7th-Generation “X Series” IGBT-IPM with “P644” Compact Package

TERASHIMA, Kenshi* OYOBIKI, Tatsuya* OSE, Tomofumi ‡

ABSTRACT

Fuji Electric has developed a new IGBT-IPM to meet the requirements of the further miniaturization, high efficiency, and high power of conversion systems by using the “P644” package, which is the industry’s smallest class for IPMs equipped with a brake circuit. This IPM is included in our line-up of the “X Series” IPMs, which uses a 7th-generation chip and packaging technologies. The new X Series IPM has lower power dissipation than the conventional “V Series” IPMs using “P636” by approximately 17% and can operate in high-temperatures up to 150 °C. These enhancements can reduce the module footprint by approximately 12% and increase inverter output current by approximately 26%.

1. Introduction

Global warming and energy savings have been important issues in recent years. To solve these issues, it is essential to improve power semiconductors, which are key devices in power electronics power conversion systems that consume energy efficiently and contribute to solving energy problems.

Through the commercialization of insulated gate bipolar transistor (IGBT) modules, Fuji Electric has contributed to the miniaturization, efficiency improvement and output power enhancement of power conversion systems. The IGBT-intelligent power module (IPM) is a highly functional IGBT module that incorporates an IGBT gate drive circuit and a protection circuit into an ordinary IGBT module consisting of IGBTs and free wheeling diodes (FWDs)(1). The gate drive circuit has been optimally designed to achieve lower power dissipation in accordance with customer requirements. This will improve the trade-off characteristics between switching loss and emission noise. In addition to improving IGBT and FWD installed in IPM, the temperature rise during operation has been reduced by the dynamic control of the gate drive power, miniaturizing the IGBT-IPM.

To meet the demand for higher efficiency and output power and further miniaturization of the power conversion systems, the 7th-generation IGBT-IPM (X Series IPM) adopts the “P644” package, which is the smallest class of IGBT-IPMs having a built-in brake circuit has been developed.

In this paper, the characters of the new product and its effect on the power converter is described.

* Electronic Devices Business Group, Fuji Electric Co., Ltd.
‡ Fuji Electric (Shenzhen) Co., Ltd.

2. Overview of the Product

Figure 1 shows the external appearance of the newly developed the X Series IPM “P644” package (X-P644). Figure 2 shows the circuit block diagram. The outline dimensions of the P644 package are W87.0 × D50.2 × H12.0 (mm). It has a 7-in-1 circuit configuration in which a three-phase inverter circuit and a brake circuit are integrated into a single module. The brake circuit eliminates an external brake circuit and it contributes to the downsizing and space-savings of power conversion systems.

Table 1 shows the product line-up of the X-P644. The product line-up consists of 50 A and 75 A for 650-V rating, and 25 A and 35 A for 1,200-V rating. The X-P644 is smaller than the conventional P636 V Series IPMs in the same rating range, and the footprint size has been reduced by 12%.

By reducing the losses of the IGBT chip using the 7th-generation chip technology and improving the gate drive circuit, the total power dissipation

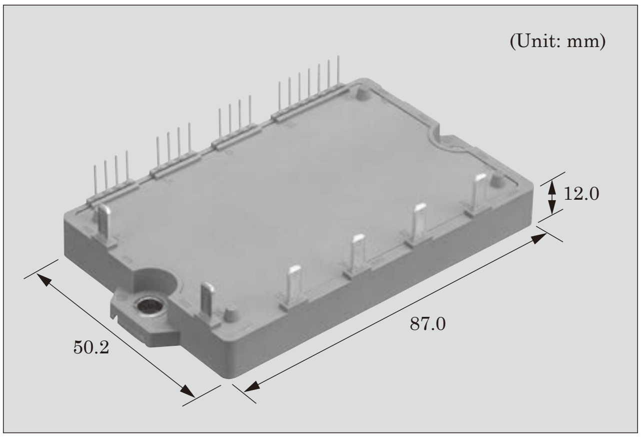

Fig.1 External product appearance of the X Series IPM "P644"

