%
Power drain	8 VA max
Input control voltages	
INHIBIT IN	7-17 V <sub>cc</sub>
0-5 V IN	0-5 V <sub>cc</sub> (15 V <sub>cc</sub> max.)
0-10V IN	0-10 V <sub>cc</sub> (15 V <sub>cc</sub> max.)
Auxilliary output voltage	
+5V OUT	5 V <sub>cc</sub> 100 mA max
Trigger current	600 mA @ V <sub>GT</sub> = 5V
Isolation	4000Vac inlet/outlet
Working frequency	45 - 65 Hz (automatic adaptation)
Working temperature	5 - 50°C
Humidity	10 - 95% without condensation
Power-on	1 second
Weight	1 kg

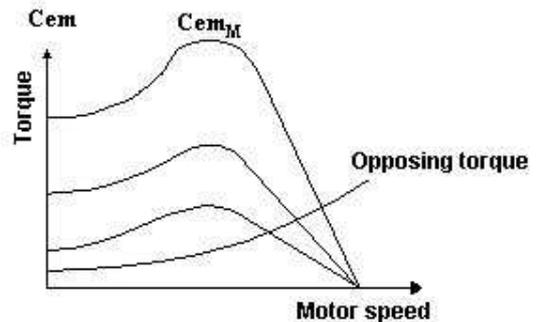
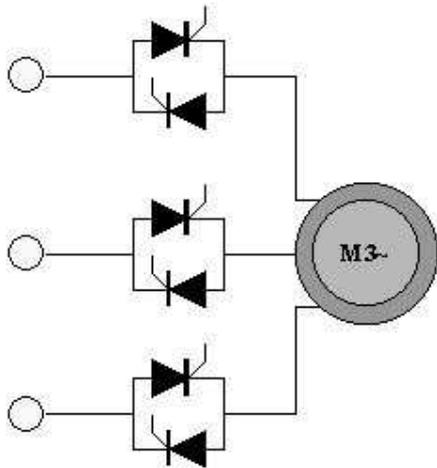
## 7. The rated parameters of the Teaching system

Parameter	Value	
	Single-phase configuration	Three-phase configuration
Supply voltage:	230 Vac	380 Vac
Maximum current (limited by connections/wires):		30 A
Maximum temperature ambient:		50 °C
Frequency of operation:	50 Hz	50 / 60 Hz
Control voltage range:	0 - 5V	0 - 5V
Cooling fan supply voltage:	230 Vac (50 / 60 Hz)	

## IV.Applications

### 1. Three phase AC controller circuit (W3C).

The school teaching stack may be configured to function as a three phase AC controller by connecting the external jumpers as shown on page 16. The three phase AC input is supplied at the input terminals and a three phase AC motor is to be connected to the output terminals for the stack to function as a softstarter. By varying the phase angle of the triggering of the thyristors, the output power of the softstarter is controlled thus controlling the speed of the motor. When the motor is to be initially started, the thyristors are triggered late so that the current at the output is low and as the motor picks up speed, the firing angle is reduced to give more power at the output.



### 2. Simple single AC controller (W1C)

This is in principle similar to the three phase AC controller except for the fact that the single phase section of the school teaching stack is used. Jumper connections are made as shown on page 16 and input given here is a single phase supply with control voltage input at the terminal marked RT380MU.

### 3. A simple three phase bridge rectifier circuit with a resistive load (B6C)

The school teaching system may be used to realise a fully-controllable three phase rectifier circuit. Connections should be made as shown in the Jumper Connections section (page 14). By providing a three phase AC supply to the terminals indicated and a 0-5V control input at the RT 380T control terminal, the rectified output waveform may be viewed across a load resistor connected to the DC output terminals of the stack. By varying the 0-5 volt input, the thyristors can be made to trigger at different phase angles and the corresponding waveforms may be viewed at the output.

