7th-Generation "X Series" RC-IGBT "Dual XT" Modules for Industrial Applications

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ABSTRACT

In recent years, demand has been increasing for high performance power converters with high output power and high reliability. Against this backdrop, Fuji Electric has developed RC-IGBTs that integrate an IGBT and FWD on a single chip and has applied this technology and a 7th-generation "X Series" technology to create the line-up of the "Dual XT" RC-IGBT modules with 1,200 V and 1,700 V ratings for industrial applications. These modules have a higher chip junction temperature of 175°C and smaller junction temperature fluctuations than conventional products using the same package while maintaining high reliability. These improvements have resulted in higher power outputs and longer lifetime of power converters.

1. Introduction

In recent years, population growth and economic growth have increased the demand for energy worldwide. Under the circumstance, there have been growing expectations placed on energy-efficient and energy-saving power electronics technology to help create a sustainable society. In particular, power conversion equipment, which is used to efficiently convert electrical energy, is becoming increasingly important. As a result, its range of application in markets such as motor drives and renewable energy is expanding. At the same time, this means that the power semiconductors used as key devices in power conversion equipment are also playing an increasingly important role.

Fuji Electric has made many technological innovations to reduce the size, lower the loss, and improve the reliability of insulated gate bipolar transistor (IGBT) modules in order to contribute to the miniaturization, cost reduction, and performance enhancement of power conversion equipment. Our latest 7th-generation "X Series" IGBT modules have achieved even lower loss and higher reliability than our previous 6th-generation "V Series" IGBT modules, thanks to innovations in chip and packaging technology. This has enabled us to increase output power (i.e., output current) per product volume while maintaining the same IGBT module package size.[(1),(2)] Fuji Electric has also developed reverse-conducting IGBTs (RC-IGBTs), which combine IGBT and free-wheeling diode (FWD) functions on a single chip.[(3),(4)] These IGBTs are already being extensively used in inverters in the power transmission units of electric vehicles (xEVs).[(5)]

By applying this RC-IGBT technology and X Series technology, we have developed a line of "X Series" RC-IGBT modules for industrial use, which offer even greater output power and higher reliability.

2. Product Line-Up

Fuji Electric offers a line-up of 1,200-V and 1,700-V "Dual XT" IGBT modules, as shown in Fig. 1, for power conversion equipment of various capacities, including general-purpose inverters and those for wind power generation systems. By employing the RC-IGBT technology, the line-up now includes high-current products

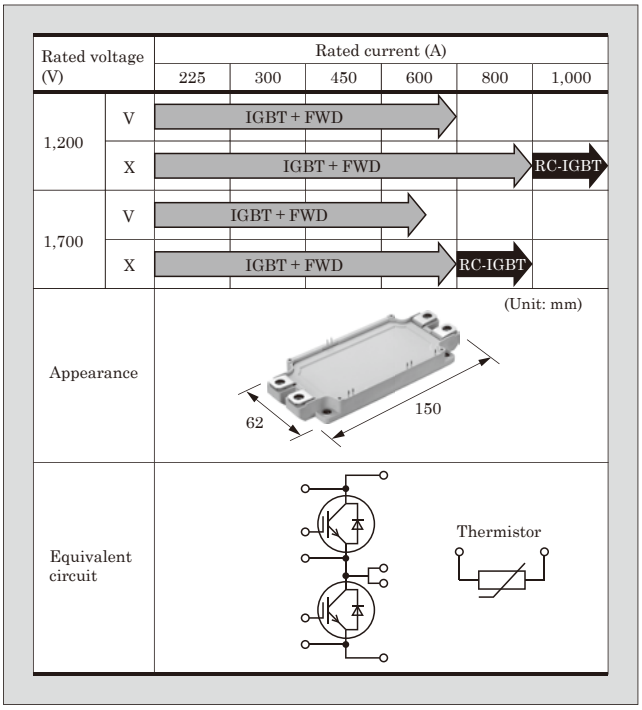

Fig.1 Line-up of the 1,200-V and 1,700-V "Dual XT" modules

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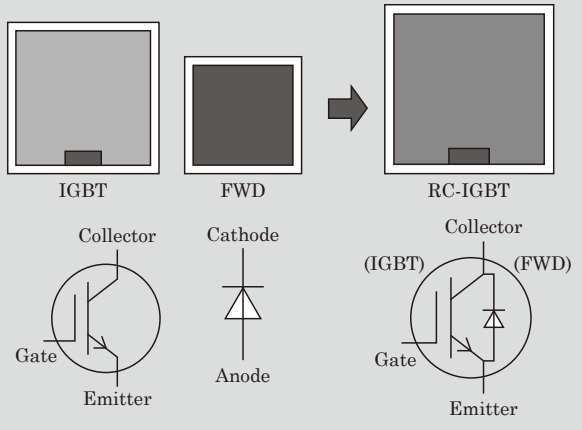
(1,200 V/1,000 A and 1,700 V/800 A).

