7th-Generation “X Series” 1,200-V/ 2,400-A RC-IGBT Modules for Industrial Applications

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ABSTRACT

In order to meet the market demand for smaller and more reliable IGBT modules, Fuji Electric has developed reverse-conducting IGBTs (RC-IGBTs), which integrate IGBTs and FWDs on a single chip. Specifically, we created a line-up of 7th-generation “X Series” 1,200-V RC-IGBT modules for industrial applications that combine 7th-generation “X Series” chip and packaging technologies with RC-IGBT technology. More recently, we have enhanced the line-up by adding 2,400-A products to increase the current rating. This enhancement substantially improves chip junction temperature and junction temperature rise during operation compared with conventional products. This contributes to further output improvement, miniaturization, and higher reliability for power conversion systems.

1. Introduction

In recent years, there has been increasing expectation that power electronics technology will further contribute to efficient energy usage and energy savings, and play an important role in combating global warming and achieving a responsible and sustainable society. In this regard, power semiconductors are becoming increasingly important as key devices for the power conversion systems used in a wide range of applications, including those of the industrial, consumer, automotive, and renewable energy sectors.

Fuji Electric has been commercializing insulated gate bipolar transistor (IGBT) power semiconductor modules since 1988. Since then, IGBT modules have contributed to the miniaturization, cost savings, and performance of power conversion systems by helping them become smaller, more efficient and reliable. However, attempts to enhance IGBT modules through miniaturization have only lead to higher operating temperatures and decreased reliability of IGBT devices and free wheeling diode (FWD) devices due to the increased power density. Therefore, it is essential to innovate chip and packaging technologies to maintain high reliability and improve the power density of IGBT modules.

Fuji Electric has commercialized its 7th-generation “X Series” as a line-up of IGBT modules that makes breakthroughs in chip and packaging technologies. The lineup realizes higher power density by achieving lower IGBT module loss and better reliability[(1),(2)]. Moreover, we have also developed a reverse-conducting IGBT (RC-IGBT)[(3),(4)], which integrates an IGBT and FWD on a single chip, allowing it to minimize the number of chips and the overall chip area, while also reducing generated loss.

The X Series RC-IGBT module combines the chip and packaging technologies of X Series IGBT modules with the technology of the RC-IGBT to achieve miniaturization through higher power density. We recently added to the line-up a 1,200-V/2,400-A rated PrimePACK™*3+ that comes equipped with the RC-IGBT.

2. Features of the 7th-Generation “X Series” RC-IGBT Module for Industrial Applications

Figure 1 shows the schematic diagram and equivalent circuit of the X Series RC-IGBT. In voltage type inverters, which are widely used as power converters,

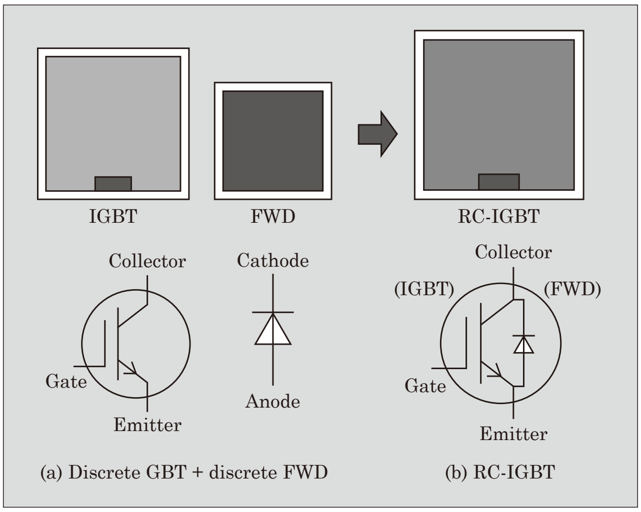

Fig.1 Schematic diagram and equivalent circuit of the 7th-generation X Series RC-IGBT for industrial applications

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* PrimePACK™: A trademark or registered trademark of Infineon Technologies AG.

it is necessary to connect an IGBT and a FWD in an anti-parallel configuration. Conventionally, two chips have been required to do this, one for the IGBT and one for the FWD. However, in an RC-IGBT, the operating regions of the IGBT and FWD are integrated into a single chip.

