New Lineup of Large-Capacity "V-Series" Intelligent Power Modules

Naoki Shimizu † **Tatsuya Karasawa** † **Kazumi Takagiwa** †

ABSTRACT

To meet the diversifying needs for power control, Fuji Electric has developed a family of large-capacity intelligent power modules (IPMs). These products with high-performance, new-generation IGBT chips, new control ICs and lower package inductance are able to reduce total power loss and radiated noise, and increase current capacity. A new solder material and divided direct copper bonding (DCB) are employed to enable a ΔTc power cycling capability significantly enhanced. Terminals and screw hole positions are compatible with existing products, allowing existing products to be replaced with the new products without major design changes.

1. Introduction(1)(2)

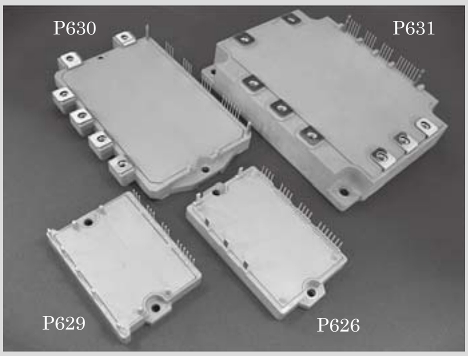
Recently, as essential items for conserving energy and reducing CO_2 emissions in the industrial field, high efficiency power converting equipment is being used more and more. Additionally, the requirements for standard insulated gate bipolar transistor (IGBT) modules that integrate an IGBT chip and a free wheeling diode (FWD) chip into a single package are becoming more diverse. An intelligent power module (IPM) integrates a control IC for internal drive and protection functions into a standard IGBT module. With an IPM, optimized drive control can be performed so that the IGBT can be driven and provided with high reliability protection with low dissipation loss and low noise. IPMs are used in a wide range of applications, such as in motor driven equipment (numerical control (NC) machine tools, general-purpose inverters, servos, elevators, etc.), uninterruptible power supplies (UPS), power conditioning systems (PCS) for solar energy generation, and the like where low dissipation loss and low noise are strongly required.

Since beginning to commercialize IPMs in 1988, Fuji Electric has responded to market requests for lower power dissipation, lower noise and smaller size with each successive generation of devices. In recent years, through developing a "V-Series" IPM using a next-generation trench gate structure field stop (FS) type "V-Series" IGBT chip, even lower power dissipation loss and smaller size have been realized. This paper describes Fuji Electric's new lineup of large capacity "V-Series" IPMs and the large capacity series of IPMs (P631 package).

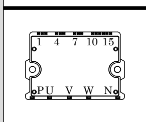
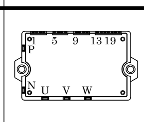
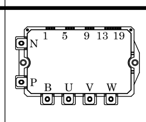
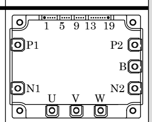
† Fuji Electric Co., Ltd.

2. "V Series IPM" Product Lineup(1)(2)

At present, Fuji Electric's V-Series of IPMs is available in the four packages (small capacity: P629, medium capacity small size: P626, medium capacity low profile: P630, large capacity: P631) as shown in Fig. 1. All of these packages comply with the RoHS



(a) Package appearance

P629 package	P626 package	P630 package	P631 package
			
L49.5×W70 ×H12.5 (mm)	L50×W87 ×H12 (mm)	L84×W128.5 ×H14 (mm)	L110×W142 ×H27 (mm)

(b) Type of package

Fig.1 Appearance of "V-Series" IPM packages

*1: RoHS directive: European Union (EU) directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment directive*1 Fuji Electric plans to expand further the V-Series IPM product lineup, increasing the capacity beyond that of the previous "R-Series" IPMs, to rated currents of 20-400 A for the 600 V rated voltage series, and to 10-200 A for the 1,200 V rated voltage series. In addition to the protective functions of overcurrent protection, short-circuit protection, control supply protection in control circuit and IGBT chip over heat protection, which are the same protective functions as had been provided previously, a cause identification function based on the width of the alarm output has been newly added. In the P629 package, the previous method of N-line current detection based on shunt resistance has been changed to a method of IGBT sense current detection, enabling protection in the case of a ground fault in which current flows only through the upper arm element.

Table 1 lists the product lineup and functions of the V-Series of IPMs.

3. Large-capacity "V-Series" IPM Product Overview

3.1 Development goals

Development goals for the large-capacity V-Series of IPMs are as follows.