3. Features of "X Series" RC-IGBT Modules

Figure 2 shows the schematic of the X Series RC-IGBT chip. In voltage inverters, which are widely used as power conversion equipment, two types of semiconductor chips, IGBT and FWD, are connected in reverse parallel (IGBT + FWD system). In contrast, an RC-IGBT integrates the IGBT and FWD functions into a single chip. This means that an RC-IGBT has a larger heat dissipation area due to its larger chip size than an IGBT or a FWD alone, compared to conventional IGBT + FWD systems at the same rated current. As a result, it reduces thermal resistance and achieve greater heat dissipation compared to an IGBT or a FWD alone. At the same time, the total chip area of the IGBT and FWD combined is smaller for an RC-IGBT than for a combination of discrete ones. An RC-IGBT thus can have higher rated currents for the same chip area. In addition, the X Series RC-IGBTs apply the X Series chip technology to improve the trade-off between collector-emitter saturation voltage $V_{CE(sat)}$ and turn-off loss E_{off} compared to the conventional V Series IGBT modules.

We have developed a new aluminum nitride (AlN) insulating substrate as the packaging technology for the X Series in order to reduce thermal resistance. In addition, we optimized the wire bonding in consideration of heat generation and used high-strength solder and high heat-resistant silicone gel. This allows the maximum junction temperature T_{vjmax} during operation from 150°C to 175°C while ensuring high reliability.

With these X Series technologies, including the chip technology to provide low loss and the package technology to ensure high reliability in high temperatures, as well as the RC-IGBT technology to improve heat dissipation, we have developed the X Series RC-IGBT modules, which have higher output power capacity despite the same package size as conventional IGBT + FWD systems.[6)-9)]



	IGBT + FWD	RC-IGBT
Area ratio	0.78 + 0.55 = 1.33	1

Fig.2 "X Series" RC-IGBT schematic and equivalent circuit

4. 1,200-V "X Series" RC-IGBT "Dual XT" Modules

Figure 3 shows a comparison of output currents at the same junction temperature during continuous operation of two general-purpose inverters of which one provided with our new 1,200-V/1,000-A X Series RC-IGBT module with Dual XT package (X Series RC Dual XT) and the other, 1,200-V/600-A V Series IGBT Dual XT module (V Series Dual XT), as a conventional product with the largest rated current in the same package size. Compared to the V Series Dual XT, the X Series RC Dual XT has reduced power loss and thermal resistance, enabling a 25% increase in output current in the same package size.

In addition to the continuous operation, it is also important to consider overload operation when there are sudden increases in motor load. Figure 4 shows the output current profile during an overload opera-