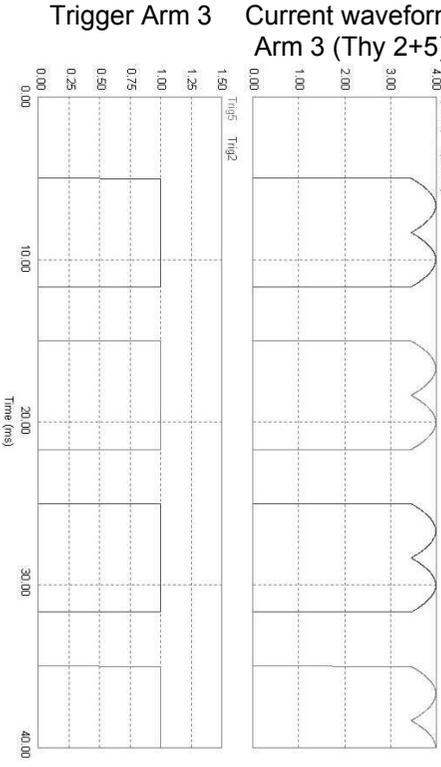
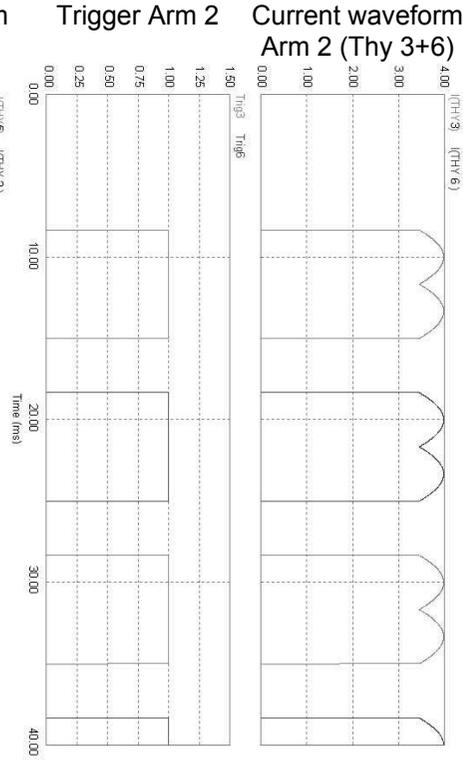
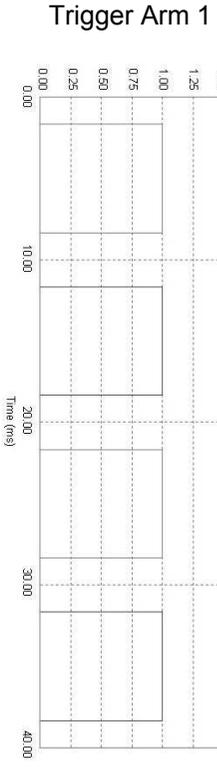
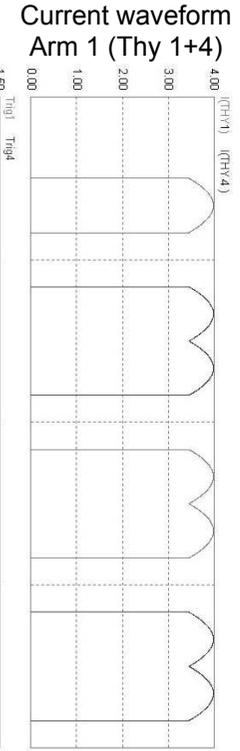
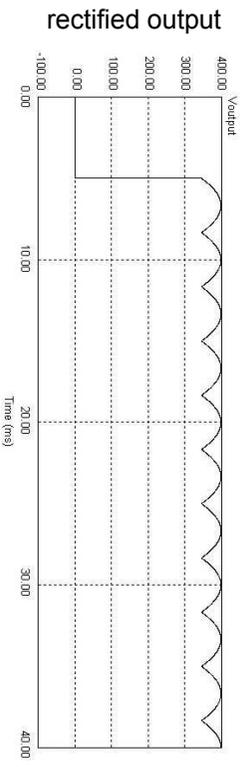
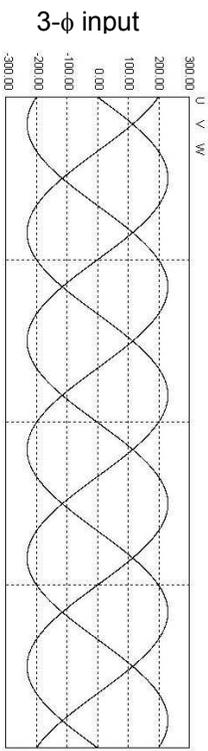
Refer to page 12 and 13 for example waveforms for two cases where the thyristors are triggered at phase angles  $0^\circ$  and  $45^\circ$  respectively.

### 4. Single phase bridge rectifier (B2C)

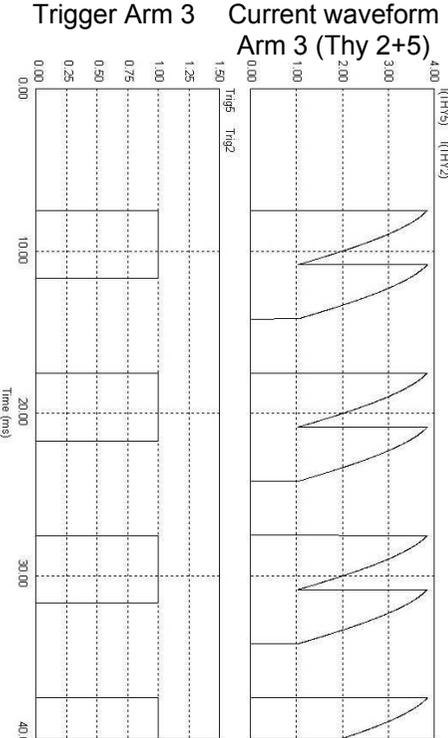
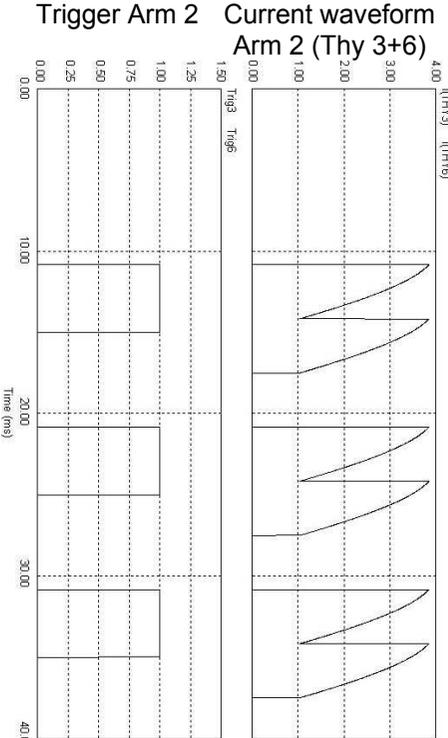