(1) Reduction of total dissipation loss
(2) Improvement of tradeoff relation between switching loss and radiation noise
(3) Expanded current rating (400 A/600 V, 200 A/1,200 V)
(4) Shorter deadtime
(5) Separate alarm output signal for each cause
(6) Upper arm alarm output (P631: alarm control terminal added for upper arm)
(7) Maintain package compatibility (tapped hole locations, guide pins)
(8) Compliance with RoHS directive
(9) Reduction of internal inductance
(10) Improvement of ΔT_c power cycling capability

Table 1 "V-Series" IPM product lineup and functions

Rated voltage	Rated current	Product type		Internal functions*						Package model
				Both upper and lower arms				Upper arm	Lower arm	
		6-in-1	7-in-1	Drive	UV	TjOH	OC	ALM	ALM	
600 V	20 A	6MBP20VAA060-50	–	○	○	○	○	–	○	P629
	30 A	6MBP30VAA060-50	–	○	○	○	○	–	○	
	50 A	6MBP50VAA060-50	–	○	○	○	○	–	○	
	50 A	6MBP50VBA060-50	–	○	○	○	○	○	○	P626
	75 A	6MBP75VBA060-50	–	○	○	○	○	○	○	
	50 A	6MBP50VDA060-50	7MBP50 VDA060-50	○	○	○	○	○	○	P630
	75 A	6MBP75VDA060-50	7MBP75 VDA060-50	○	○	○	○	○	○	
	100 A	6MBP100VDA060-50	7MBP100 VDA060-50	○	○	○	○	○	○	
	150 A	6MBP150VDA060-50	7MBP150 VDA060-50	○	○	○	○	○	○	
	200 A	6MBP200VDA060-50	7MBP200 VDA060-50	○	○	○	○	○	○	
	200 A	6MBP200VEA060-50	7MBP200VEA060-50	○	○	○	○	○	○	P631
	300 A	6MBP300VEA060-50	7MBP300VEA060-50	○	○	○	○	○	○	
	400 A	6MBP400VEA060-50	7MBP400VEA060-50	○	○	○	○	○	○	
1,200 V	10 A	6MBP10VAA120-50	–	○	○	○	○	–	○	P629
	15 A	6MBP15VAA120-50	–	○	○	○	○	–	○	
	25 A	6MBP25VAA120-50	–	○	○	○	○	–	○	
	25 A	6MBP25VBA120-50	–	○	○	○	○	○	○	P626
	35 A	6MBP35VBA120-50	–	○	○	○	○	○	○	
	50 A	6MBP50VBA120-50	–	○	○	○	○	○	○	
	25 A	6MBP25VDA120-50	7MBP25VDA120-50	○	○	○	○	○	○	P630
	35 A	6MBP35VDA120-50	7MBP35VDA120-50	○	○	○	○	○	○	
	50 A	6MBP50VDA120-50	7MBP50VDA120-50	○	○	○	○	○	○	
	75 A	6MBP75VDA120-50	7MBP75 VDA120-50	○	○	○	○	○	○	
	100 A	6MBP100VDA120-50	7MBP100VDA120-50	○	○	○	○	○	○	
	100 A	6MBP105VEA120-50	7MBP100VEA120-50	○	○	○	○	○	○	P631
	150 A	6MBP150VEA120-50	7MBP150VEA120-50	○	○	○	○	○	○	
	200 A	6MBP200VEA120-50	7MBP200VEA120-50	○	○	○	○	○	○	

* : Drive: IGBT drive circuit, UV: Control supply undervoltage protection, TjOH: IGBT chip over heat protection, OC: Overcurrent protection, ALM: Alarm output

3.2 Characteristics[1][2]

(1) Reduction of total dissipation loss

To improve equipment controllability, as is requested by customers, the IPM dissipation loss must be reduced in order to realize a higher carrier frequency and larger output current. Moreover, a reduction in dissipation loss enables the cooling system for the equipment to be simplified, such as with smaller-sized air-cooling fins and fans, and also contributes to a lower overall low cost of the equipment.

Figure 2 compares the total dissipation loss during PWM inverter operation for a V-Series IPM and the previous product (R-Series IPM), both of which are 300 A/600 V devices. The V-Series IPM realizes at least 20% lower dissipation loss than the previous product.