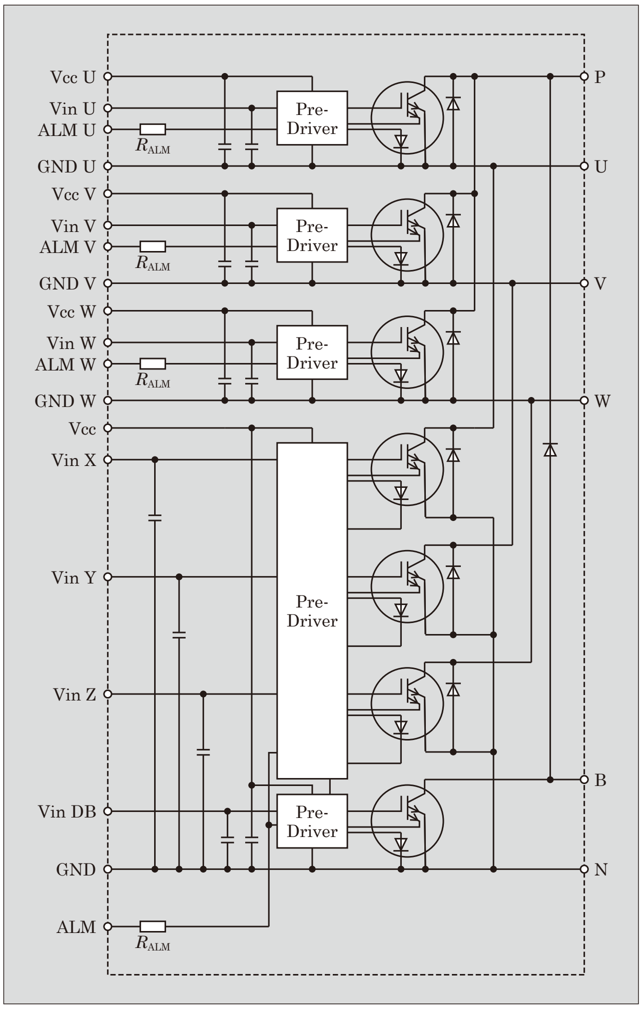

Fig.2 Circuit block diagram

Table 1 Product line-up

Rated voltage	Rated current INV	Rated current DB	Product type	Built-in function
650 V	50 A	30 A	7MBP50XJA065-50	○ IGBT drive circuit ○ Overcurrent protection ○ Control power supply input voltage reduction protection ○ Chip heating protection ○ Alarm output (upper and lower arms)
	75 A	50 A	7MBP75XJA065-50	
1,200 V	25 A	15 A	7MBP25XJA120-50	
	35 A	25 A	7MBP35XJA120-50	

of the module is smaller than that of the conventional V Series IPMs. In addition, the guaranteed continuous operation junction temperature T_{vjop} has been increased to 150 °C from 125 °C in the V Series IPMs, enabling high-temperature operation.

The alarm output function of the break circuit in the X Series IPM is independent from the other lower arm*1 protection function. The conventional V Series IPM stops the operation of all lower arms, including the brake circuit when the lower arm alarm function is activated. Therefore, when the lower arm protection is activated, the brake circuit is unable to consume the rotational energy of the motor, and the voltage between P and N terminals is increased. In the worst case, some semiconductor devices are damaged due to the overvoltage. To solve this problem, the brake circuit of the X Series IPMs independently detects an error and outputs an alarm. This suppresses the increase in the P-N voltage due to regeneration power during breaking the motor. In the event of protection is activated in the brake unit, the other lower arms of the inverter unit are protected simultaneously with the brake unit as before[1].

3. Miniaturization and Reduction of Power Dissipation

3.1 Improvement of turn-off characteristics

When attempting to achieve both miniaturization of package and high power output of the X-P644, increasing of chip temperature due to heat concentration and thermal interference inside the package caused by the increase in power density had to be solved. To overcome this challenge, it was important to reduce the power dissipation of IGBT-IPMs.

The 7th-generation IGBT has improved the trade-off characteristics between collector-emitter saturation voltage and turn-off loss by miniaturizing the trench-gate structure on the surface and thinning the drift layer using thin wafer processing technology[2],[3].

