

THE BIDIRECTIONAL CONTROL THYRISTOR (BCT)

by

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ABSTRACT

The Bidirectional Control Thyristor (BCT) is a new concept for high power thyristors integrated on a single silicon wafer with separate gate contacts. This unique design, based on free-floating silicon technology, successfully overcomes the traditional problems of interference experienced by bidirectional thyristors during dynamic operation which previously prevented the use of such devices. Such components are suitable for applications at high voltages like a normal thyristor but where triacs can no longer be used.

This new product continues the trend of power integration. A reduced component count results in lower cost and increased reliability. The following contribution refers to a family of 96 mm diameter wafer devices in 35 mm high housings rated between 2.8 and 6.5 kV. The BCT allows system cost reductions of up to 30% to be reached in such installations as SVCs, cyclo-converters, transformer tap changers, soft starters and 4Q-DC drives.

1. INTRODUCTION

Several important applications in Power Electronics involve the use of thyristor components in antiparallel. These include Static VAR Compensators, industrial motor drives, soft starters and transformer tap changers in power quality applications.

In such high voltage applications several thyristor levels are often required in the valve, each level comprising two thyristors. Conventionally, each thyristor needs its own mounting clamps and connections to the cooling circuit. In some applications the snubber circuitry is connected to each thyristor, in others it is shared for an antiparallel pair of thyristors. It is advantageous if the space requirements for the equipment can be reduced. For industrial drives, mobile SVCs or marine applications, space reduction becomes a serious economic issue where the system has to be as compact as possible.

A semiconductor component which allows the two antiparallel thyristors to be integrated into one wafer enables the valve designer to provide such a solution. Along with the cost advantage of the smaller system in terms of real estate, snubber and control circuits can be more compactly designed and valve assembly is simplified. These factors result in cost savings for such a system of up to 30% compared to a conventional system. Since such a system requires less components, the reliability of the installation should be improved, assuming that the bidirectional component has the same reliability as a conventional thyristor.

In the Bidirectional Control Thyristor (BCT), figure 1, the integration of two antiparallel high voltage thyristors with blocking voltages of up to 6.5 kV has been achieved.

The two component thyristors in the BCT function completely independently of one another under static and dynamic operating conditions. Each component thyristor in the BCT has a performance equal to that of a separate conventional device having the same current carrying capability.

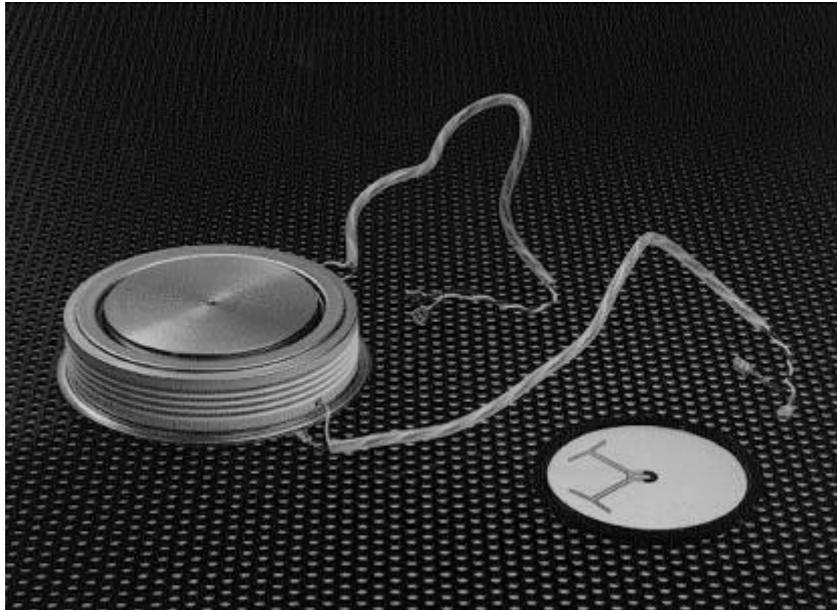


Figure 1

Photograph of a BCT60 element and wafer. The dimensions of the hockey-puck type ceramic housing correspond to those of standard thyristors. Note the two gate connectors to allow independent control of the two antiparallel integrated thyristors.