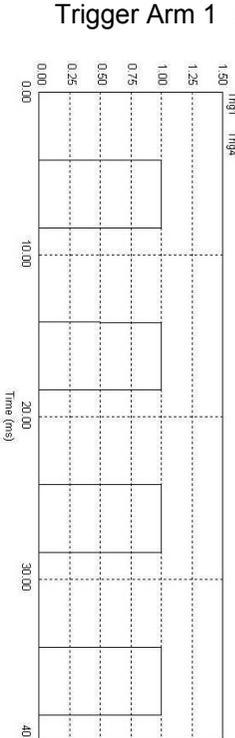
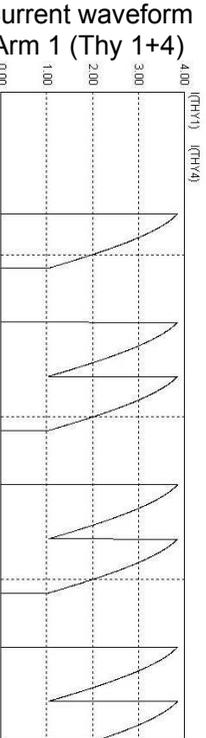
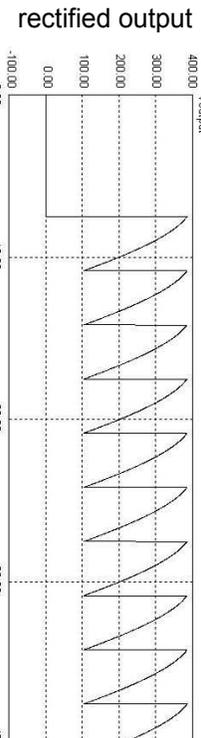
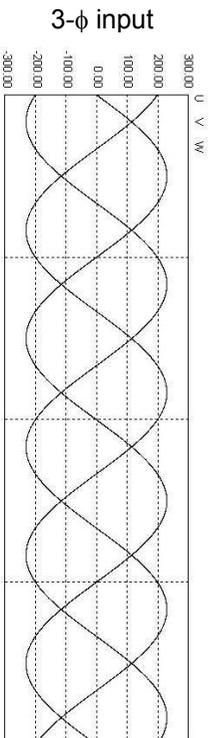
This is in principle similar to the three phase bridge rectifier except here the single phase section of the school teaching stack is used. Jumper connections are made as shown on page 15. A single phase AC supply is given to the input and the 0-5V control is given at the RT380MU input to trigger the thyristors at different phase angles.