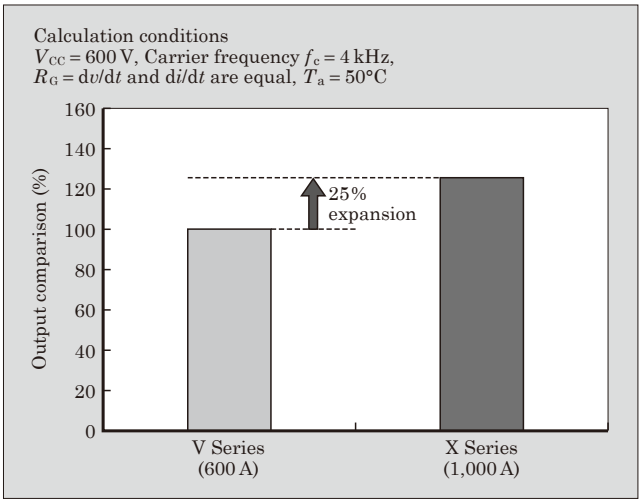


Fig.3 Comparison of output currents during steady-state inverter operation

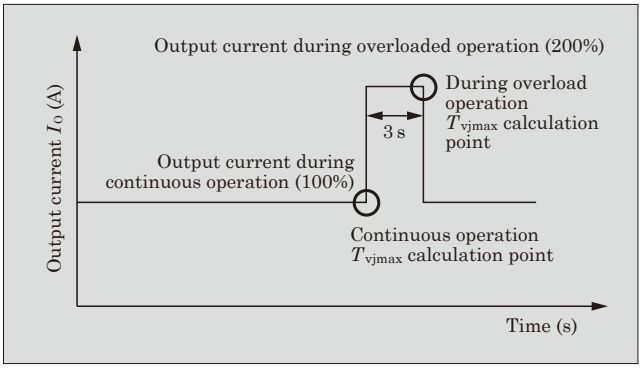


Fig.4 Current pattern of inverter operation

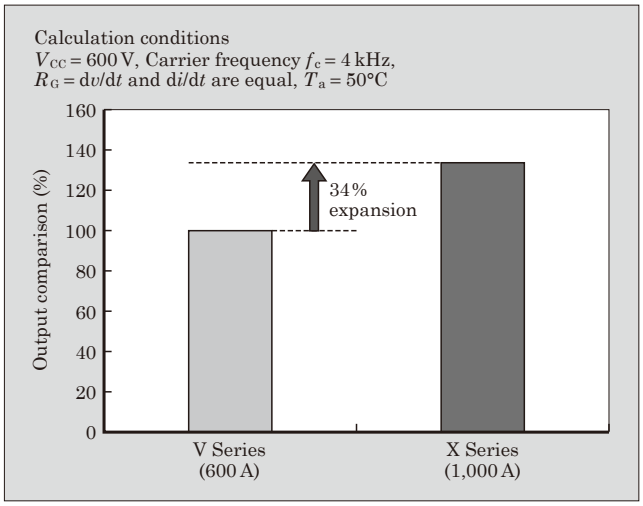


Fig.5 Comparison of output currents during steady-state inverter operation (during overload operation)

tion. This operation assumes that the inverter operates continuously and then become 200% overload for 3 seconds. Figure 5 shows a comparison of output currents during the overload operation. Under overload operation, the X Series RC Dual XT can increase output current by 34% compared to the conventional V Series Dual XT.

This allows the X Series RC Dual XT to significantly increase rated current compared to the V Series Dual XT, which is the conventional IGBT + FWD system. As a result, it increases output power while maintaining the same size of the power conversion equipment.

5. 1,700-V "X Series" RC-IGBT "Dual XT" Modules

IGBT modules with a rated voltage of 1,700 V are widely used in wind power generation, which is one of the most important sources of renewable energy. Figure 6 shows a schematic diagram of a wind power generation system. On the generator side, AC current generated by the wind turbine, whose rotational speed varies with wind speed, is converted to DC power by the AC/DC power conversion equipment. The DC power is converted to AC power by the DC/AC power conversion equipment on the grid side to provide stable power to the grid.

(1) Improved power cycling life time at low frequency operation

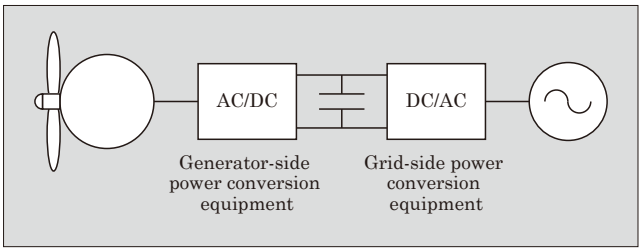


Fig.6 Schematic diagram of wind power generation system

For power conversion equipment on the generator side of a wind power generation system, it is particularly important to consider temperature changes during low-frequency operation at a few hertz. During low-frequency operation, a long single period increases the time of the current flowing through semiconductor devices, causing a junction temperature raise. On the other hand, the time during which no current flows is also long, causing a device temperature decreasing during this period. Therefore, low-frequency operation results in large temperature fluctuations and shortens product life. Figure 7 shows an example of the chip junction temperature T_{vj} waveforms during low-frequency operation.

In the V Series Dual XT, which utilizes a conventional IGBT + FWD system, no current flows through the FWD chip during IGBT operation, resulting in no heat generation, only heat dissipation. As a result, the difference ΔT_{vj} between the maximum value T_{vjmax} and the minimum value T_{vjmin} of the FWD junction temperature during a single cycle was 50°C. On the other hand, the X Series RC Dual XT has a lower T_{vjmax} thanks to the improved heat dissipation resulting from the larger chip area, which is a characteristic of RC-IGBTs. Moreover, in RC-IGBTs, T_{vjmin} increases owing to the alternating heat generation in the IGBT and FWD regions within the single chip. As a result, the ΔT_{vj} of the X Series RC Dual XT is much smaller (17°C) than that of the conventional IGBT + FWD system (50°C), enabling a significant improvement in ΔT_{vj} power cycling lifetime at low-frequency operation by reducing repetitive thermal stress on the aluminum wire and solder.