The correct orientation of the amplifying gate finger electrodes is crucial to achieve a fast turn-on and to prevent unwanted interference between the two thyristors in the BCT. The anode area is unpatterned. Bidirectional devices such as the triac already exist for blocking voltages up to approximately 1 kV. However, above that voltage level the thickness of the device makes the uniform control of the two thyristor structures via one gate impracticable.

The main challenge to overcome was to ensure that charge carrier interaction between the two integrated devices was suppressed. If there is not sufficient separation between the two thyristors, the integrated antiparallel thyristor device can be destroyed by uncontrolled triggering at high dV/dt values after commutation.

After describing some application examples, the achievement of separation of the two thyristors by wafer design will be described and investigations to test the discrete function of the BCT under near application conditions will be discussed.

2. APPLICATION EXAMPLES

2.1. SVCs

SVCs are to be found in either industrial or utility use.

The power quality SVCs are mainly used in the steel manufacturing industry. These are compensators for arc furnace and rolling mill compensation purposes. The utility SVCs are used in power grid systems.

SVCs consist of capacitor banks and phase angle controlled reactors. Thyristor valves are used for phase angle control of the current through the reactors and for switching of the capacitor banks.

Power quality SVC plants for arc furnaces are in most cases connected at a level of 33 kV. Their typical size is in the range of 75-150 MVar. Rolling mill SVCs are normally smaller and connected at a voltage level of 15 kV. The thyristor valves for these applications normally have current ratings less than 2000 A. The voltage level necessitates series connection of typically 10-20 levels of antiparallel thyristors. The 4" BCT (96 mm wafer) covers the interesting current and voltage ranges for power quality SVCs, thus the BCT substitutes for conventional 2" and 3" thyristors.

Utility SVCs in many cases have power ratings in the range of several hundreds of MVars. These plants require thyristor valves having current ratings above 3000 A and are therefore out of reach of the 4" BCT. Additionally there is a group of SVCs smaller than 100 MVars used in subtransmission networks. For these plants the BCT ratings are sufficient.

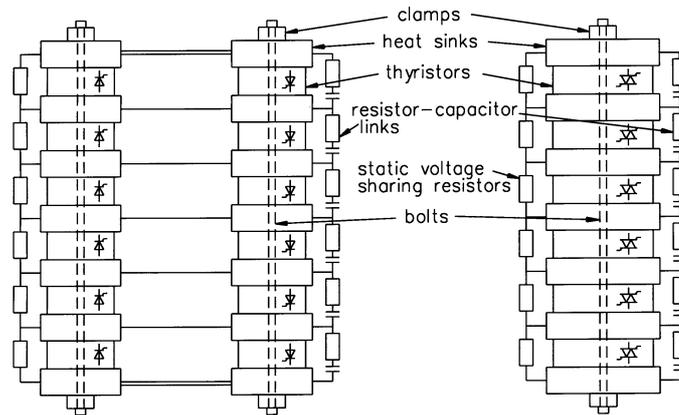


Figure 2

The BCT solution for SVC (right) only needs 50% of the thyristor units used in the conventional PCT solution (left).

Figure 2 shows a comparison between a conventional single phase SVC valve assembly and one based on the BCT concept. In the BCT valve one of the thyristor stacks is eliminated. The lack of a second thyristor stack means a significantly reduced number of other components in the valve beside the 50% reduction in the number of thyristor units. Obviously, there is no support structure for that stack but all joints normally required between the stacks on each thyristor level are also gone. Another important saving is in the number of connection points for the water cooling pipes and tubes.

The simplified design and reduced number of components leads to considerable savings in labour and totally more than 10% savings in costs.

The footprint of the valve is also reduced, even though not dramatically due to the existence of the snubber circuits.

The first BCT valve is planned to commence commercial operation in 1999.

2.2. MOTOR DRIVES

Another application example is that of Motor Drives. The BCT may be incorporated directly into DC drives and in the feeding sections for AC drives with the return (regeneration) of energy to the power grid during breaking. The standard solution for a regenerative DC drive is the so called (BC6)2 connection which consists of two fully controlled rectifiers in antiparallel connection. This is accomplished using an assembly with 12 thyristors. The reduction in components achieved when BCTs are used is shown in figure 3.