Figure 3 shows the trade-off characteristics between saturation voltage and turn-off loss for the X-P644 and the conventional V Series IPM “P636” (V-P636). The X-P644 reduces the saturation voltage by approximately 0.1 V and turn-off loss by approximately 29% compared with the V-P636. As a result, as shown in Fig. 7, the sum of steady-state loss P_{sat} and the turn-

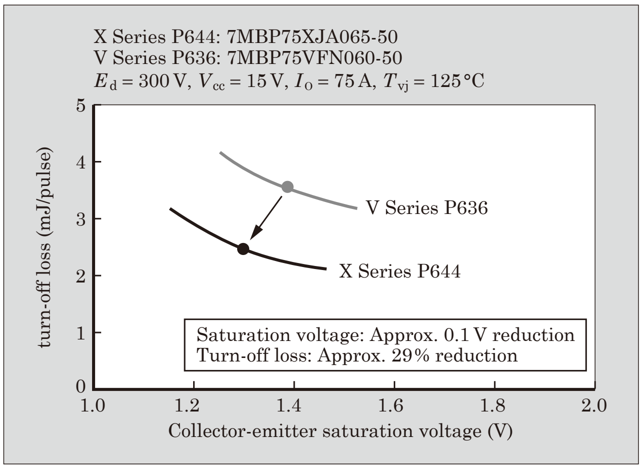

Fig.3 Trade-off characteristics of the 7th-generation IGBT

*1 For information on the upper and lower arms, refer to “Supplemental explanation” on page 243.

off loss, which account for approximately 60% of the total power dissipation in an IGBT-IPM, is lower for the X-P644 than the V-P636 by approximately 19% in continuous operation of inverter applications.

In addition, by optimizing the field stop (FS) layer of the backside structure, the negative effects due to thinning of wafers such as the blocking voltage reduction and voltage oscillation at the time of turn-off was avoided.

3.2 Improvement of turn-on characteristics

To reduce the power dissipation of the X-P644, the turn-on loss of the IGBT, which accounts for approximately 20% of the power dissipation in an inverter application, was improved in addition to the improvement of the IGBT trade-off characteristic described above. As shown in Fig. 4, the X-P644 reduced the turn-on loss by approximately 13% compared with the V-P636.

The X Series IPM is equipped with a new function of dynamic control of the gate drive power when the IGBT turns on according to the chip junction temperature of the IGBT to reduce the turn-on loss during switching. In general, the higher the temperature, the smaller the voltage change dv/dt and current change di/dt, and switching becomes slow. Therefore, the power dissipation increases at high temperature. For the X Series IPMs, the temperature of the IGBT is monitored in real time by using temperature sensors built into the IGBT, and the turn-on drive power is dynamically switched and controlled so that the voltage change dv/dt and current change di/dt during switching are not reduced due to high temperature[1]. As shown in Fig. 5, the turn-on loss at the rated current can be reduced by approximately 25% using this function.

If the switching characteristics dv/dt and di/dt are increased to reduce the switching loss, the emission noise becomes larger. In other words, there is a trade-off between switching loss and emission noise. The X Series IPMs have optimized the dynamic control of turn-on drive power so that the dv/dt and di/dt are equivalent to those of the conventional V Series IPMs. Therefore, the radiated noise suppression and the switching loss reduction are achieved. As shown in Fig. 6, the emission noise of the X-P644 is at the same level as that of the V-P636 for the same rated product (650 V / 75 A).

