“P631” Package 7th-Generation “X Series” High Power IGBT-IPM

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ABSTRACT

Fuji Electric has developed a 7th-generation “X Series” high-capacity IGBT-IPM and added it to the “P631” package line. The new IGBT-IPM achieves high output current and high heat dissipation to meet the demand for higher output power, higher efficiency, and higher reliability in power conversion equipment. Its rated current is up to 1.5 times higher than that of the existing high-capacity “V Series” IPMs. In addition, it improves the loss generated during continuous operation by approximately 7% and operates at high-temperature up to 150°C. This contributes to increasing the output current of inverters by approximately 1.3 times.

1. Introduction

In recent years, the market placed growing expectations on energy-efficient and energy-saving power electronics equipment to mitigate global warming and help create a responsible and sustainable society. In particular, power semiconductors used in power conversion equipment are the key devices playing a very important role in various fields, such as industry, automobiles, and renewable energy.

Fuji Electric started producing power semiconductor insulated gate bipolar transistor (IGBT) modules in 1988 and since then has achieved miniaturization, lower loss, and higher reliability through many technological innovations. The IGBT intelligent power module (IGBT-IPM) is a power semiconductor device that incorporates gate drive circuits and protective functions. Our IGBT-IPMs incorporate the industry’s first IGBT chip overheat protection function and alarm-cause identification function, enabling them to meet the demand for higher reliability and functionality. In addition, the 7th-generation “X Series” IGBT-IPM also incorporates the industry’s first chip temperature warning function and standalone brake operation function, contributing to higher system’s flexibility.[1)-3)]

Among IPMs, the high power ones are often used in elevators, injection molding machines, and other equipment where the applied current is larger and the power chips are subjected to high thermal stress. This means that they must be capable of high output currents and be resistant to breakage. To meet these requirements, Fuji Electric has used the 7th generation “X Series” technology into the “P631” package and reduced the loss, increased the operating temperature and got higher power output.

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2. Product Overview

Figure 1 shows the appearance of the “P631” high power IGBT-IPM, and Fig. 2 shows its internal structure. The P631 uses a double layer structure defined by a power section and control units. To increase heat

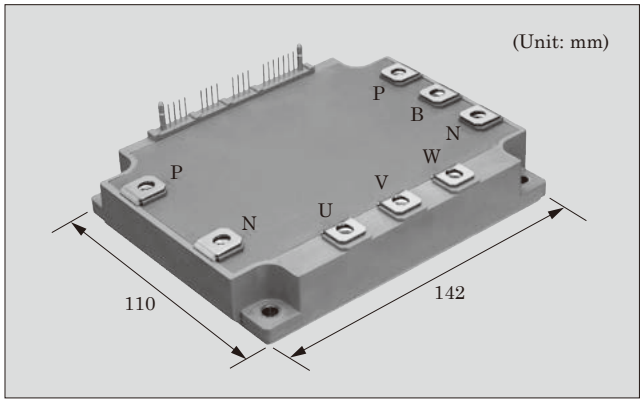

Fig.1 “P631” high power IGBT-IPM

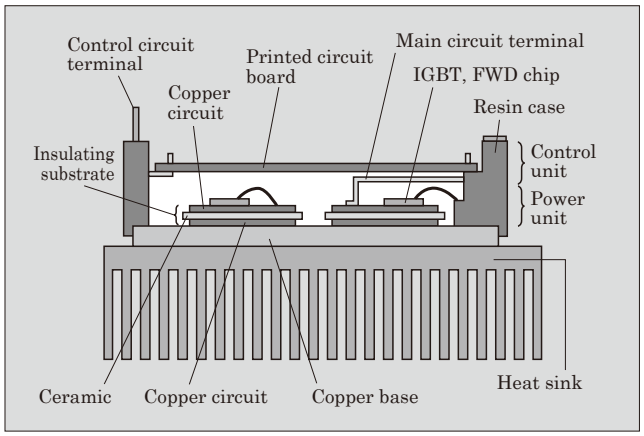

Fig.2 Internal structure of the “P631” high power IGBT-IPM

Table 1 Product line-up

(a) High power V Series IPM (conventional product)