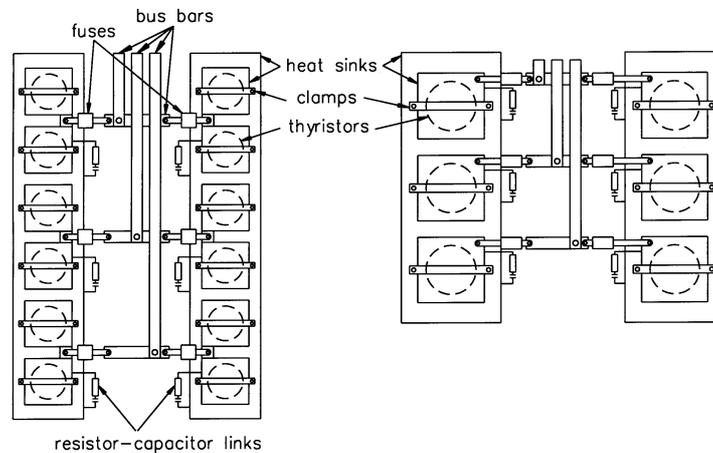


Figure 3

The drive installation height may be reduced with BCTs, enabling high power DC drives to be used in locations with height restrictions, like a harbour crane. PCT assemblies (left) and BCT assemblies (right) for 4-quadrant DC drives.

2.3. SOFT STARTERS

Soft starters, employed when starting an asynchronous machine directly fed from a three phase supply, are the third example to be discussed. The soft starter consists of pairs of anti-parallel thyristors having one pair per phase. As can be seen from figure 4, these can be directly replaced by a BCT. As for the DC drive this substitution leads to a reduced number of mechanical parts like mounting clamps and the solution is more compact.

The improvement potential of employing BCTs instead of PCTs is summarised in Table 1.

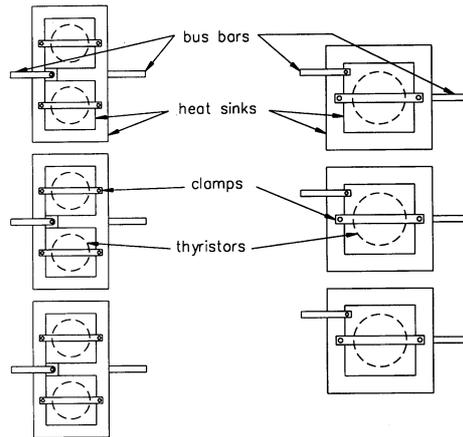


Figure 4
Comparison of three-phase soft starter assemblies using PCTs and BCTs.

Application	Power Level	Anticipated average volume improvement* (%)	Anticipated average parts count reduction* (%)
DC-drive	800 kW	30 %	30 %
DC-drive	2000 kW	30 %	25 %
Soft starter	250 kW	25 %	20 %
Soft starter	450 kW	30 %	20 %
SVC	50 MVA _r	35 %	35 %

* compared to conventional PCT solutions

Table 1.

3. WAFER DESIGN¹ TO SUPPRESS INTERFERENCE BETWEEN COMPONENT THYRISTORS.

In order to guarantee the separation of function of the component thyristors two aspects had to be considered: (i) suppressing unwanted carrier diffusion under dynamic conditions and (ii) limiting I_{GT} and V_{GT} to acceptable values at turn-on.

To understand why it is so necessary to prevent charge carrier interaction between the BCT component thyristors, it is important to consider the characteristics of a bidirectional device. In such a device it is not possible to define unique forward and reverse blocking directions as is the case for a standard thyristor. Each wafer face has both anode and cathode regions, divided from each other by a separation region.

Each component thyristor (labelled A and B in the cross section of the BCT given in Figure 5) is formed by an anode region and the corresponding cathode region on the reverse face of the wafer.

Since both A and B are subjected to the same potential difference, for a given blocking voltage one thyristor is in the forward blocking state and the other is blocking in reverse (figure 6).