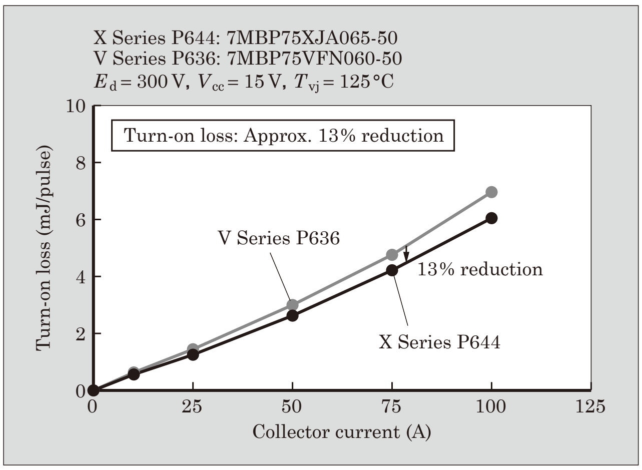

Fig.4 Comparison of turn-on loss

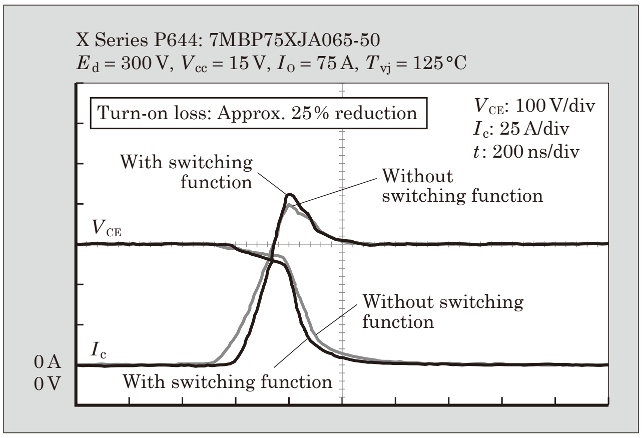

Fig.5 Effect of improvement of turn-on loss by turn-on drive capability switching function

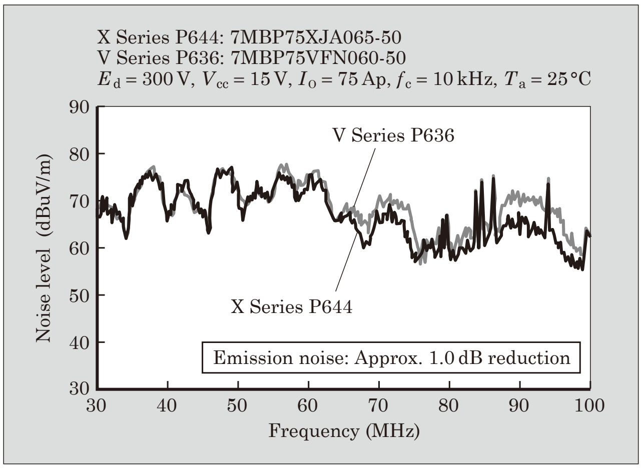

Fig.6 Comparison of the emission noise (the result of the relative comparison test)

3.3 Power dissipation for inverter application

Figure 7 shows the simulation results of the power dissipation while operating the PWM inverter for the same rated X-P644 and V-P636 (650 V / 75 A). Due to the improvements of characteristics applying new technologies, the total power dissipation of the X-P644 was reduced by approximately 17% during continuous operation and by 8% during motor lock*2 operation (f_c =

*2 Motor lock is a state in which the motor maintains a position in a controllable state. For example, if the stopping position is displaced due to an external force, the motor lock function will activate to return it to its stopping position.

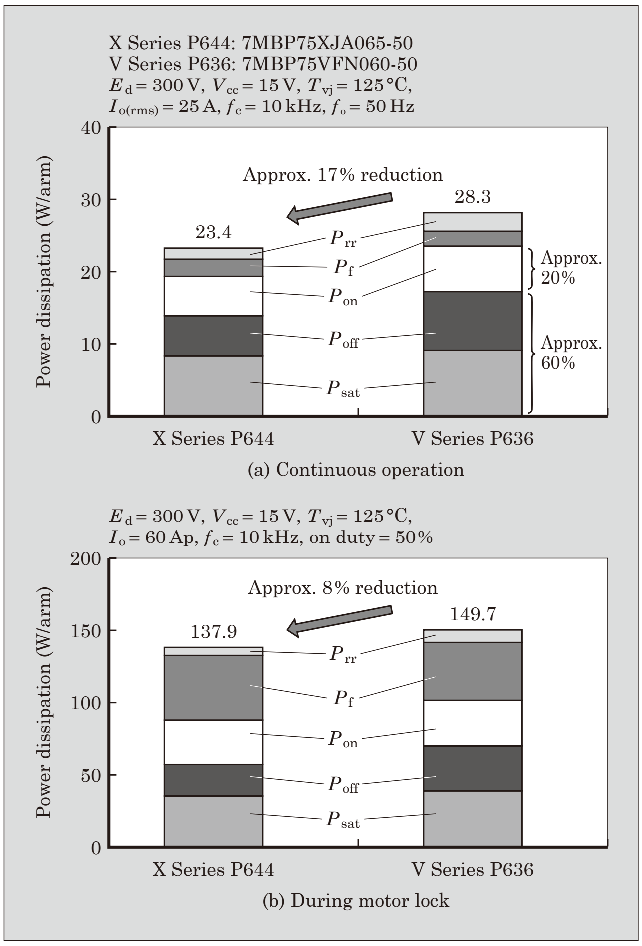

Fig.7 Comparison of power dissipation by simulation

10 kHz) compared with the V-P636.