**Note:** For all inductive loads, the provided free-wheeling diode may be connected using the jumper connections shown on page 14 and 15 for B6CF and B2CF configurations respectively.

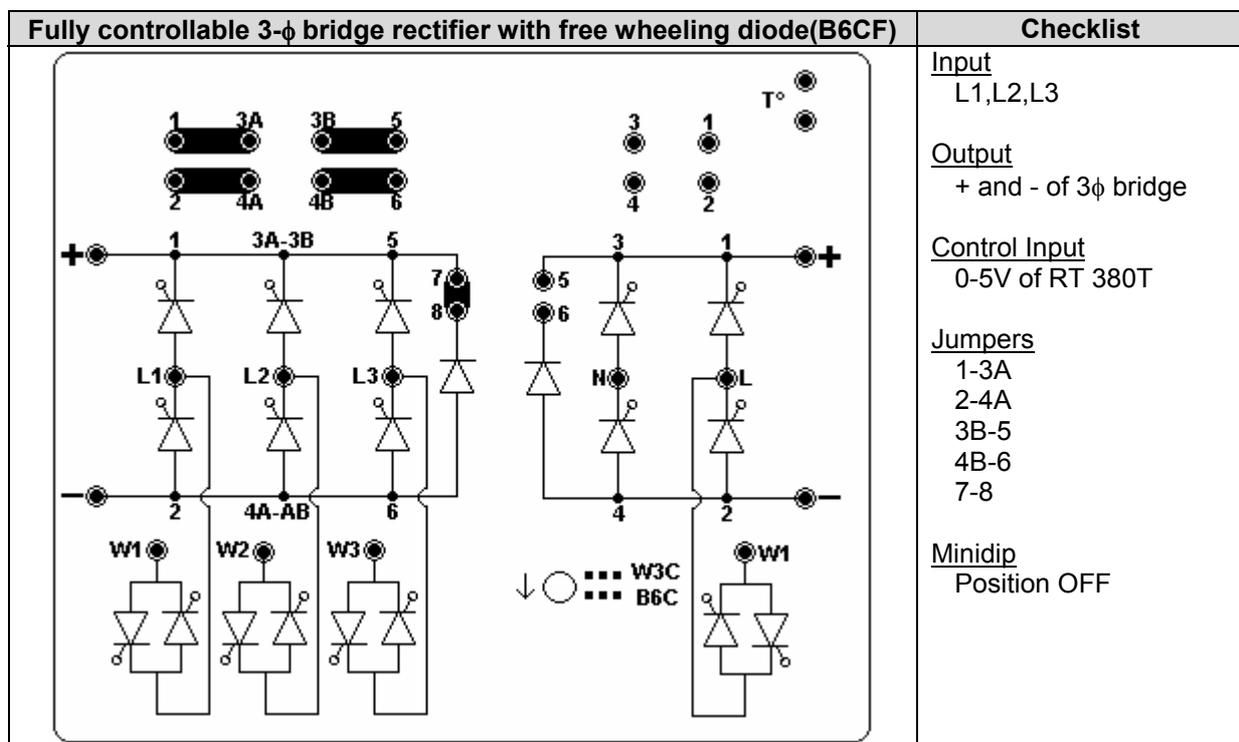
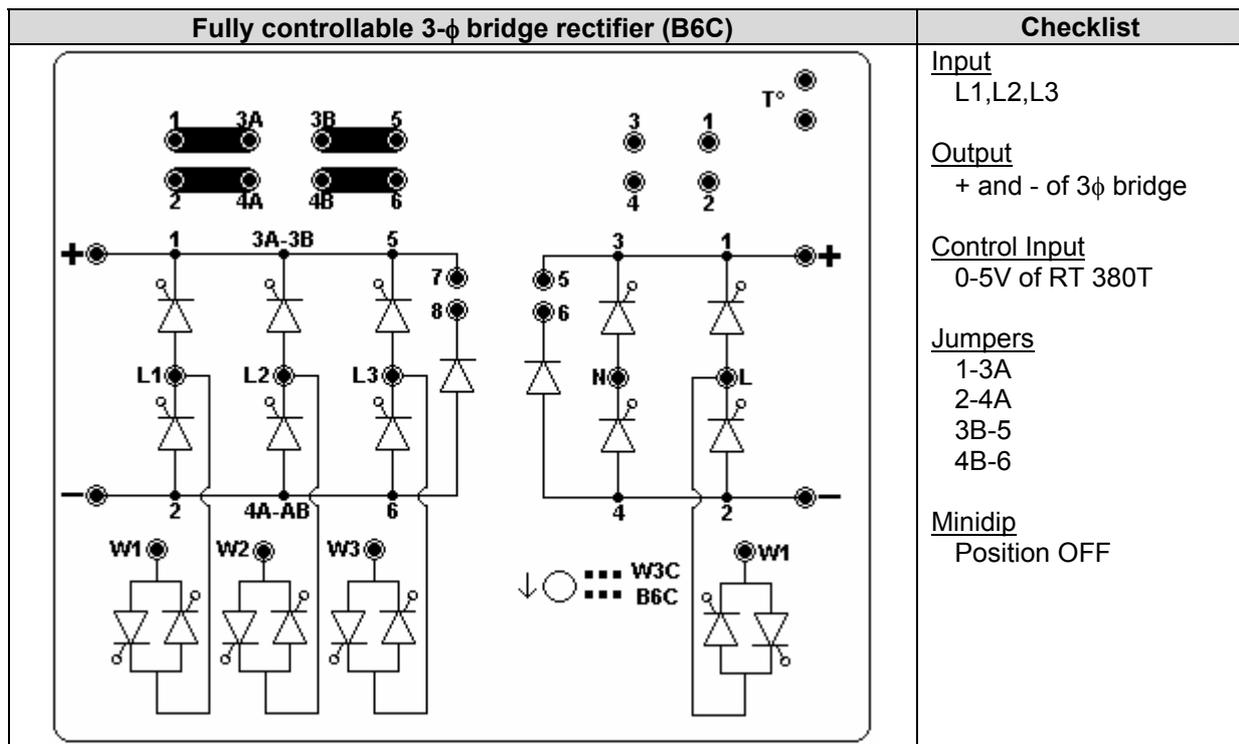
**B6C Configuration with 0° Firing Angle (purely resistive load)**