The X Series RC-IGBT uses X Series chip technology to achieve finer pattern design than that of 6th-generation “V Series” IGBTs. This has significantly reduced collector-emitter saturation voltage $V_{CE(sat)}$. Furthermore, by applying the most advanced thin wafer processing technology, we were able to improve the trade-off relationship between $V_{CE(sat)}$ and switching loss. In general, the use of thin wafers can cause voltage oscillation and blocking voltage degradation during turn-off, but the X Series RC-IGBT uses an optimized chip structure to suppress voltage oscillation and blocking voltage degradation.

Moreover, the X Series IGBT module uses a high heat dissipating insulating substrate as one of its packaging technologies. This has significantly reduced thermal resistance. Furthermore, the module ensures high reliability and continuous operation at a junction temperature of 175 °C by optimizing the wire bonding and using high-strength solder and high heat-resistant silicone gel.

These technologies have enabled the RC-IGBT module to provide a higher current rating with the same package size as conventional IGBT modules that have an independent IGBT chip and a FWD chip separately[(5)-(8)].

3. Product Line-Up

Table 1 shows the line-up of the X Series RC-IGBT modules.

In addition, Table 2 shows the external appearance of the newly added X Series RC-IGBT module with PrimePACK™3+ package. The RC-IGBT module achieves a rated current of 2,400 A in the same package size as conventional X Series IGBT modules with a current rating of 1,800 A.

4. Features of the 7th-Generation “X Series” RC-IGBT PrimePACK™3+ Module for Industrial Applications

(1) Turn-off loss

Figure 2 shows the trade-off characteristics between $V_{CE(sat)}$ and turn-off energy of the X Series RC-IGBT module. Compared with V Series IGBT modules, X Series RC-IGBT modules reduce saturation voltage by 0.65 V and turn-off loss by 42%, while significantly improving trade-off characteristics. This has allowed the X Series to achieve higher efficiency and higher current density.

Table 1 Line-up of X Series RC-IGBT modules

Product name	Product type	Rated voltage	Rated current	Remarks
Small-PIM2	7MBR50XRKD120-50	1,200 V	50 A	Solder pin
	7MBR50XRKB120-50			Press fit pin
PC3	6MBI250XRBE120-50		250 A	Solder pin
	6MBI250XRXE120-50			Press fit pin
DualXT	2MBI1000XRNE120-50		1,000 A	Solder pin
	2MBI1000XRNF120-50			Press fit pin
PrimePACKTM3+	2MBI2400XRXG120-50		2,400 A	–
DualXT	2MBI800XRNE170-50	1,700 V	800 A	Solder pin
	2MBI800XRNF170-50			Press fit pin
PrimePACKTM*3+	2MBI2200XRXG170-50		2,200 A	–

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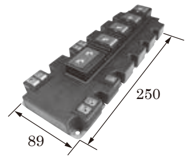
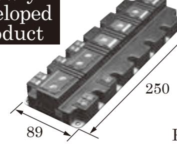
Table 2 Product appearance

		Rated current (A)		
		1,400	1,800	2,400
1,200 V	X Series	X-IGBT + X-FWD		X-RC-IGBT
	V Series	V-IGBT + V-FWD		
Product appearance		Conventional product (Unit: mm)  PrimePACK™*3		Newly developed product (Unit: mm)  PrimePACK™*3+

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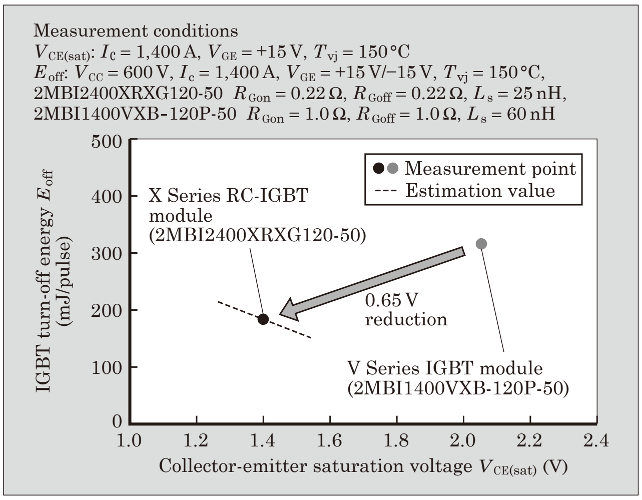