Reducing ΔT_{vj} in IGBT modules leads to an increase in product life because of the reduction in repetitive thermal stress on junction members inside the IGBT module. Figure 8 shows the calculation results

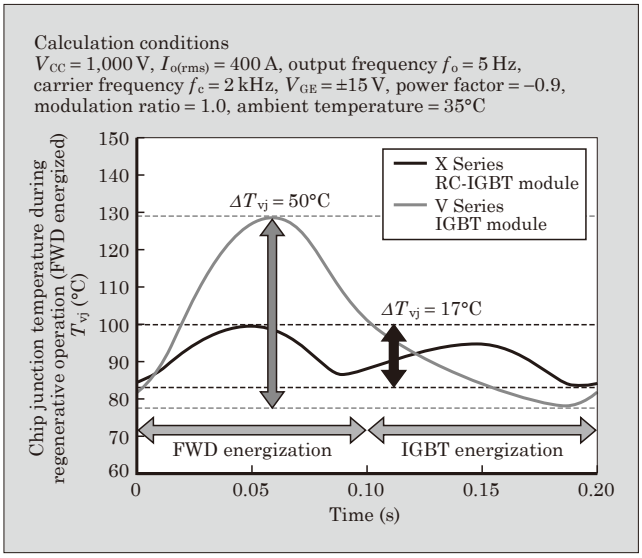


Fig.7 T_{vj} calculation results during low-frequency operation

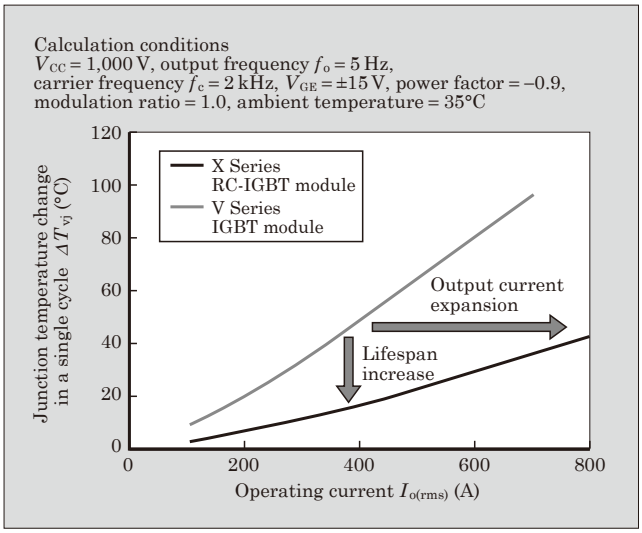


Fig.8 ΔT_{vj}–I_o calculation results during low-frequency operation

of ΔT_{vj} and output current I_o at low-frequency operation. At the same output current, the X Series RC Dual XT has a lower ΔT_{vj} than the V Series Dual XT that utilizes a conventional IGBT + FWD system. This reduces ΔT_{vj} by approximately 35°C when the output current I_o is the same at 400 A. This corresponds to an increase in power cycling lifetime of more than 1,000 times due to the reduction in repetitive thermal stress fluctuations caused by smaller temperature changes in the IGBT module. Compared with the V Series Dual XT at a ΔT_{vj} of 50°C, the X Series RC Dual XT can expand the output current twofold or more while maintaining the power cycling life time.

(2) Improved output current during LVRT operation

It is important for wind power generation systems to have low voltage ride through (LVRT) capability, that is, the ability to continue operation in the event of a momentary voltage drop in the grid. During LVRT operation, the converter on the grid side continues to operate. This results in a large current flowing through the FWD of the IGBT module and the charge stored in the capacitor being discharged. Consequently, a large charging current flows into the capacitor through the FWD on the generator side.