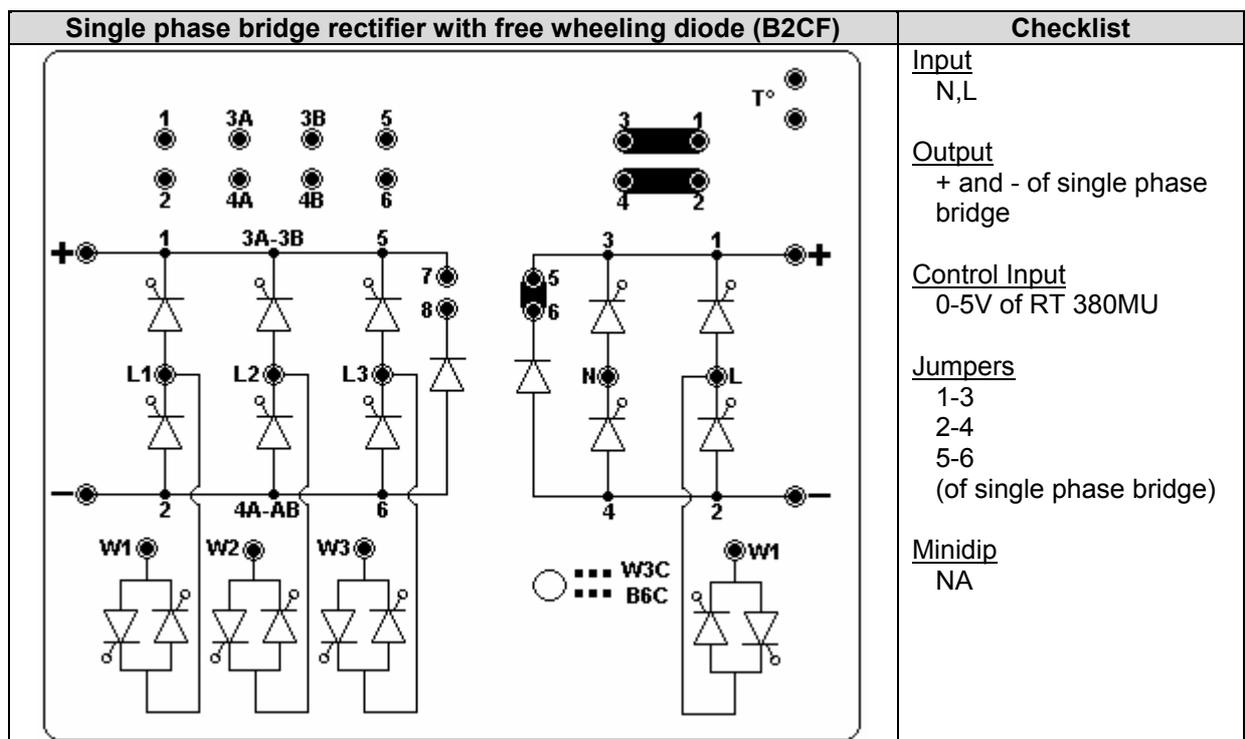
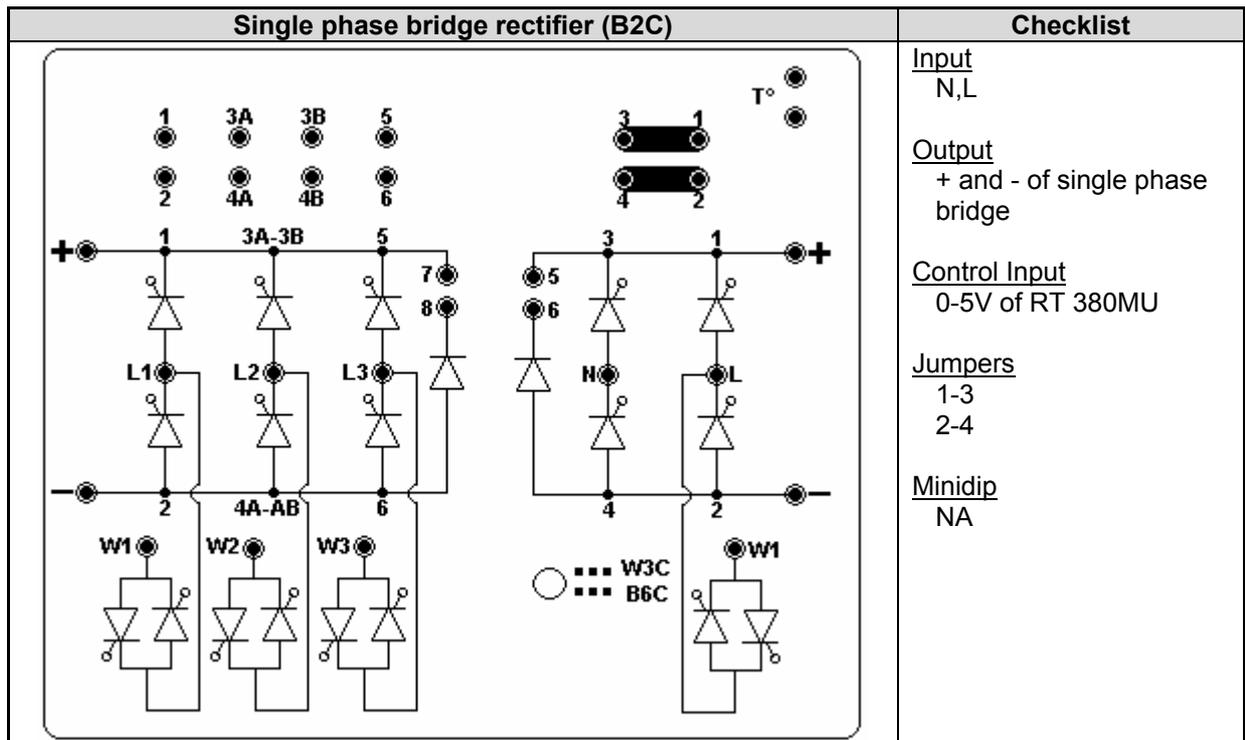


