

The selection of thyristors for connection in parallel in high power circuits follows many of the same rules as used for rectifier diodes. The basic problem is to ensure that the devices share the load current as evenly as possible. The sharing calculations have to take account of the need to operate over a range of currents and device heatsink temperatures and with devices with different on-state characteristics. In the discussion below it is assumed that the diodes and thyristors are used in a mains rectification role, typically at 50 or 60Hz.

For thyristors, this brings the additional problem of needing to trigger into conduction every mains cycle. Variations in turn-on times can cause late firing of some of the paralleled group, effectively reducing the average current in those thyristors. Another problem arises when one thyristor turns on much faster than the rest, hogging all the current and thus preventing the turn-on of the remainder.

The well known solution to paralleling problems both at turn-on and in the fully-on state is to use reactors in series with each

device. Unfortunately, reactors are bulky and often expensive so designers usually prefer 'hard paralleling' i.e. direct connection to the common busbars without reactors. However, even short busbars have some inductance and this has to be taken into account.

## BASIC REQUIREMENTS FOR PARALLELING

The basic rules for paralleling rectifier diodes and thyristors in the continuous current operating mode are given in standard power electronics textbooks and elsewhere. Because devices must always be initially selected for continuous operation the essential rules are re-stated here.

### Stage 1 - On-state voltage banding

Fig 1 shows the idealised on-state characteristics at room temperature of 2 rectifier diodes connected in parallel. Assuming zero impedance in the interconnection the voltage across each device will be the same. At  $V_2$  the current in device (1) is  $I_1$  and in (2) is  $I_2$ . The total load current  $I_{load}$  is  $(I_1 + I_2)$ . Clearly, this current mis-sharing could overload one device and underload the other. The ideal solution is to have devices with identical characteristics but production tolerances do not allow this. However, special selections can match device  $V_f$  values into defined bands. A band width at normal operating current of 200mV is typical but a width as low as 50mV is possible if lower yield and higher cost is acceptable.

Note that matching is usually done at room temperature, approximately 20 to 25°C.

### Stage 2 - Heatsinking

The shape of the  $V_f$  characteristic varies with junction temperature so that the close  $V_f$  banding described above has no value if operating junction temperatures are not near-equalised. The major determinant here is the heatsink performance. Every effort should be made to ensure that the heatsink temperature is the same for each device. If possible, mount all the devices on the same heatsink close to each other. Mounting more than 2 devices in a vertical column of air-natural cooled fins can sometimes cause problems.

Fig 2 shows the  $V_f$  curves for a particular device at two junction temperatures. Notice that at low currents, below the 'crossover' point,  $V_f$  decreases with increase in temperature and above the