With the V-Series IPM, in the case of a 300 A/600 V device, the static loss P_{sat} and the turn-off loss P_{off} of the IGBT account for approximately 50% of the total dissipation loss during inverter operation. The on-voltage $V_{CE(sat)}$ and turn-off loss E_{off} characteristics that determine these two types of loss have a tradeoff relationship with the short-circuit withstand capability of the IGBT. Improving the tradeoff is a key point for reducing the dissipation loss. V-Series IGBT chips for standard IGBT modules feature an optimized surface structure to reduce the resistance of the drift layer and make the chip thinner, thereby lowering $V_{CE(sat)}$ and improving E_{off}[3]. On the other hand, IGBT chips for V-Series IPMs feature an even finer surface structure and an improved tradeoff relationship with $V_{CE(sat)}$ and E_{off}[4]. As a result of the finer structure, however, because $V_{CE(sat)}$ decreases and the current flows with greater ease, short-circuit current will increase and the short-circuit withstand capability (allowable time) will decrease. Therefore, a chip that features an improved tradeoff relationship between $V_{CE(sat)}$ and E_{off} can be used to speed up the short-circuit protection function.

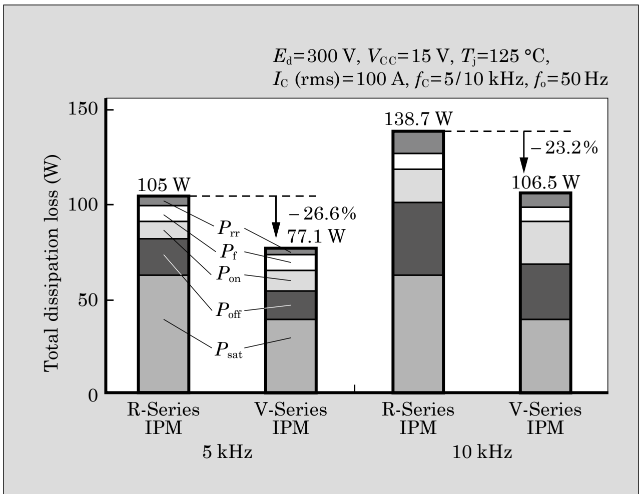


Fig.2 Comparison of total dissipation loss in 300 A/600 V products

For the 600 V series, because the rated current is larger and the difference between rated voltage and working voltage is smaller than the 1,200 V series, the design must take into consideration the surge voltage. In addition to reducing the internal impedance of the package, as will be described later, by shifting the $V_{CE(sat)}$ and E_{off} tradeoff to the low $V_{CE(sat)}$ side where the turn-off di/dt is smaller, the device was optimized so that the surge voltage would be equivalent to that of previous products.

(2) Improvement of tradeoff relation between switching loss and radiation noise

A tradeoff relationship exists between switching loss and radiation noise. To improve this relationship, the internal capacitance of the IGBT was reduced, the temperature dependence of the control IC was improved, and the internal circuit wiring pattern of package was optimized[5]. As a result, in a relative comparison of radiation noise using inverter test equipment, the peak radiation noise in a 300 A/600 V product was reduced by approximately 3 dB compared to the previous product as is shown in Fig. 3.

(3) Expanded current rating (400 A/600 V, 200 A/1,200 V)

With the V-Series large-capacity IPM (P631), the two power chips (IGBT and FWD) used in parallel in the R-Series large-capacity IPM (P612) are integrated into a single chip, and the chip size is miniaturized and optimized to reduce the total area of the 300 A/600 V power chip by 32%. By configuring the control circuit as a two-level structure positioned above the power unit, the product series could be expanded to 400 A/600 V and 200 A/1,200 V in an package of equivalent size and having the same mounting position as previous products. This was a first in the industry.

(4) Shorter deadtime

For the purpose of preventing upper and lower arm short circuits, the inverter control is provided with a deadtime interval. Shortening the deadtime interval is important for improving waveform distortion and rotational unevenness. With V-Series IPMs, the control IC switching time has been optimized and temperature dependence has been improved to reduce the minimum deadtime interval to 1 µs from the previous value of 2.4