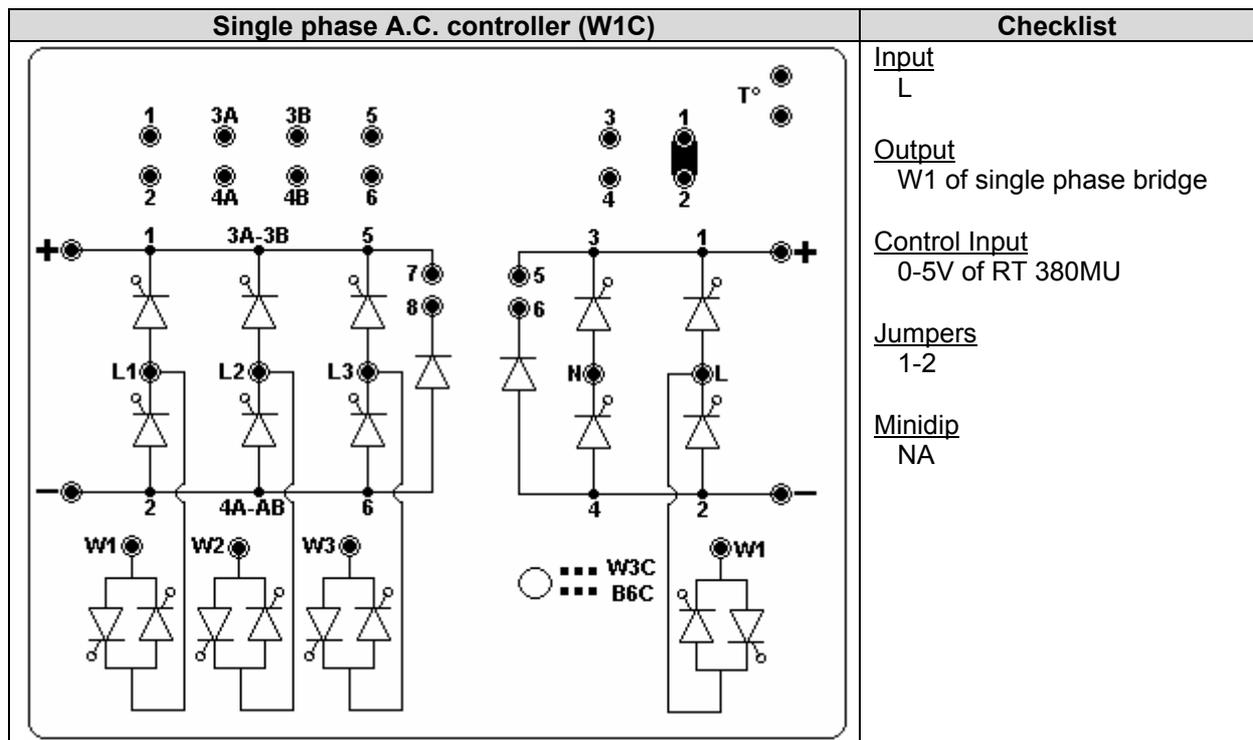
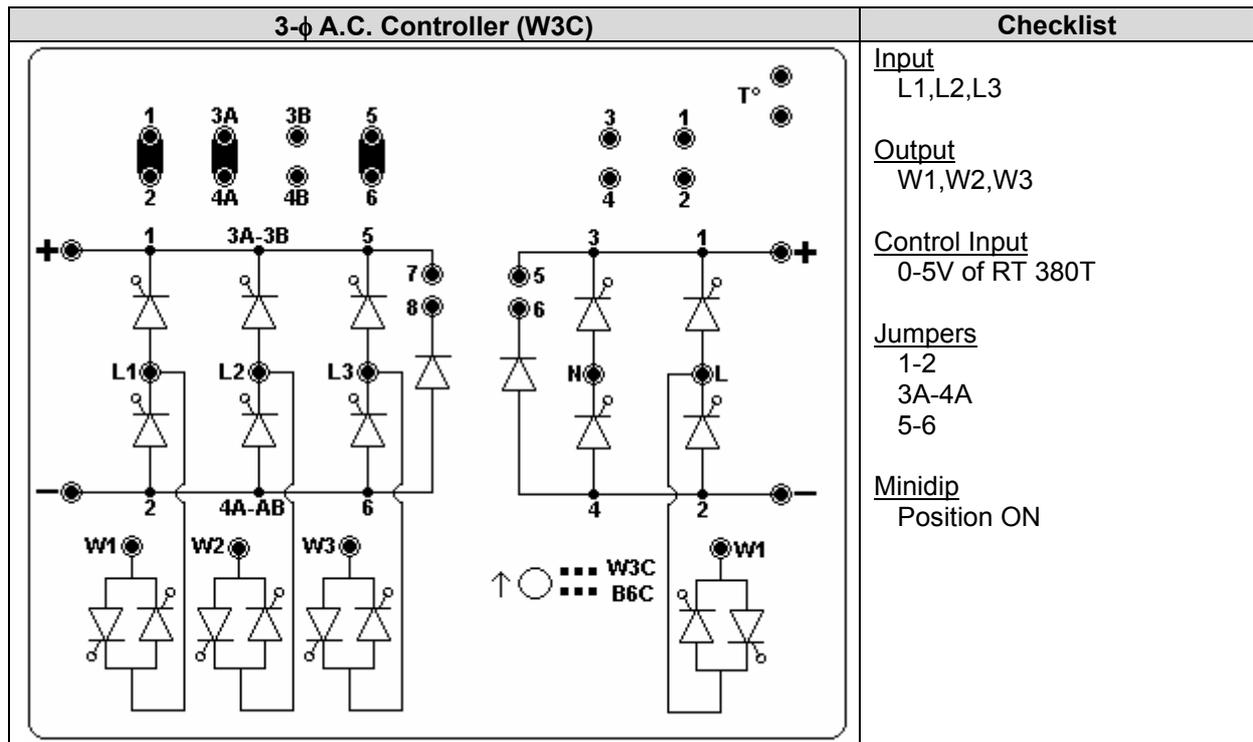
**B6C Configuration with 45° Firing Angle (purely resistive load)**



## V.External Jumper connections







## VI. Thyristor power loss calculations

### 1. On-state power loss $P_T$

This is the power loss resulting from the flow of on-state current; In general the mean value  $P_{TAV}$  is calculated over one cycle of the operating frequency, and it is displayed by a set of curves as a function of the mean on-state current  $I_{TAV}$  for both sinusoidal and rectangular current waveforms at a variety of conduction angles.

The instantaneous power loss  $P_T$  and the mean power loss  $P_{TAV}$  can be calculated from the values of threshold voltage  $V_{T(TO)}$  and slope resistance  $r_T$  by the equations:

$$P_T = V_{T(TO)} \times i_T + r_T \times i_T^2$$

$$P_{TAV} = V_{T(TO)} \times I_{TAV} + r_T \times I_{TRMS}^2$$

$$I_{TRMS}^2 / i_T^2 = 360^\circ / \theta \text{ for rectangular pulses}$$

$$I_{TRMS}^2 / i_{TAV}^2 \approx 2,5 \times 180^\circ / \theta \text{ for part half sinewaves}$$