Rated voltage (V)	Rated current (A)	Product type	
		6 in 1 No brake unit	7 in 1 Built-in brake unit
600	200	6MBP200 VEA060-50	7MBP200 VEA060-50
	300	6MBP300 VEA060-50	7MBP300 VEA060-50
	400	6MBP400 VEA060-50	7MBP400 VEA060-50
1,200	100	6MBP100 VEA120-50	7MBP100 VEA120-50
	150	6MBP150 VEA120-50	7MBP150 VEA120-50
	200	6MBP200 VEA120-50	7MBP200 VEA120-50

(b) High power X Series IPM (new product)

Rated voltage (V)	Rated current (A)	Product type	
		6 in 1 No brake unit	7 in 1 Built-in brake unit
650	200	6MBP200XEN065-50	7MBP200XEN065-50
	300	6MBP300XEN065-50	7MBP300XEN065-50
	450	6MBP450XEN065-50	7MBP450XEN065-50
1,200	100	6MBP100XEN120-50	7MBP100XEN120-50
	150	6MBP150XEN120-50	7MBP150XEN120-50
	200	6MBP200XEN120-50	7MBP200XEN120-50
	300	6MBP300XEN120-50	7MBP300XEN120-50

Table 2 Function comparison

Function		V Series IPM (Conventional product)	X Series IPM (New product)
Driving circuit		○	☆
Protective function	Short circuit protection	○ (2 μs)	☆ Faster (1 μs)
	Chip overheat protection	○ (150°C or higher)	☆ (175°C or higher)
	Power supply undervoltage protection	○	○
Chip temperature warning output function		×	☆ (6 in 1 only)
Standalone brake operation function (during alarm)		×	☆
Alarm-cause identification function		○ 2 ms, 4 ms, 8 ms Identification interval min = 0.1 ms	☆ 2 ms, 4 ms, 8 ms Identification interval min = 1.1 ms

○: With function; ×: Without function
☆: Improvements and new features compared with V Series IPM

dissipation, which is essential for high power products, it uses a 4-mm thick copper base. The power unit is positioned on the top surface of the copper base, which will be in contact with the external cooling unit / heat sink. Furthermore, the internal inductance has been reduced by using laminated bus bars as internal wiring of the main circuit. Moreover, the P and N terminals are located at both ends of the package so that the snubber capacitors can be connected at two locations and get an effective suppression of surge voltages, making the P631 IPM suitable for large capacitance applications.[4]

Table 1 shows the product line-up of the 7th generation high power X Series IPMs and the conventional 6th-generation high power V Series IPMs. Among the conventional V-series product line-up, current ratings for 600-V products are up to 400 A, and up to 200 A for 1,200-V products. For the high power X Series IPM, the output current of 650-V rated products is increased to 450 A, and 1,200-V rated products to 300 A to meet the market demands for high capacities.

Table 2 shows a functional comparison between the high power X Series IPMs and high power V Series IPMs.

3. Features

This chapter describes the loss reduction, which is the most important feature of the high power X Series IPM.

3.1 IGBT saturation voltage and turn-off loss

The 7th-generation IGBT has improved the trade-off characteristics between collector-emitter saturation voltage and turn-off loss by miniaturizing the surface trench gate structure and thinning the drift layer using thin wafer processing technology.[1),5)]

Figure 3 shows the trade-off characteristics between $V_{CE(sat)}$ and E_{off} of the 1,200-V high power X Series IPM. Compared to the conventional high power V Series IPM, the high power X Series IPM has reduced the saturation voltage by approximately 0.3 V while maintaining the same turn-off loss. In addition, by optimizing the field stop (FS) layer of the backside structure, Fuji Electric achieved higher chip breakdown voltage compensating the drop due to wafer thinning and also got reduced voltage oscillation during turn-off.