If one thyristor, e.g. A, which was previously conducting is suddenly commutated off, it experiences a peak reverse voltage which is defined by the external circuit inductances and snubber circuit component values. This voltage appears as a rapid rise in forward blocking voltage for the second thyristor, B. Normally, B would not trigger unless dV/dt exceeds a given value. However, if charge carriers from A

¹ A patent protecting the wafer design has been applied for.

(which had been previously conducting) have diffused across the separation region into B in sufficient numbers, B will trigger locally under the dV/dt transient causing the probable destruction of the device.

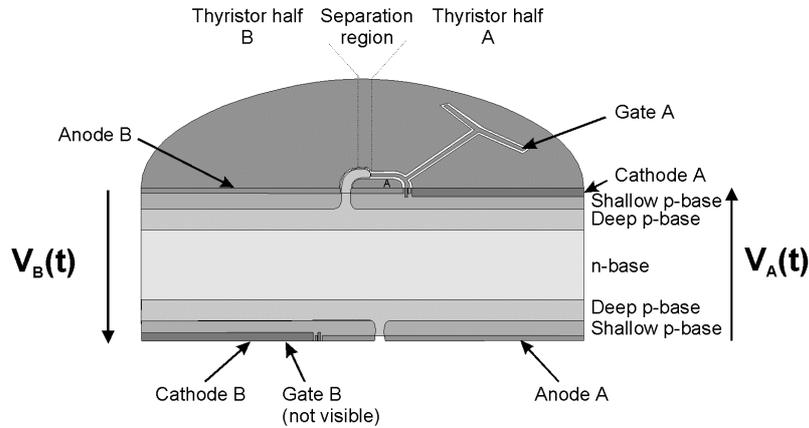


Figure 5

Cross-section of a BCT wafer showing the antiparallel arrangement of the A and B component thyristors. The arrows indicate the convention of forward blocking for A and B.

Lateral carrier diffusion between A and B could be reduced to insignificant levels by ensuring that the emitter separation (anode A-cathode B etc.) amounted to a reasonable number of minority carrier diffusion lengths. In addition to increasing the geometrical separation between emitters on the same wafer face, the removal of unwanted charge carriers was improved by increasing the density of cathode shorts along the edge of the cathode emitter and in the regions of the pilot thyristor cathode closest to the anode of the second thyristor, thus enabling the triggering sensitivity there to be drastically reduced.

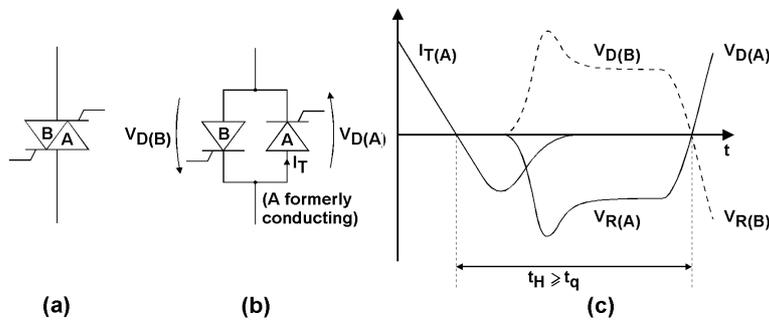


Figure 6

Currents and voltages experienced by the BCT component thyristors during the turn-off of BCT component thyristor A. The rate of rise of reverse voltage across A after commutation appears simultaneously as a forward dV/dt across B, which can lead to the destruction of the device by local triggering, if sufficient charge carriers have diffused from A across to B.

Since the n and p base regions of the BCT are continuous, I_{GT} and V_{GT} for component thyristors A or B could be expected to be larger than for a conventional thyristor because of the parasitic current path between the gate contact of A and the anode of B on the same face. By incorporating a high impedance

region between the gate contact of A and the anode of B, the horseshoe shaped region in figure 5, acceptable values of I_{GT} and V_{GT} were obtained.