Fig.2 IGBT trade-off characteristics

It is also important to note that conventional V Series IGBT modules are limited in regard to how much they can expand output current. This is because wiring resistance of the output terminal can cause heat generation and excessive temperature rise when a large current flows on the module. X Series RC-IGBT modules reduce wiring resistance by applying two output terminals instead of one, while maintaining the same external size as V Series IGBT modules.

(2) Output terminal temperature

Figure 3 shows the results of measuring the output terminal temperature of a V Series IGBT module and X Series RC-IGBT module during a heat run test. The X Series RC-IGBT modules can reduce its current per terminal when energized. As a result, the terminal temperature of the X Series IGBT module was 51 °C lower than that of the V Series module when applied with 1,100 A. This has enabled the rated current of the X Series to be increased.

(3) Power loss and junction temperature when used with an inverter

Figure 4 shows the simulation results for the power loss and junction temperature T_{vj} and junction-to-case temperature rise $T_{vj\text{-}c}$ when utilizing a V Series IGBT module and X Series RC-IGBT module in a voltage-type inverter. Compared with V Series IGBT modules, the X Series reduces power loss by 16% under the same operating conditions. Furthermore, the combination of X Series packaging technology and RC-IGBT technology significantly lowered the thermal resistance, while also reducing $T_{vj\text{-}c}$ by 17 °C, enabling the maximum junction temperature T_{vjmax} to be decreased by 29 °C.

(4) Power cycle capability

Figure 5 shows the simulation results for T_{vj} at low-frequency inverter operation, such as during motor acceleration and deceleration. In the conventional IGBT and FWD structures, the IGBT and FWD each repeatedly generate and dissipate heat. As a result, ΔT_{vj} (i.e., the difference between the minimum and maximum temperatures of T_{vj} per cycle) can be as high as 90 °C. However, in RC-IGBT modules, the IGBT and FWD regions are integrated into a single chip, and this allows the device's IGBT and FWD regions to generate heat in an alternative manner. This means that in the RC-IGBT module, heat generated by the IGBT will also be transferred to the FWD region, and vice versa. Compared with IGBT and FWD structures, the effect of expanding the heat dissipation area reduces thermal resistance, and this reduces the temperature change of T_{vj} by approximately 25%, resulting in a per-cycle ΔT_{vj} of merely 21 °C. Moreover, this substantially reduces the thermal stress on the aluminum wire bonding and solder bonding underneath the silicon chips.