where  $\theta$  is the conduction angle

$i_T$  is the instantaneous value of on-state current

$I_{TAV}$  is the mean value of on-state current

$I_{TRMS}$  is the r.m.s. value of on-state current

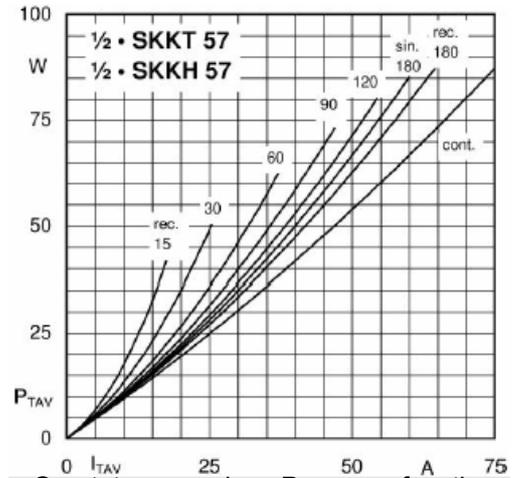


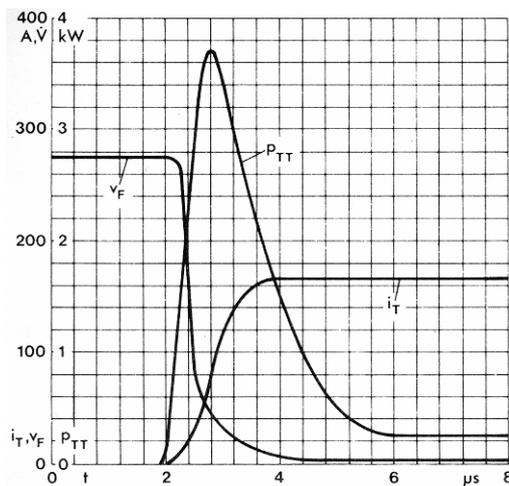
Fig: On-state power loss  $P_{TAV}$  as a function of the mean on-state current  $I_{TAV}$  for smoothed d.c. (cont.),  $180^\circ$  half sinewaves (sin.180) and for rectangular pulses  $15^\circ$  to  $180^\circ$  (rec.15 to 180)

Exact values for part half sinewaves

$\theta$	$180^\circ$	$120^\circ$	$90^\circ$	$60^\circ$	$30^\circ$	$15^\circ$
$\frac{I_{TRMS}^2}{I_{TAV}^2}$	2,47	3,5	4,93	7,7	15,9	31,8

### 2. Turn-on power loss $P_{TT}$

This is the power loss dissipated as heat when the thyristor switched from its off-state to its on-state. At operating frequencies below 500 Hz  $P_{TT}$  is usually neglected. Above this frequency, it plays an important part and account must be taken of it in the calculation of the total power loss.

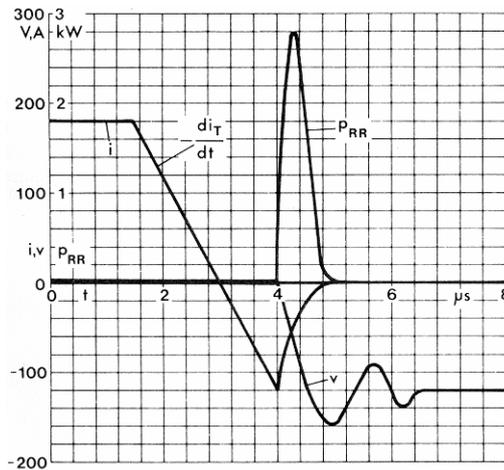


Example waveforms of on-state current  $i_T$ , on-state voltage  $v_T$ , and turn-on power loss  $P_{TT}$  as a thyristor is switched on with a very steeply increasing current

### 3. Turn-off power loss $P_{RR}$

The power loss dissipated as heat which occurs as the thyristor switches from its on-state to a specified reverse condition. At operating frequencies below 500 Hz  $P_{RR}$  is usually neglected. Above this frequency there are two possibilities:

1. Connection of a rectifier diode antiparallel to the thyristor so that the reverse voltage is limited only to a few volts and  $P_{RR}$  can be neglected
2.  $P_{RR}$  must be taken into account when calculating total power loss.



Example waveforms of principal current  $i$ , principal voltage  $v$ , and turn-off power loss  $P_{RR}$  as a thyristor is switched off with a very steeply decreasing current

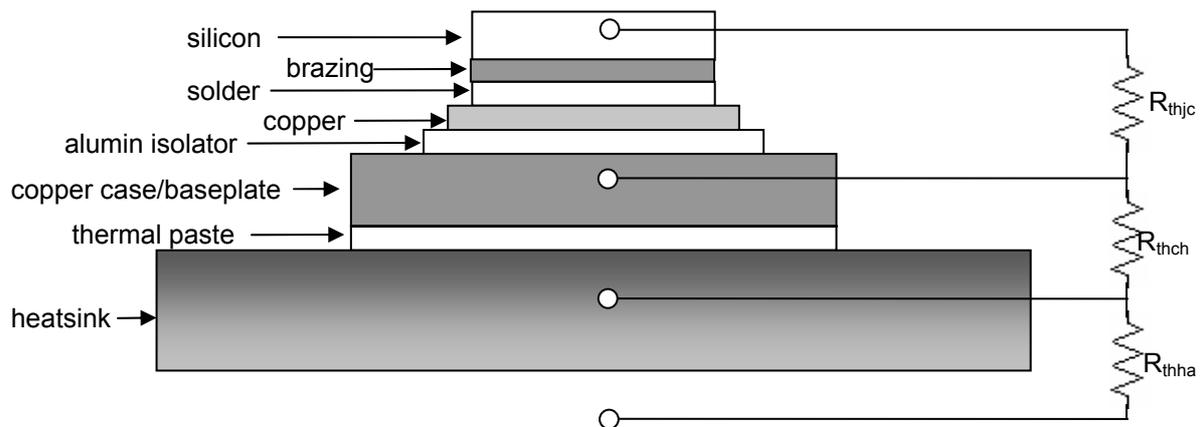
## VII. From thyristor power losses to temperatures

The losses seen in the previous section have to be dissipated for the component to be kept at a reasonable temperature. That is why a heatsink is required in the system. The thermal resistance of a material is the resistance of the material to conduct heat through it.