Unlike a triac the BCT has two separate gate contacts, one for each thyristor. The design of the gate was kept as close as possible to that of standard PCTs. The amplifying gate and finger structure were designed to ensure fast turn-on. The finger gate is oriented at 45° to the separation region between the two thyristors. This arrangement ensures that during turn-on the plasma starts to spread out simultaneously from the edge of the cathode emitter closest to the finger gate, resulting in a fast turn-on. By orienting the finger gate away from the separation region, turn-on is made more efficient. This is because of the heavier cathode emitter shorting near the separation region and because the available anode emitter area underneath the cathode is effectively reduced there. The cathode emitter of B is arranged directly above the anode emitter of B. The gate contact is so constructed that the cathode emitter of the pilot thyristor lies directly above the anode of B.

4. INVESTIGATION OF INTERFERENCE IN THE FUNCTION OF THE TWO BCT THYRISTOR HALVES.

The presence of interference between the two BCT component thyristors was investigated in a laboratory experiment and during a complete qualification.

The laboratory circuit is shown in figure 7. Typical current and voltage characteristics are shown in figure 8. The test object was a BCT device with a blocking voltage of 6500 V at 125°C and $I_{TAV}=1390\text{A}$ at 70°C , corresponding to a 28 cm^2 wafer area for each component thyristor. The capacitor C was charged up to a voltage of 3000 V. When the thyristor in forward blocking is triggered, C is at first discharged and then recharged to practically the same voltage but of the opposite polarity. The thyristor which had been previously conducting is commutated off and the negative capacitor voltage appears across the BCT.

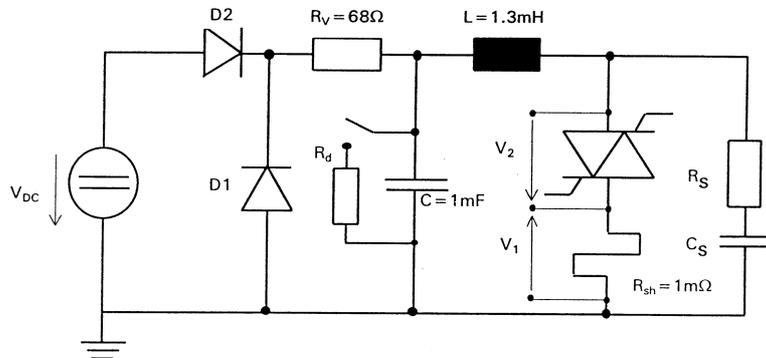


Figure 7

Laboratory circuit to investigate the thyristor separation in the BCT under commutation conditions.

Interference between the two thyristors in the BCT would manifest itself as a sudden breakdown in the "reverse" blocking voltage accompanied by a large peak in the reverse current. The term "reverse" refers here to the BCT thyristor which had just been conducting prior to commutation.

The breakdown would be due to an uncontrolled partial triggering of the BCT thyristor which is parallel to the previously conducting part and caused by the presence of significant numbers of charge carriers which had diffused between the two BCT thyristors.

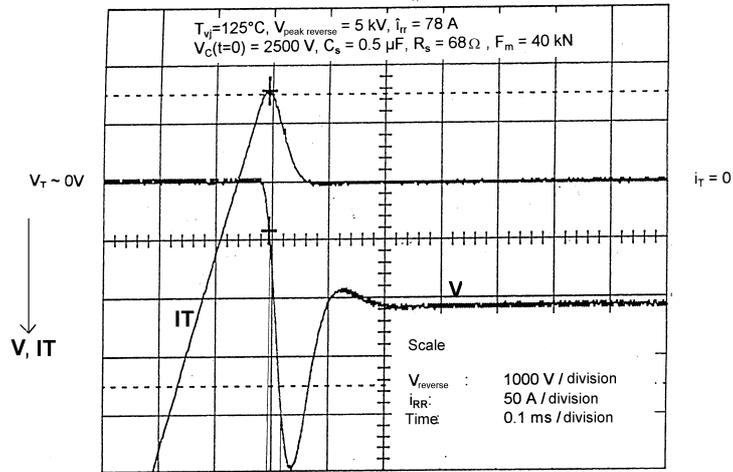


Figure 8

Current and voltage traces for a BCT during commutation. No breakdown in V_{RR} was seen demonstrating the separation of the antiparallel BCT thyristors. A typical result from the circuit of figure 7.