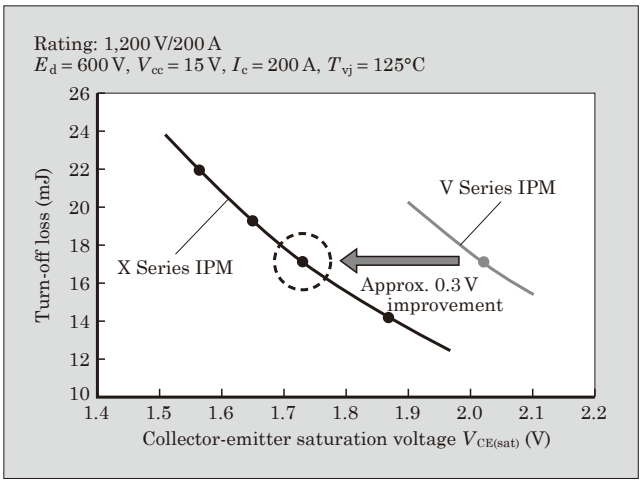

Fig.3 Collector-emitter saturation voltage and turn-off loss trade-off

3.2 Turn-on loss

In general, the higher is the junction temperature of the IGBT chip, the smaller is the voltage change rate dv/dt and the higher is the switching loss of the IGBT. On the other hand, increasing the gate drive current to reduce switching loss and increasing dv/dt during switching will tend to increase emission noise.

The high power X Series IPM features a new function that optimally controls the gate drive current during turn-on according to the IGBT chip junction temperature in order to reduce the turn-on loss during switching. It monitors the IGBT chip temperature in real time using the temperature sensor built into the IGBT chip. This enables the driver to control the gate current switching so that dv/dt during the operation does not decrease due to temperature rise.[(1)-(3)]

The high power X Series IPM has been optimized so that dv/dt at switching will follow the gate current changeover and make the new IPM's equivalent or lower than that of the conventional and industry-proven high power V Series IPM, enabling the X-IPM to reduce switching loss and also suppressing the emission noise.

Figure 4 shows the simulation results for the generated loss of a 1,200-V/200-A IPM during PWM inverter operation. As a result of the above mentioned characteristic enhancements, the generated loss of the high power X Series IPM has reduced by approximately 7% compared to the high power V Series IPM.

Figure 5 shows the emission noise comparison between the above mentioned types. As a result, the emission noise of the high power X Series IPM remains at the same level of the high power V Series IPM.

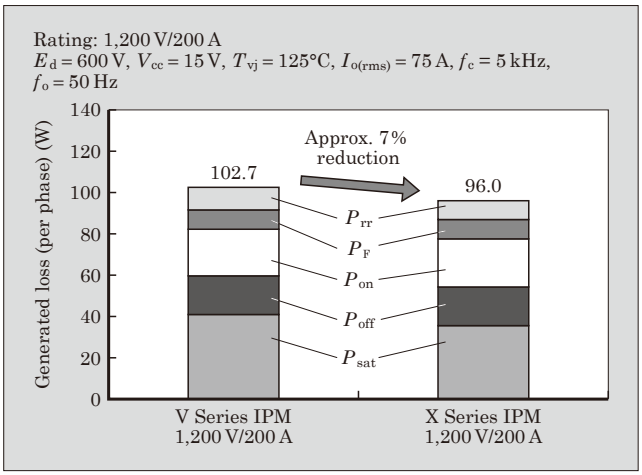

Fig.4 Comparison of generated loss

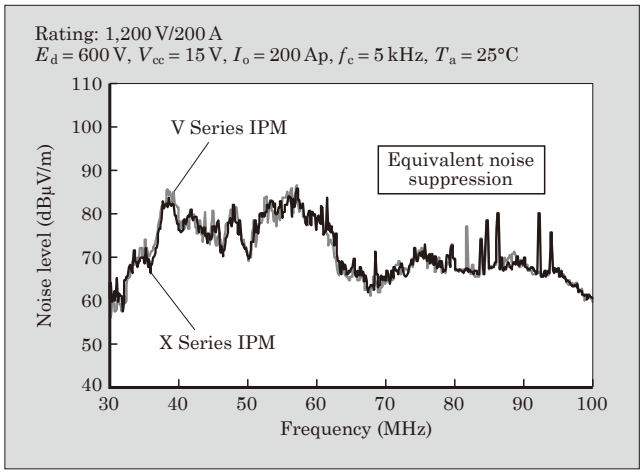

Fig.5 Comparison of emission noise (relative comparison test results)

4. High Temperature Operation

Table 3 compares the operating temperatures of the high power X Series IPM with those of the V Series ones. The high power X Series IPM employs the 7th-generation packaging technologies for high temperature operation, which use high heat resistant gels and high reliability solders, thus taking advantage from the new chip characteristics and raising the chip junction temperature T_{vjop} during continuous operation from 125°C to 150°C and maximum chip junction temperature T_{vjmax} from 150°C to 175°C compared to the high power V Series IPM.