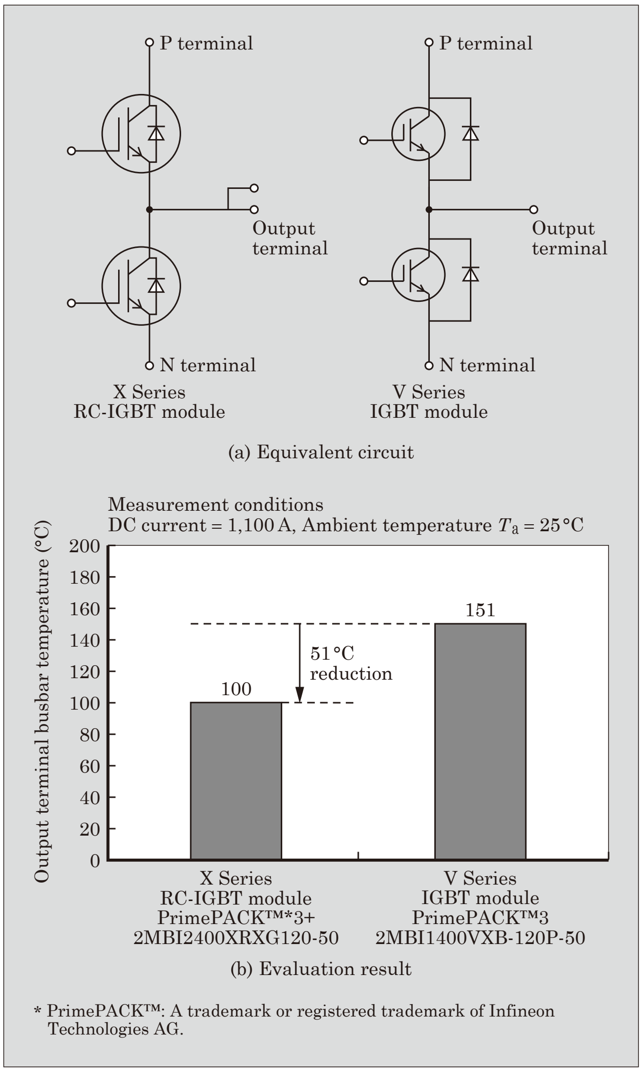

Fig.3 Equivalent circuit and terminal temperature evaluation results

Figure 6 shows the ΔT_{vj} power cycle capability and the calculated temperature rise during the inverter's low-frequency operation. The significantly lower ΔT_{vj} has enabled the X Series RC-IGBT module's ΔT_{vj} power cycle capability during low-frequency operation to increase from 7 × 10^4 cycles to 4 × 10^9 cycles, dra-