The level of the peak reverse voltage (and hence dV/dt) could be adjusted by changing snubber component values. No breakdown was observed even using the hardest conditions (peak reverse voltage = 5 kV at 125°).



Figure 9

Compact solution for a single phase SVC valve. Photograph of the BCT test valve.

An even harder test was performed during the qualification of the test valve. A stack with eight BCT60 devices (figure 9) having a surge voltage capability of 6.5 kV at 125°C formed the single phase valve of figure 10.

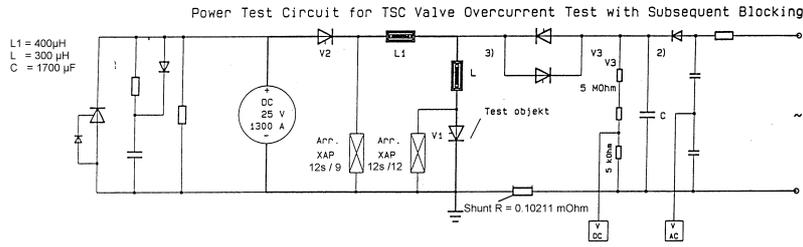


Figure 10
Experimental test valve set-up for surge current measurements

The current and voltage behaviour during the surge current test with reapplied blocking voltage are shown in figures 11.

The stack was first heated to 120°C and then 5 BCT devices in series were triggered. The peak current reached was 20kA. After conduction a reverse blocking voltage of 10kV was applied across the valve. The peak reverse voltage across the stack reached -18kV without failure.

In a further test, the BCT carried the peak current successively in both directions followed by a similar reapplied voltage without any indication of interference between the two BCT thyristors (figure 12).

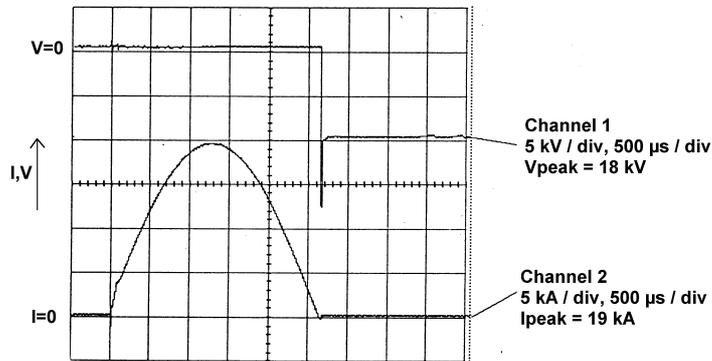


Figure 11
Surge current test with reapplied reverse voltage across BCT test valve.

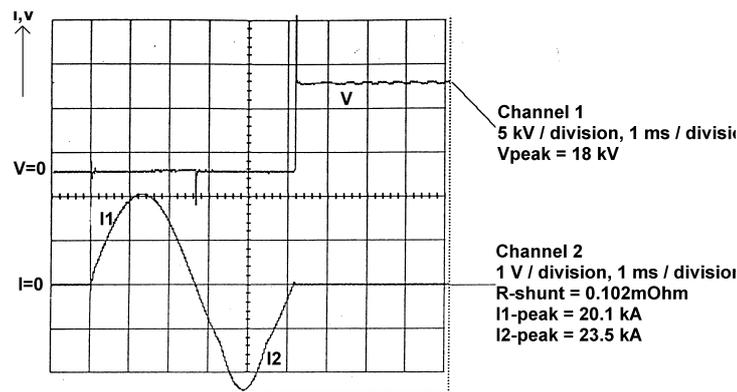


Figure 12

The BCT test valve passes surge current successively in both directions with reapplied voltage. Separation is demonstrated by the ability to block voltage immediately after the surge current pulses.

5 CONCLUSION

The investigations have shown that the BCT concept works well: it is possible to integrate two distinct antiparallel oriented thyristors onto one silicon wafer and maintain their separate function. The BCT can be used as a bidirectional device up to 6.5 kV and can be implemented into systems which conventionally use two separate components in antiparallel. System advantages are in terms of cost and space. These come from the reduction in the number of thyristor components and associated equipment. Such a system is planned for commercial operation in 1999.

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