In order to achieve high temperature operation for these products, Fuji Electric has improved the accuracy of the protective operating temperature of the chip overheat protection function built into the IPM. The temperature detection device for chip overheat protection, which is embedded into the IGBT chip itself, is a diode having a temperature-dependent output voltage. The output voltage of the diode is detected by the control IC to monitor the chip temperature and provide overheat protection. Figure 6 shows the relationship between the chip junction temperature and output voltage of the chip temperature detection diode built into the IGBT. The output voltage change per 1°C in the temperature detection diode of the high power X Series IPM is approximately three times bet-

Table 3 Comparison of operating temperatures

Item	V Series IPM	X Series IPM
Maximum case temperature T_{cmax}	110°C	125°C
Chip junction temperature during continuous operation T_{vjop}	125°C	150°C
Maximum chip junction temperature T_{vjmax}	150°C	175°C

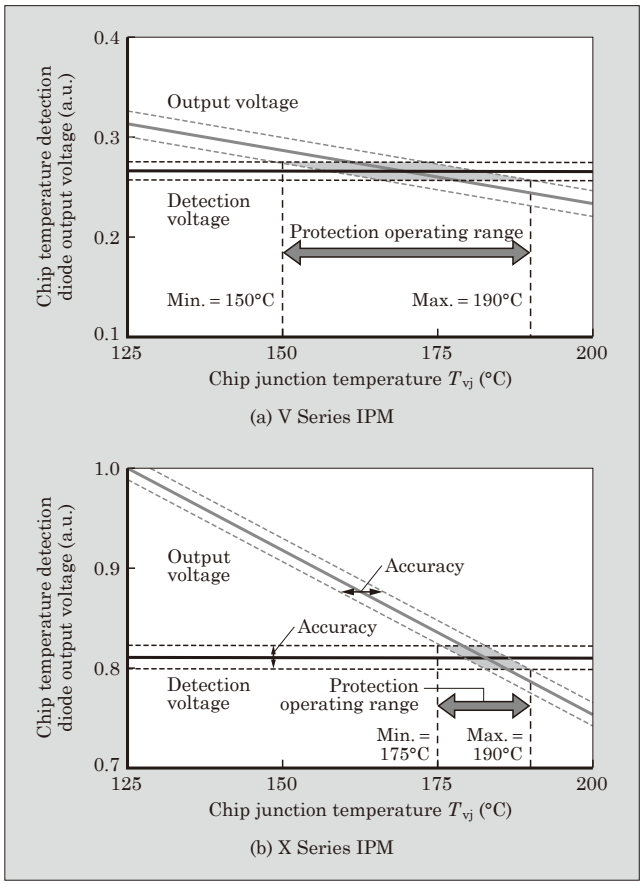

Fig.6 Output voltage-temperature characteristics of chip temperature detection diode

ter than that of the high power V Series IPM. Furthermore, the fluctuation in the detection voltage of the high power X Series IPM is approximately half that of the high power V Series IPM, allowing to increase its lower temperature limit from 150°C to 175°C without changing the upper temperature limit for chip overheat protection. This enables high-temperature operation. The upper temperature limit for chip overheat protection is the same as that of the high power V Series IPM, eliminating thermal breakdown risk.

5. Expanded Output Current

The high power X Series IPM offers higher power density by the increased output current achieved through the higher IGBT chip junction temperatures and lower generated losses. Figure 7 shows a comparison of the output currents versus the chip junction temperatures of an inverter, which is a typical characteristics of power conversion equipment, when it uses respective IPMs. The high power X Series IPM can output higher current than the high power V Series IPM by approximately 1.3 times.