Thermal / Electric analogies

- Temperature ( $^{\circ}\text{C}$ )  $\leftrightarrow$  voltage (V)
- Power loss (W)  $\leftrightarrow$  current (A)
- Thermal resistance ( $^{\circ}\text{C}/\text{W}$  or  $\text{K}/\text{W}$ )  $\leftrightarrow$  resistance ( $\Omega$ )

### 1. The thermal levels



Thermal levels and interfaces in a typical power electronic system

All the materials shown above have their own intrinsic thermal resistance and all interfaces between them also add additional thermal resistances. To improve the heat transfer from the silicon junction to the heatsink, the total value of the thermal resistance should be as low as possible.

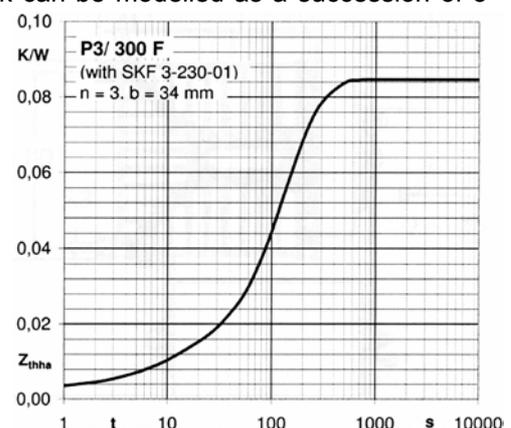
- From the point of view of thermal efficiency the case should be as thin as possible. SKiiP, MiniSKiiP, SKiM and SEMiX products made by SEMIKRON have solved this problem by doing away with the copper case and mounting the ceramic directly onto the heatsink.
- A thermal grease between the module and the heatsink improves the exchange of heat by filling the irregularities between the two contact surfaces.
- Optimization of the heatsink: A large exchange surface will improve the exchange coefficient with air, a bigger mass allows to have greater capacitances for stocking heat and a bigger gradient of temperature.

### 2. Modelling - thermal electrical equivalence

As shown in the above figure, the component on its heatsink can be modelled as a succession of 3 thermal resistances as indicated:

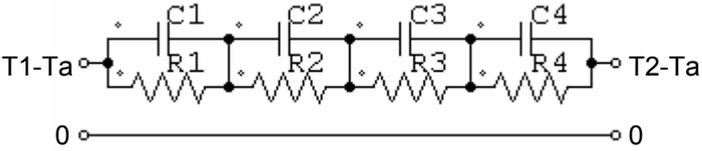
- $R_{thjc}$ : Junction to case thermal resistance
- $R_{thch}$ : Case to heatsink thermal resistance
- $R_{thha}$ : Heatsink to ambient thermal resistance

However, this model is only an approximation for the steady state. If we take a look at graph alongside we see that the thermal resistance is time dependant.



When there is a sudden increase in temperature of the semiconductor (due to an increase in current etc), initially all the extra energy is used to heat up the material immediately adjoining the junction. a short time later an increasing proportion of this extra energy starts to heat up the adjacent metal contact layers as well. Next the increased heat flow passes via the electrically insulated layer, the semiconductor housing/base and at last reaches the heatsink which transfers the extra heatflow to the cooling medium. Only when a new steady state condition has been reached will all the extra heat pass into the surrounding medium.

The different layers of material which must be transversed before the step increase in heat flow reaches the cooling medium can be compared to a chain of resistors and capacitors which are subjected to a step increase in current. Thus an equivalent circuit can be constructed using thermal resistance and capacitance values, which describes the performance of the semiconductor and its heatsink. In producing the equivalent circuit, it is assumed that the heat flows only in one direction (or symmetrically in both directions). Thus we can model each transient impedance as a network of RC, such as the one shown above.



In the case of semiconductors, for long time periods, these impedances are not taken into account but only the resistances. However for heatsinks, this approach of calculating impedances is more useful since the time constants are of a larger magnitude for a large mass of aluminium.

For heatsink P3 used in the thyristor school teaching stack (with 3 nos. SEMIPACK modules, ie.n = 3),

$t_i$	0,5	70	180	2000
$R_i$	$3,44 \times 10^{-3}$	$1,6 \times 10^{-2}$	$7,08 \times 10^{-2}$	$5,95 \times 10^{-3}$

At any time, the thermal impedance is equal to  $Z_{th}(t) = \sum R_i (1 - e^{-t/t_i})$

**VIII.Going deeper**

Before any modification of the converter is attempted, one should be aware that SEMIKRON is not in any way responsible for what may result from any change in the electrical or mechanical part of the stack.

However if you are interested in having a closer look at the different parts or experimenting with the different configurations possible using the triggering modules, please make sure all power connections are disconnected before opening the box.

In any case, for any modification, we recommend extreme caution to prevent electrical shocks to personnel or damage to the stack. For application engineering assistance, please contact SEMIKRON.