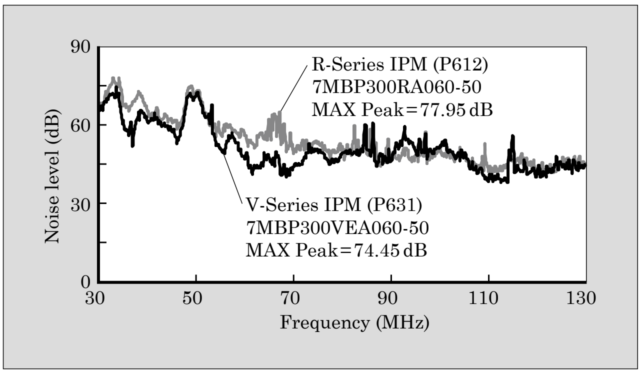


Fig.3 Comparison of radiation noise

issue: Power Semiconductor contributing in energy and environment region

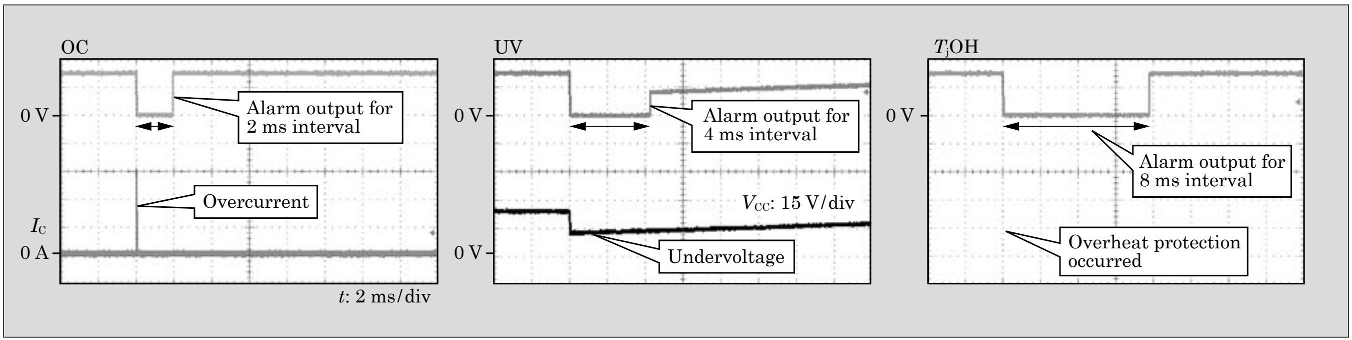


Fig.4 Alarm cause identification function

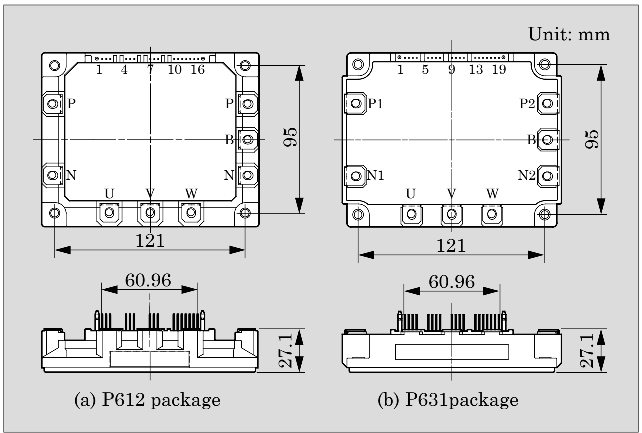


Fig.5 Package dimensions

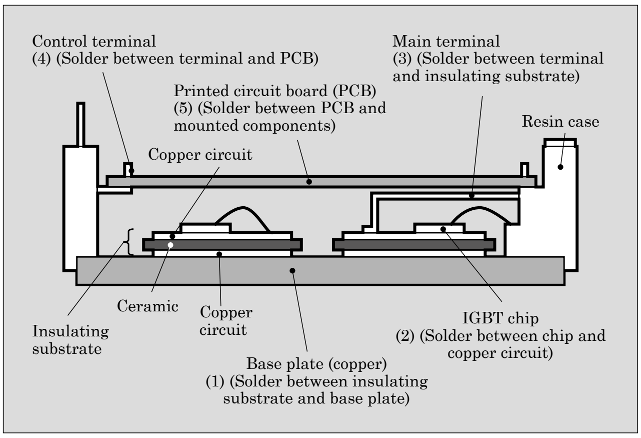


Fig.6 Internal structure of P631 package

µs.

(5) Separate alarm output signal for each cause

With V-Series IPMs, the widths of outputted alarm pulses differ according to the alarm cause (see Fig. 4). As a result, the cause of the protective alarm can be identified easily, and after the equipment has been stopped by the IPM alarm, cause analysis and restoration can be performed in a shorter amount of time.

4. Package

4.1 Package dimensions

Figure 5 shows the dimensions of the P631 and P612 packages. The P631 is provided with the same mounting holes, terminal locations and height dimensions as the existing P612, and maintains package compatibility when being installed in equipment. Additionally, an alarm output terminal has been added to each phase of the upper arm, and the terminal pitch and total width of the control terminals was made common.