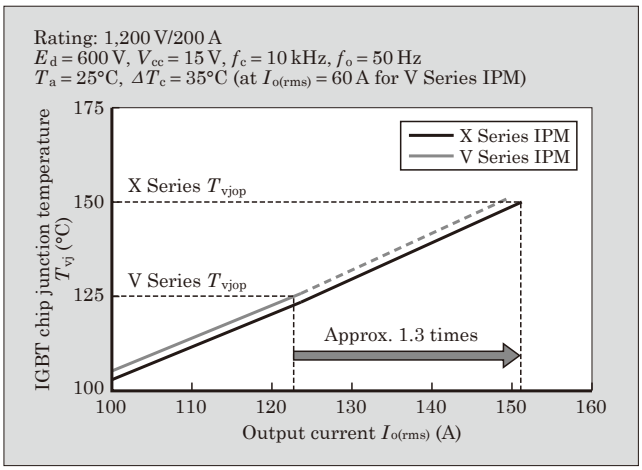

Fig.7 Expansion of output current

6. Faster Short-Circuit Protection

The high power X Series IPM retains the same external dimensions as previous types while aenhancing the maximum current rating without increasing the chip size. Therefore, it is necessary to protect them avoiding to increase the short-circuit energy during short circuits. The high power X Series IPM has speeded up the operation of the gate voltage suppression circuit and shortened the delay times during short circuits, resulting in faster short-circuit protection.

Figure 8 compares the short-circuit waveforms

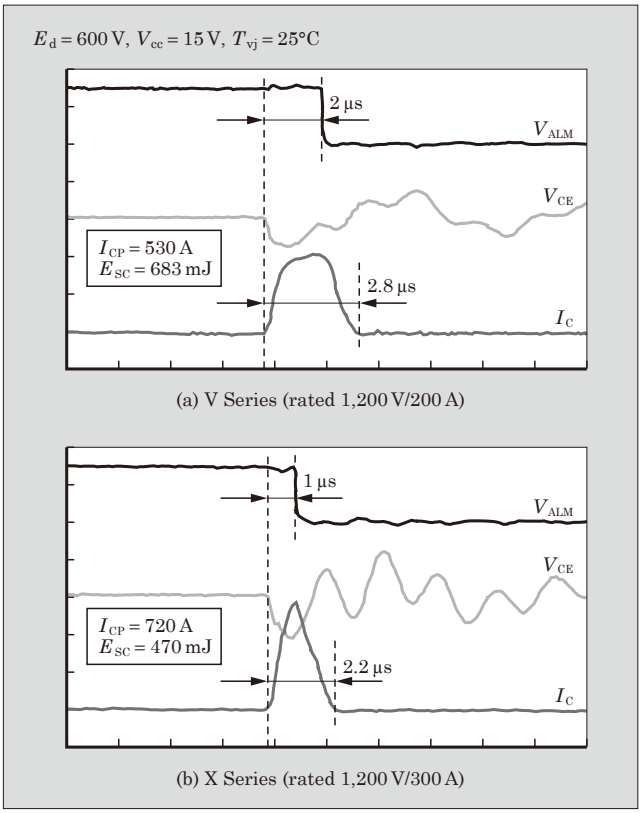

Fig.8 Comparison of short-circuit waveforms

of the maximum rated high power V Series IPM (1,200 V/200 A) and the maximum rated high power X Series IPM (1,200 V/300 A). The high power V Series IPM over current protection circuit takes 2 μs from the start of short-circuit current flow until alarm signal is released to output, but the high power X Series IPM has reduced this time to 1 μs. This allows the high power X Series IPM to suppress short-circuit energy by approximately 30% during short circuits, contributing to the increase of the current ratings.

7. Postscript

In this paper, we described the "P631" packaged 7th generation "X Series" high power IGBT-IPM.

Fuji Electric is confident that the expansion of our line-up "X Series" high power IGBT-IPM products will even deliver to power conversion equipment higher outputs, wider functionality and contribute to higher efficiency.

In the future, we intend to promote further technological innovation and concur to provide countermeasures against global warming, thus creating a responsible and sustainable society through the development of enhanced IGBT modules.

References

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