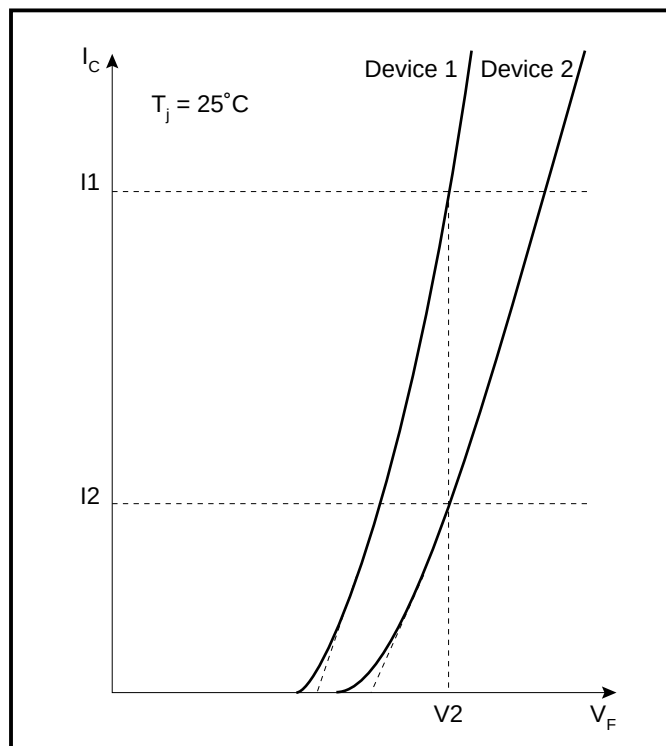


**Fig. 1 Idealised on-state characteristics at room temperature of two rectifier diodes in parallel**

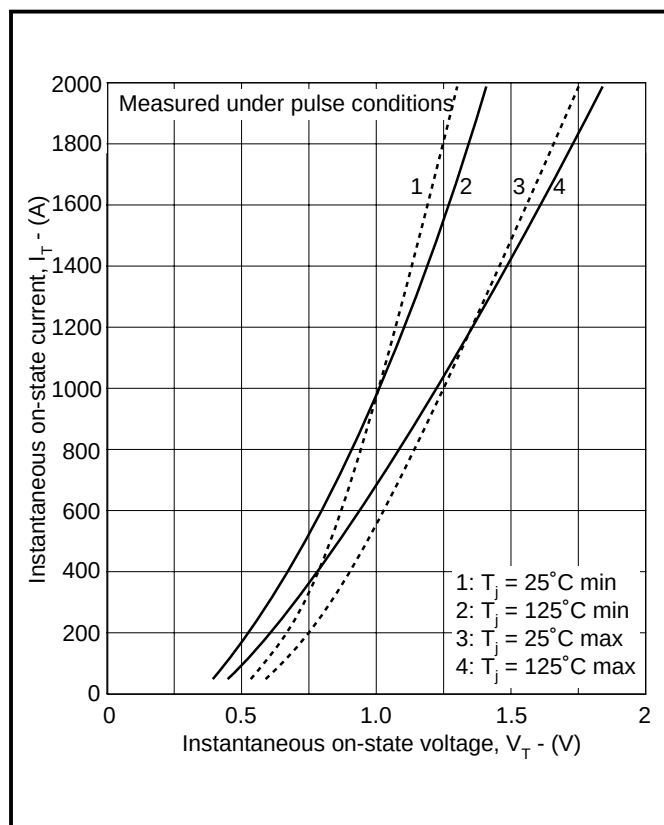


Fig. 2 Thyristor limit on-state characteristics

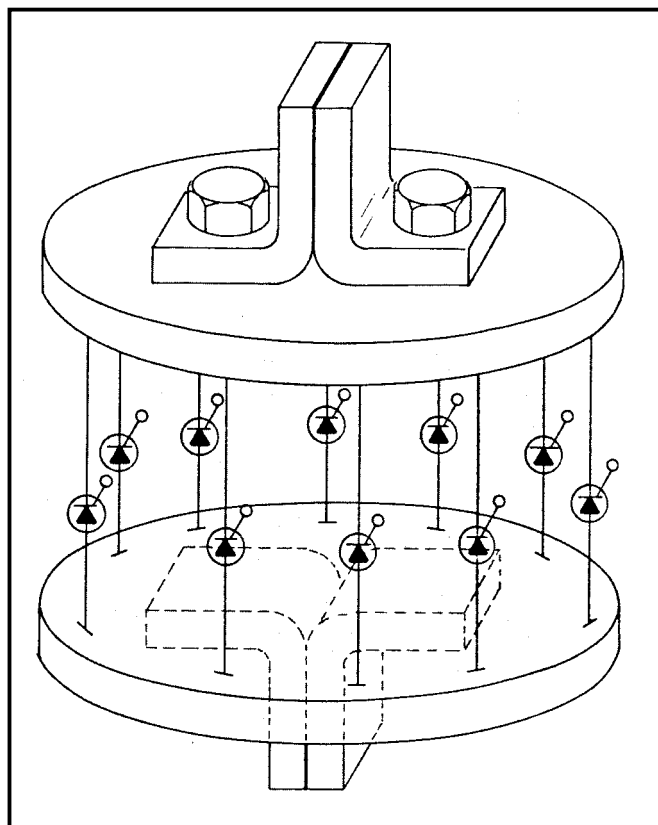


Fig. 3 Thyristor cylindrical arrangement

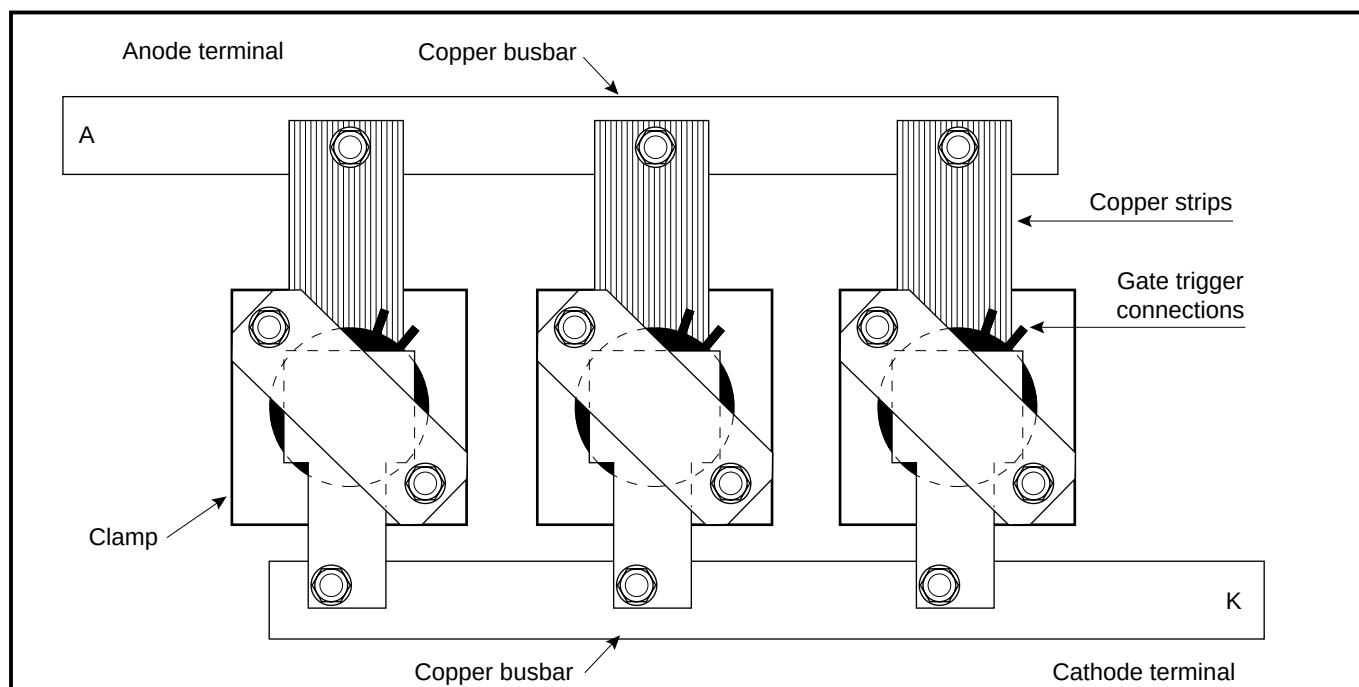


Fig. 4 Typical busbar arrangement - 3 clamped thyristors in parallel (heatsink not shown)

crossover point the reverse is true. The maximum and minimum of the production spread are shown.

Thus, at low currents without good control, the hotter devices will tend to become even hotter. Fortunately, at high currents the opposite is true and a self sharing effect takes over.

### Stage 3 - Busbar connections

The least considered part of the paralleling exercise is usually the interconnections. Unless the conductors linking each device to the common power connections are of equal lengths the devices will not share. All this in spite of the careful parallel banding in stage 1, above. Fig 3 shows diagrammatically a cylindrical arrangement with equal length connections and, clearly, this is not easy to achieve for high current devices. More typical is the non-symmetrical arrangement of Fig 4. If tightly banded devices are used in such an arrangement poor current sharing is the most likely result! Some positions in the connection will be seen to be current 'hoggers' and others current 'shunners'.