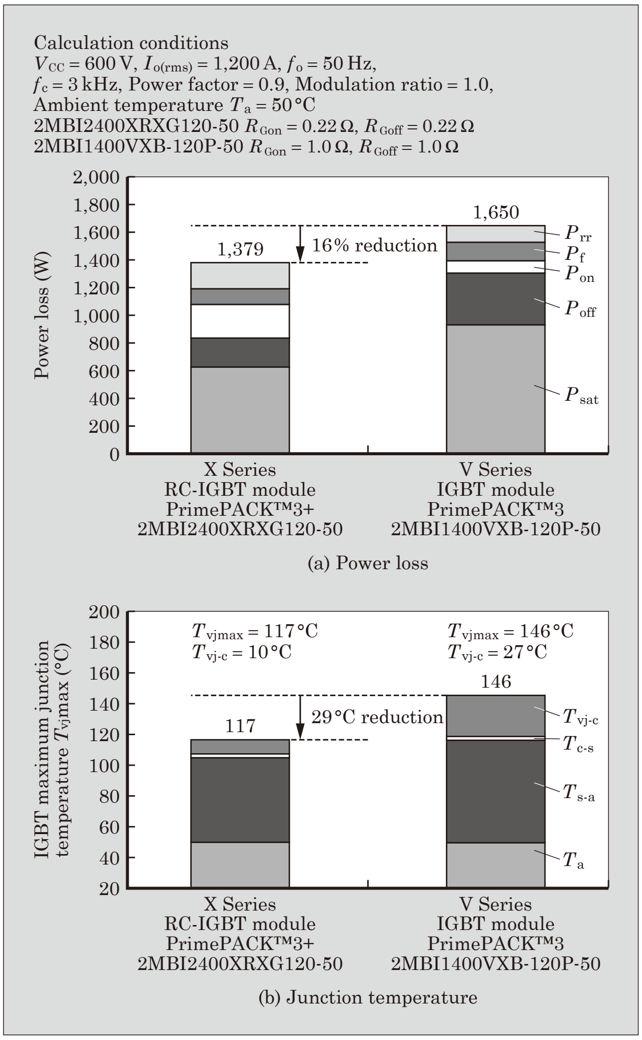

Fig.4 Power loss and junction temperature

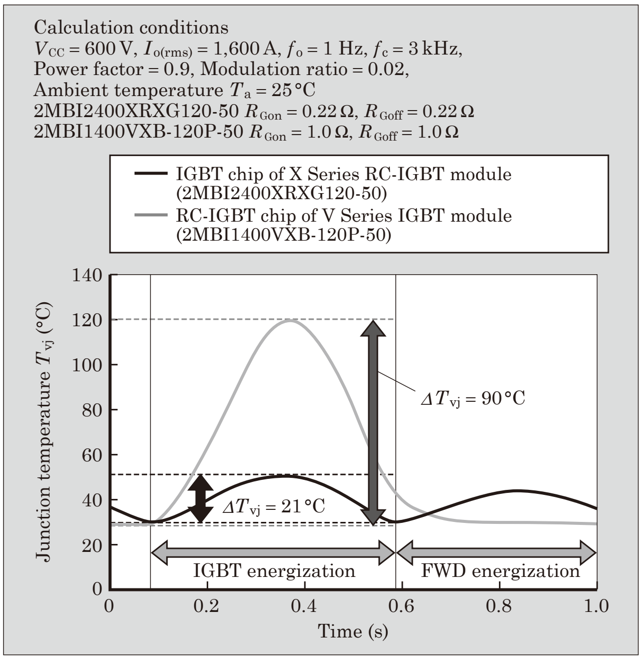

Fig.5 Low-frequency operation junction temperature T_{vj} time fluctuation

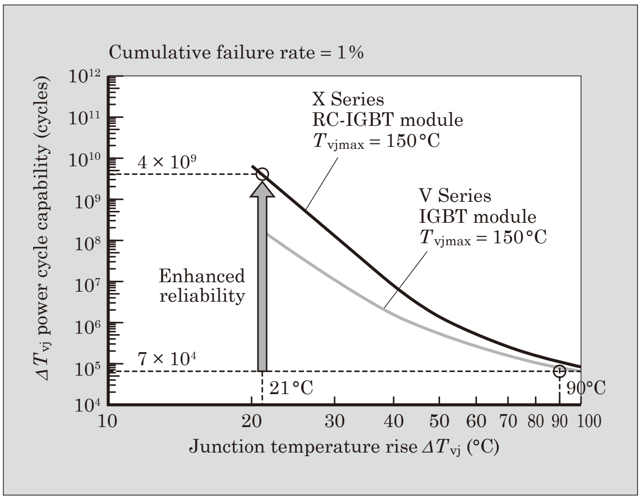

Fig.6 ΔT_{vj} power cycle capability

matically improving reliability. This also means that it can handle a higher output current under the same conventional power cycle capability conditions.

(5) Improved output current

We also simulated continuous operation. As shown in Fig. 7, we found the increasing of output current by 55% using the same package as V Series IGBT modules. This was made possible because of the reduced power loss and thermal resistance and the increased maximum junction temperature during continuous operation, which was raised from 150 °C to 175 °C.

I_O and T_{vjmax} relationship for the RC-IGBT module was investigated. As shown in Fig. 8, an inverter output at first output 100% of the rated current and then overcurrent, 200% of the rated current, for 3 seconds. As shown in Fig. 9, the X Series RC-IGBT module can output higher current by up to 54% even during overloaded operation.

Figure 10 shows the simulation results for I_O and T_{vjmax} during continuous operation. The result shows that a single X Series 2,400-A RC-IGBT module was

