Power conversion circuits currently in widespread use a DC-linked type converter that consists of rectifiers, electrolytic capacitors and DC reactors.

The electrolytic capacitor however, is a major obstacle in the production of more compact, lower-cost, and longer-life devices. For this reason, research on direct linked type converter such as matrix converters is being conducted to provide power conversion without the use of the rectifier circuit.

Fig. 1 shows the main circuit configuration of a matrix converter. A direct linked type converter requires a switch that can block the voltage in both directions. General-purpose switching elements do not have a withstand voltage (reverse withstand voltage) against a reversely applied voltage, complicating the circuit configuration of a bidirectional switch. Also, blocking the voltage in both directions requires an AC snubber circuit, which also has a complex configuration. Fuji Electric is currently developing a new insulated gate bipolar transistor (IGBT) with reverse withstand voltage performance (referred to as a reverse-blocking IGBT hereafter). We built prototypes of bidirectional switch modules using the reverse-blocking IGBT and investigated the commutation operation and conversion efficiency when the prototypes were used in direct linked type converter (AC chopper circuits).

This article reports on the structure and operation of the reverse-blocking IGBT.

Reverse-blocking IGBT

The reverse-blocking IGBT is a new device with reverse withstand voltage performance that is not possible with conventional IGBTs. [1]

Fig. 2 shows a bidirectional switch with a conventional IGBT and a bidirectional switch with a reverse-blocking IGBT. When the reverse blocking IGBT is used in direct linked type converter such as matrix converters, the diodes required for obtaining reverse withstand voltage in conventional switch are no longer necessary. Elimination of the diodes should lead to the following benefits:

- Lower cost and smaller packages because there are fewer chips.
- Lower on-state voltage: About 4 V

Table 1: Main components.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Component name</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Capacitor</td>
<td>μF/630 V</td>
</tr>
<tr>
<td>L</td>
<td>Reactor</td>
<td>2mH/15 A</td>
</tr>
<tr>
<td>Qr~Qs</td>
<td>Reverse-blocking IGBT</td>
<td>600 V / 50 A</td>
</tr>
<tr>
<td>CT</td>
<td>Current detector</td>
<td>100 A - 4 V</td>
</tr>
<tr>
<td>PT</td>
<td>Voltage detector</td>
<td>200 V - 5 V</td>
</tr>
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</table>

Fig. 1: Main circuit configuration of a matrix converter.

Fig. 2: Bidirectional switch using a reverse-blocking IGBT.

Fig. 3: Cross-section of the chip when a reverse voltage is applied.

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in conventional IGBTs + diodes, but about 2 V in reverse-blocking IGBT only.

Described next is the reverse withstand voltage structure of a reverse-blocking IGBT.

Fig. 3 (a) shows a schematic cross-section of a conventional IGBT chip, Fig. 3 (b) shows a mesa-type reverse-blocking IGBT chip, and Fig. 3 (c) shows an isolation type reverse-blocking IGBT chip. In the final stage of the chip manufacturing process, chips are cut out from the wafer (dicing process), leaving the side surfaces of the chips with crystal deformations and high density crystal defects. In a conventional IGBT, if a reverse bias is applied, the depletion layer extending from the pn junction at the back surface - that is, a high electric field region - also appears on the dicing surface. Because carriers generated continuously from the crystal defects are transported by the electric field, resulting in a large leakage current, we could not obtain any reverse withstand voltage (Fig. 3 (a)).

In a mesa-type reverse-blocking IGBT, the chip periphery is etched through the n-layer to isolate the active area and dicing surface electrically. Because there is no electric field on the dicing surface, there is no leakage current. When a reverse bias is applied, the depletion layer extends from the pn junction that appears on the etching groove surface. Because no silicon crystal deformation exists in this area, the leakage current is small.

In addition, because the pn junction has a positive bevel structure, the electric field is relaxed, preventing local enhancement of the electric field (Fig. 3 (b)). In an isolation type reverse-blocking IGBT, a very deep isolation region (p+) is formed from the wafer surface in advance so that an isolation region appears at the back surface after back lap of the wafer, and the dicing surface is completely covered with the isolation region.

Next, formation of the p+ collector layer on the back surface extends the depletion layer along the adjacent collector layer at the back surface and the isolation region. Because it does not reach the dicing surface, generation of the leakage current can be prevented (Fig. 3 (c)).