4.2 Compliance with RoHS directive

Figure 6 shows the internal structure of the P631 package. In a conventional IPM, lead is used primarily at soldering locations. Solder material is used at five locations: (1) the junction between the insulating substrate and base plate, (2) the junction between the chip and copper circuit, (3) the junction between main terminals and the insulating substrate, (4) the junction between control terminals and the printed circuit board, and (5) the junction between the printed circuit board and mounted components. The P631 uses lead-free solder at all of these locations, and is compliant with the RoHS directive.

4.3 Reduction of inductance

Figure 7 shows a schematic drawing of the internal wiring, and Fig. 8 compares the results of measurement of the internal inductances of the P631 and P612 packages. Aiming to reduce internal inductance through the mutual inductance effect, a parallel plate configuration employing overlapping P and N line terminal bars was used. As a result, the internal inductance is reduced by approximately 22% compared to the P612 package, and an effect is obtained whereby the radiation noise is lower and the turn-off surge does not become excessive, as described in Section 3.

4.4 Improvement of ΔT_c power cycling capability

IGBT modules are typically formed by soldering together a base having a heat dissipating surface and an insulated circuit board. Because these materials have different coefficients of thermal expansion, stress is repeatedly generated in the soldered junction between the materials whenever the temperature changes. In a ΔT_c power cycling test in which the case temperature was varied, it was confirmed that solder in the junction between the insulating substrate and the base plate will crack, expand and ultimately break.

With the P631 package, the insulating substrate has been subdivided and miniaturized to ease the stress on the solder. Additionally, the solder material used in the junction between the insulating substrate and the base plate has been changed to material having higher mechanical strength. As a result, ΔT_c power cycling capability at ΔT_c=80 K has been improved by more than twice as that of the P612.

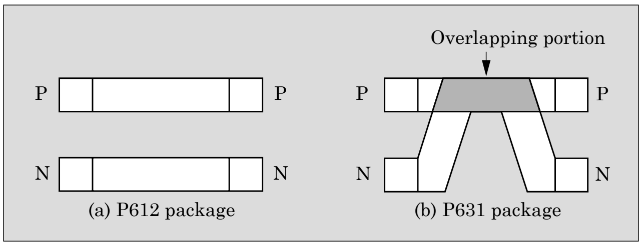


Fig.7 Schematic of internal wiring in package

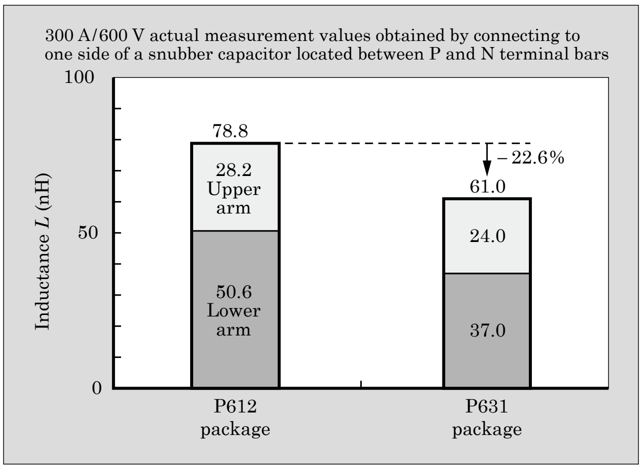


Fig.8 Comparison of results of internal inductance measurement

5. Postscript

This paper has described Fuji Electric's new lineup of large-capacity "V-Series" IPMs and the large-capacity series of IPMs (P631 package). The V-Series of IPMs realize low power dissipation, low noise and RoHS compliance, as requested in the marketplace, and also provide such value-added features as larger capacity, shorter deadtime, an alarm cause identification function, and package compatibility.

In the future, Fuji Electric intends to continue to improve the performance and expand the lineup of available packages, and will focus on developing products capable of contributing to the conservation of energy and protection of the environment.

References

(1) Motohashi, S. et al. "The 6th Gen. Intelligent Power Module," in Proc. 2011 PCIM, p.161-166.

(2) Shimizu, N. et al. V Series' Intelligent Power Modules. FUJI ELECTRIC REVIEW. 2010, vol.56, no.2, p.60-64.

(3) Kobayashi, Y. et al. "The New concept IGBT-PIM with the 6th generation V-IGBT chip technology," in Proc. 2007 PCIM.

(4) Momose, M. et al. "A 600 V Super Low Loss IGBT with Advanced Micro-P Structure for the next Generation IPM," in Proc. 2010 ISPSD.

(5) Onozawa, Y. et al. "Development of the next generation 1200 V trench-gate FS-IGBT featuring lower EMI noise and lower switching loss," in Proc. 2007 ISPSD, p.13-16.