When more than 2 devices are paralleled, experience has shown that it is better to have devices spread across a fairly wide  $V_f$  band. 200mV is about right. The user then fits high  $V_f$  devices into current 'hogger' positions and low  $V_f$  ones into current 'shunner' positions. This approach usually gives a satisfactory result.

### THYRISTORS - CURRENT SHARING AT TURN-ON

All the procedures described above are also essential for good sharing of thyristors at turn-on. The additional requirement is for thyristors to turn on as near together in time as possible, otherwise the average current in a late turning on thyristor is less than in the other (normal speed) devices. Note that turn-on problems only occur in a minimum of situations and only for some device types.

#### Unequal conduction due to delay time variations and gate drive performance:

Even if all the thyristor gates are triggered at the same time, variations in **delay time** will lead to variations in turn-on time. Experience has shown that, provided high gate currents are used, delay time differences are small for a particular thyristor type. Selection on delay time is only necessary for sensitive applications.

At low gate drives the devices turn on adequately but there are significant variations in the delay times. As gate currents are increased the delay time variations become smaller until an optimum gate current is reached where there are no further reductions. Similar comments apply regarding gate current rise time where further reductions in rise time have no effect.

Happily, a high current, fast rising gate pulse also gives a good thyristor  $di/dt$  rating.

**Gate pulse length** has some effect on sharing performance but only when the thyristor load current source is low voltage. This is particularly true for amplifying gate devices. For example, a thyristor switching a 50Hz, 10V rms ac current source is unlikely to switch on until about 700us from voltage zero.