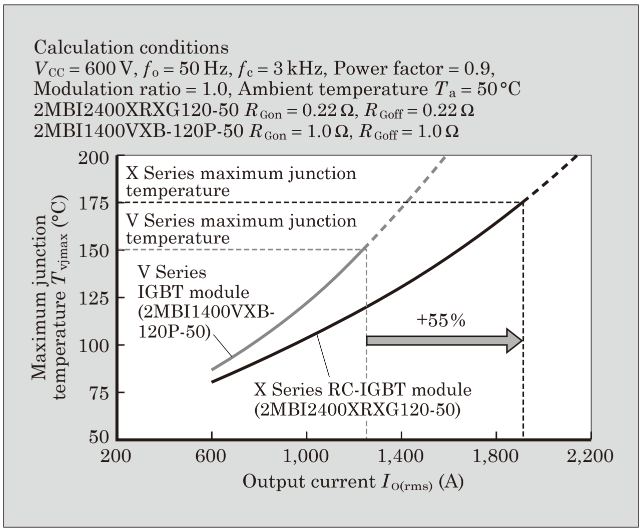

Fig.7 Maximum junction temperature at continuous operation

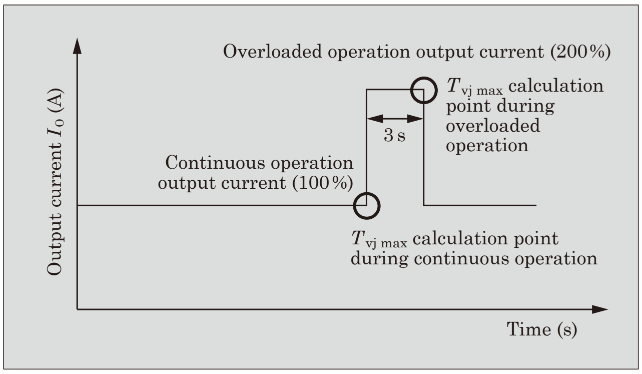

Fig.8 Operation pattern when overloading inverter overload

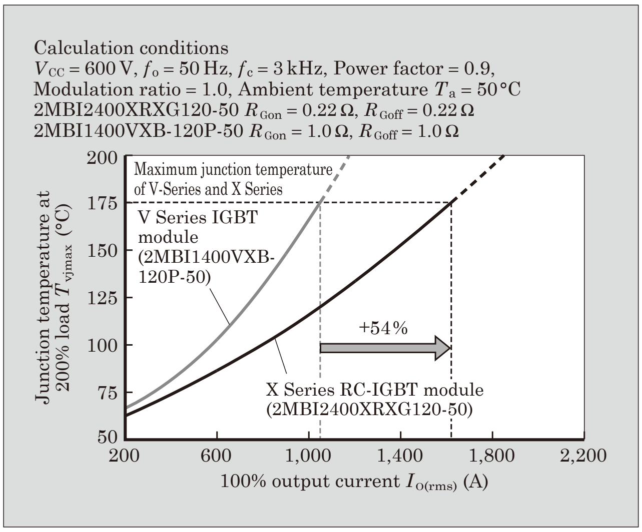

Fig.9 Maximum junction temperature at overloaded operation

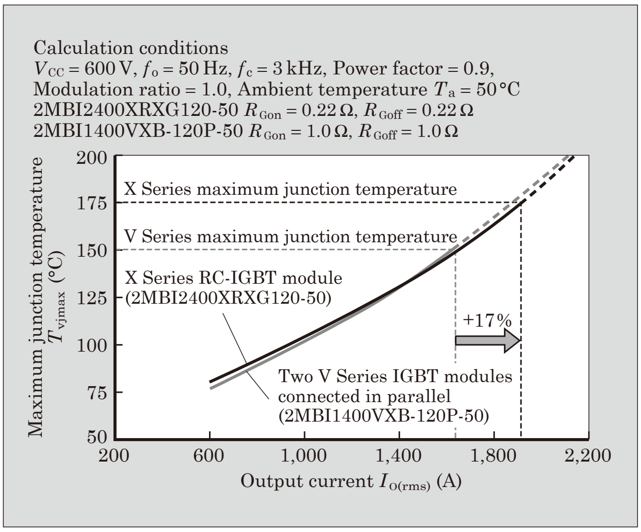

Fig.10 Maximum junction temperature at continuous operation

able to replace two V Series 1,400-A IGBT modules used in parallel. Furthermore, the X Series RC-IGBT module can increase output current by 17% and achieves space savings.

5. Postscript

In this paper, the newly developed 7th-Generation “X Series” 1,200-V / 2,400-A RC-IGBT module for industrial applications is described. By using this module in power conversion systems, it is possible to achieve output current expansion that was difficult to achieve so far. Furthermore, the module contributes to the miniaturization, higher efficiency, higher reliability and lower cost of power conversion systems.

We plan to continue pursuing technological innovation in IGBT modules so that we can contribute to realizing a responsible and sustainable society.

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