Figure 9 shows the temporal fluctuation of current assuming a state of LVRT operation. In LVRT operation, the current is assumed to flow more than five times as much as in normal operation. Therefore, in order to expand the output power of wind power generation systems, it is necessary to consider expanding the output current during LVRT operation as well as during normal operation. Figure 10 shows the relationship between T_{vjmax} and the maximum output current I_o flowing in the FWD during LVRT operation. The X Series RC Dual XT can expand I_o by 96% during LVRT operation compared to the V Series Dual XT. This is due to the effect of improved thermal resistance resulting from the larger heat dissipation area compared to the conventional IGBT + FWD system. This is one of

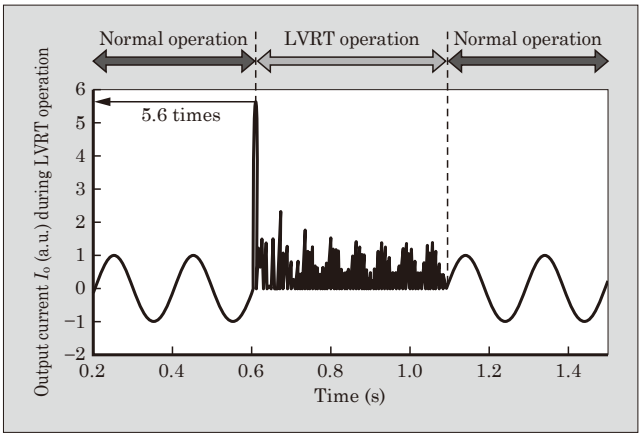


Fig.9 Example of current waveform during LVRT operation

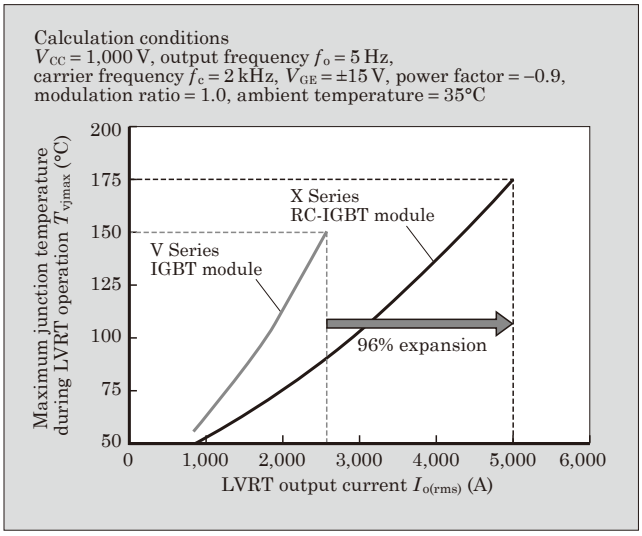


Fig.10 Relationship between T_{vjmax} and I_o during LVRT operation

the advantages of the X Series RC Dual XT.

(3) Improved I²t capability

Figure 11 shows a comparison of the current squared time (I²t) capability* of the X Series RC Dual XT and V Series Dual XT. Integrating IGBT and FWD

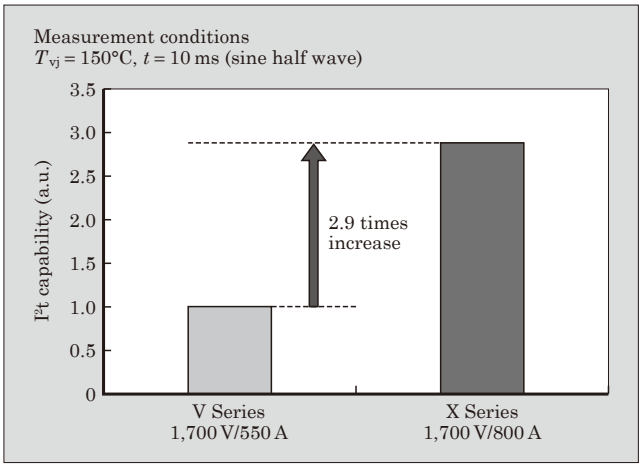


Fig.11 Comparison of I²t capability

into a single chip to improve heat dissipation, the X Series RC Dual XT has a three times higher I^2t capability than the V Series Dual XT.

6. Postscript

In this paper, we described our 7th-generation "X Series" RC-IGBT "Dual XT" modules for industrial applications. Fuji Electric has incorporated a RC-IGBT in a Dual XT package, which is one of the 7th-generation IGBT modules. This enhancement has improved performance of the 1,200 V and 1,700 V rated voltage modules and increased power output and reliability.

Moving forward, we will continue to promote further technological innovations in IGBT modules to contribute to the creation of a responsible and sustainable society.

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* Current squared time (I^2t) capability: I^2t is the Joule-integral value of the overcurrent acceptable to the extent that the device does not breakdown. Overcurrent is defined by a single cycle with a time width of 8 to 10 ms associated with the line frequency sine half wave. I^2t capability refers to the device's resistance to breakdown.

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