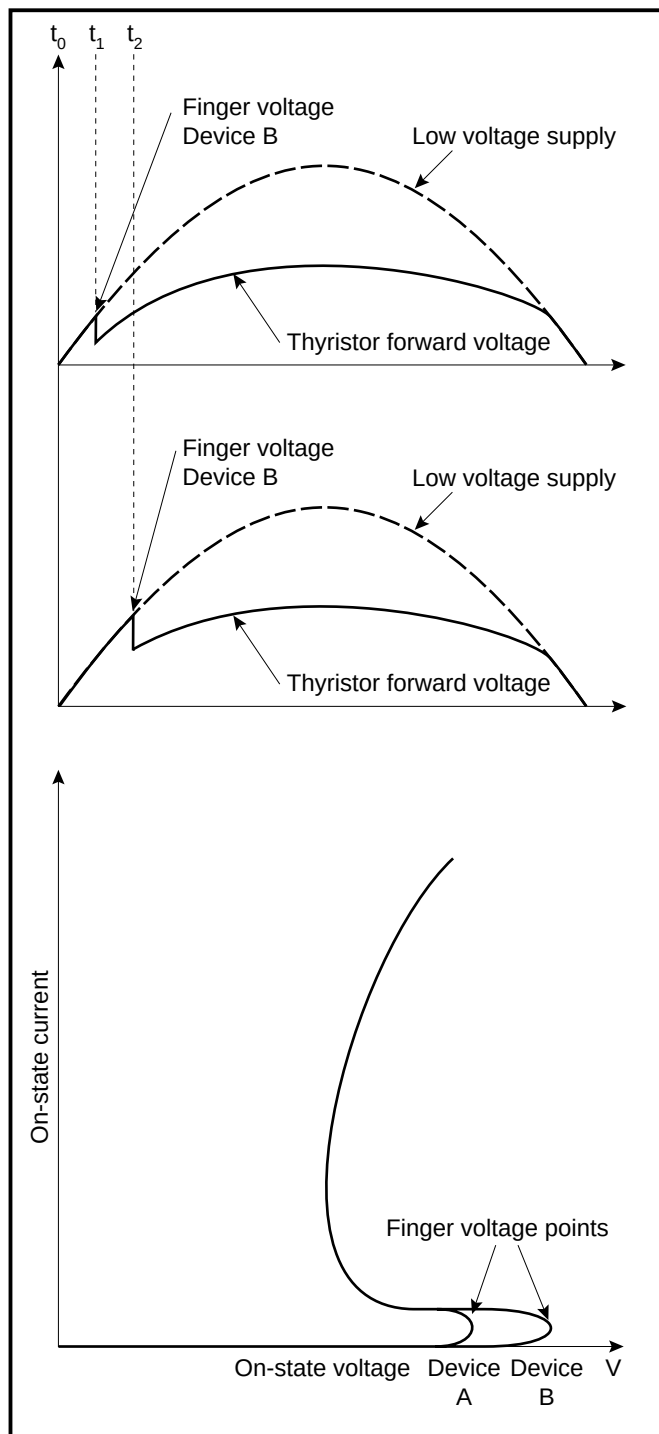


**Fig. 5 Finger voltages**

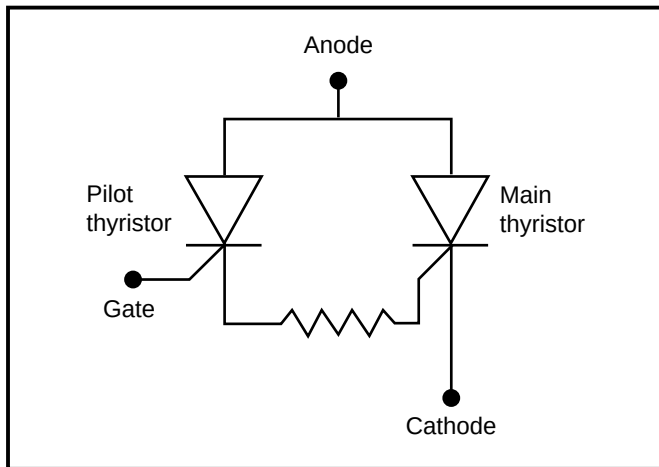


Fig. 6

This corresponds to about 3V anode to cathode which is the minimum needed for turn on of a large thyristor. Clearly, a gate pulse width of 10 to 15µs is OK for a switched load of several hundred volts but a 1ms pulse is needed for a 10V source.

#### Unequal conduction due to transient on-state voltage variations:

As indicated above, thyristors need a minimum anode to cathode voltage to turn on. This is indicated by the well known thyristor switching characteristic, Fig 5. The minimum value is sometimes known as the 'finger voltage'

It is clear that a group of thyristors connected in parallel with different finger voltages and different delay times could present a problem for turning on.

The problem is sometimes worse when amplifying gate devices are used. The amplifying gate thyristor is effectively a main thyristor, darlington driven by a pilot thyristor connected between anode and gate, Fig 6.

When an amplifying gate thyristor is triggered current initially flows in the pilot thyristor until enough current is flowing to trigger the main device. Then the circuit current transfers to the main thyristor. Usually, the initial voltage across the pilot thyristor must reach a minimum level to initiate transfer. This minimum level appears as a 'spike' on the  $V_f$  waveform. Fig 7 is an example of a high spike voltage. 'Spike' voltage values can vary across a batch of devices.

In a paralleled system, if one of the thyristors has a high spike voltage it may be late to turn on and so conduct for only part of the half sine wave period. The consequence is a low average current. In the worse case the device may fail altogether to turn on.

The other extreme condition is where one thyristor in the paralleled batch has an exceptionally low spike voltage. This device turns on early and can hog all the current.

Generally, the lower the supply voltage the worse are the paralleling problems.

In practice, a small increase in busbar inductance in series with each thyristor can usually overcome the turn-on problem.

#### DEVICE SELECTION

How can devices be selected to overcome paralleling problems? The easy solution is to include large series reactors so that mis-sharing is negligible, even with unselected devices.

If this is not possible the following procedures should be adopted:

- Maximum effort should be made to equalise busbar lengths. This will help both steady state and turn-on sharing.
- Ensure that as near as possible the device case temperatures are equalised.
- Ensure that a high gate drive current is used (similar to that recommended for good  $di/dt$  rating).
- Finally, determine the equipment operating current at which current sharing is most important. Usually, this is the full load operating current but sometimes overload current is more important.

At this stage a preliminary choice of thyristor should be made for continuous operation, assuming a mis-sharing of current between devices of, say, 15%:

Define mis-sharing factor, 'm' as:

$$m = \frac{(I_{max} - I_{min})}{I_{max}} \times 100\%$$

Where  $I_{max}$  is the current flowing in the highest current device and  $I_{min}$  is the current flowing in the lowest current device.