The combination of a technology that performs a very deep selective diffusion without degrading crystal properties and a manufacturing technology that treats very thin wafers enabled implementation of such a device structure. Fig. 4 shows the appearance of the prototype bidirectional switch modules.

**Configuration of direct linked type converter**

As our testing circuit for the reverse-blocking IGBT, we selected, from among the direct linked type converters, a very simple AC chopper circuit. Fig. 5 shows the main circuit configuration of the step-down AC chopper circuit, and Table 1 lists the main components:

**Input filter (L, C)**

We connected a reverse-L filter that reduces the high harmonic current by the PWM (pulse width modulation) operation.

**Bidirectional switch**

Each switch is configured using an antiparallel connection of the reverse-blocking IGBTs (rated 600 V / 50 A) currently under development.

Also, we used for each switching device a dynamic clamp snubber circuit that is serial connection of diodes and Zener diodes in opposite direction between the collector and gate of the reverse-blocking IGBT.

**Detector**

We connected the load current detection and the supply voltage detection PT for controlling commutation of the bidirectional switch.

**Input power and load circuit**

Input power was single-phase 200 V 50 Hz, and the load circuit was R-L inductive load.

**Commutation method and pattern**

During switching in a direct linked type converter, not only must the circuit be shortened, but the load terminal must not be open. As the switching pattern (commutation pattern) of each switch during switching, a method in which commutation occurs (depending on load current) and a method in which commutation occurs (depending on input voltage) are provided.

Fig. 6 shows examples of the ignition pulse patterns of each reverse-blocking IGBT in load current commutation method and input voltage commutation method. Load current commutation method is a method in which each IGBT is controlled individually according to the polarity of the load current. For example, as shown in Fig. 6 (a), if the polarity of the load current is positive (in Fig. 5, the direction indicated by the arrow on the load is assumed to be positive), the load current is commutated by overlapping the IGBT to be commutated (Q2 and Q3 in the figure). As a protection against a short-circuit, a dead time for preventing a short circuit is provided for the IGBTs of the same polarity. Input voltage commutation method, on the other hand, is a method in which each IGBT
is controlled according to the polarity of the supply voltage. For example, as shown in Fig. 6 (b), if the polarity of the input voltage is positive (in Fig. 5, the direction indicated by the arrow on the capacitor is assumed to be positive), an open circuit on the load terminal is prevented by always leaving the IGBTs under reverse bias on-state (Q1 and Q3 in the figure).

In addition, a dead time for preventing a short circuit is provided for the IGBT (Q4 in the figure) that has the same polarity as the polarity of the IGBT to be commutated (Q2 in the figure). In both methods, surge current or surge voltage that, in the worst case, damages devices is generated near the zero cross of the detection signal (load current or input voltage) as a result of commutation failures from detection errors.

As a protective measure, we proposed the multiple commutation method. In this method, commutation is performed by changing the conventional load current commutation and input voltage commutation methods. We then checked the effects in experiments.

Fig. 7 shows the commutation switching pattern for the input voltage waveforms and load current waveforms. We gave priority to the input voltage commutation pattern and controlled commutation failures by changing to the load current commutation pattern during the small input voltage.

**Experimental results of commutation operation**

Fig. 8 shows the experimental results of commutation operation in each commutation method. It can indicate that the surge voltage or surge current generated in load current commutation method or input voltage commutation method is controlled by the operation in multiple commutation method.

**Dissipation loss**

We used the testing circuit shown in Fig. 5 to measure the conversion efficiency when a bidirectional switch was configured in an antiparallel connection of the prototype reverse-blocking IGBT and in a serial connection of conventional modules (2MB50N-060, 600 V / 50 A). Table 2 lists the testing conditions for measurement of dissipation losses, and Fig. 9 shows the results of measurement. We verified that the device dissipation loss is reduced to about 65% due to elimination of series diode conduction losses.

**Conclusion**

The reverse-blocking IGBT may become an important part in implementing a direct linked type converter. In addition, it can also be expected to be applied to the current fed inverters. Our aim is not only early commercialisation of the reverse-blocking IGBT, but also the development of the circuits and control methods that realises application of reverse-blocking IGBT to various types of systems.

**References**


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