- From the thyristor supplier determine the available  $V_f$  selections for paralleling at the  $T_j$  and current you require. Calculation procedures can then be used which input device maximum and minimum  $V_f$  curves and the device busbar connection inductance to determine steady state mis-sharing factor.
- Finally consider turn-on mis-sharing due to turn-on spike voltage variations. This is unusual unless very short busbar lengths are used. Also, the problem only affects a few device types but if a problem is likely it should be mentioned to the supplier in case a selection is needed.

## CONCLUSION

The possibility of turn-on mis-sharing of large thyristors in parallel is sometimes forgotten. However, if a problem exists it

can usually be overcome by using slightly longer than normal busbars. As a final resort a supplier can select to eliminate extreme values of spike voltage. Use of high output gate drive is also important.

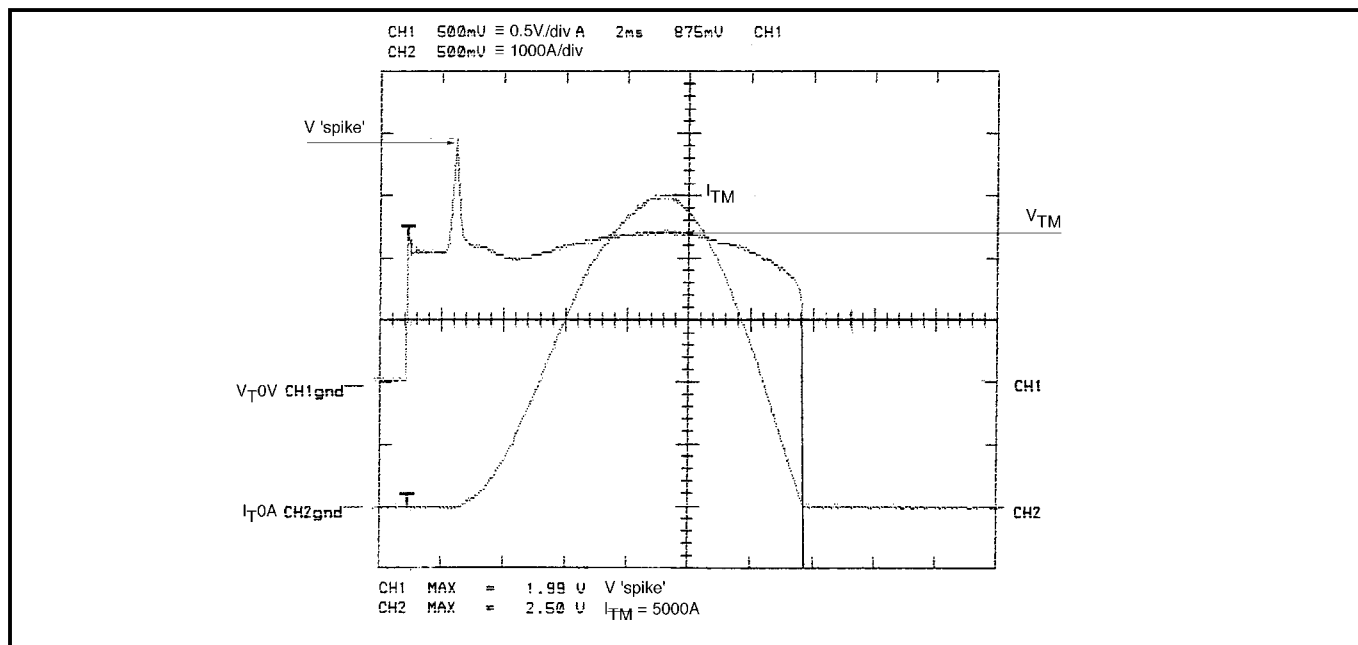


**Fig. 7 Example of high spike voltage**

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Using the latest CAD methods our team of design and applications engineers aim to provide the Power Assembly Complete Solution (PACs).

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