4. Operation at High Temperatures

Table 2 shows a comparison of the maximum rating of operating junction temperatures of the X-P644 and the V-P636. The X-P644 can operate at high temperature by adopting the 7th-generation package technologies, such as high heat-resistant gel and high-reliability solder. These technologies increase the allowable continuous operating junction temperature T_{vjop} to 150 °C from 125 °C in V Series IPMs and the maximum junction temperature T_{vjmax}, to 175 °C from 150 °C[(1)-(3)].

Table 2 Comparison of the maximum operating temperature

Item	X Series IPM	V Series IPM
Maximum case temperature T_{cmax}	125 °C	110 °C
Chip junction temperature at the time of continuous operation T_{vjop}	150 °C	125 °C
Maximum chip junction temperature $T_{vj\,max}$	175 °C	150 °C

5. Adoption of Low Cost Insulating Substrate

The conventional product, the V-P636, which uses AlN (aluminum nitride) material that has high thermal conductivity, was suppressed in the temperature rising due to the thermal concentration by the lower thermal resistance. On the other hand, the X-P644 has a wider operating temperature range because it allows the chip to operate at higher temperatures. Furthermore, since the power dissipation was reduced, the X-P644 can use Al_2O_3 (alumina) material for insulating substrate, which is lower cost than AlN material and widely used in general, was adopted as the insulating substrate to achieve a lower price.

Transient heat transfer analysis using the finite element method (FEM) was performed to confirm the temperature rise due to thermal concentration and thermal interference by the modified insulating substrate and miniaturized package of the X-P644. Figure 8 shows a comparison of the temperature distribution simulation results for the X-P644 and V-P636 under the same continuous operating conditions. The V-P636 has a margin of only 5 °C to the junction temperature limit of T_{vjop} = 125 °C for continuous operation, while the X-P644 has a wide margin of 26 °C to the junction temperature limit of T_{vjop} = 150 °C. Therefore, the Al_2O_3 material insulating substrate can be applied without temperature concern.

6. Miniaturization and Increase of Output Power

As shown in Fig. 9, the X-P644 can increase the output current by approximately 26% compared with the V-P636.

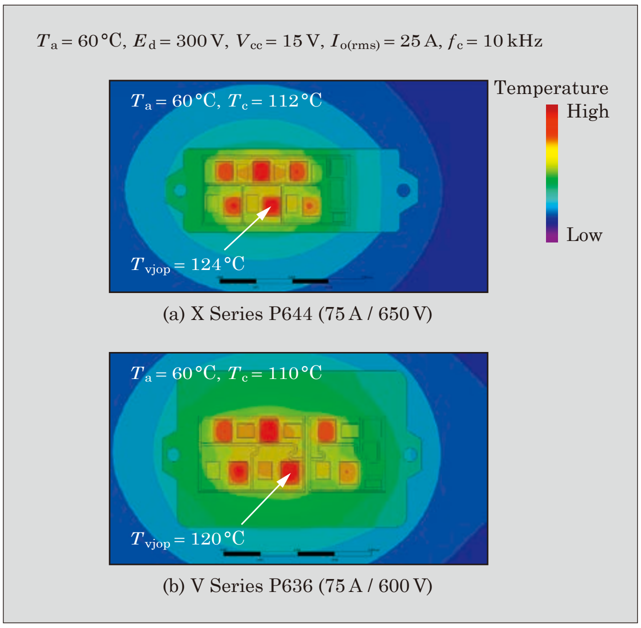

Fig.8 Comparison of temperature distribution during continuous operation (the result of transient heat transfer analysis)

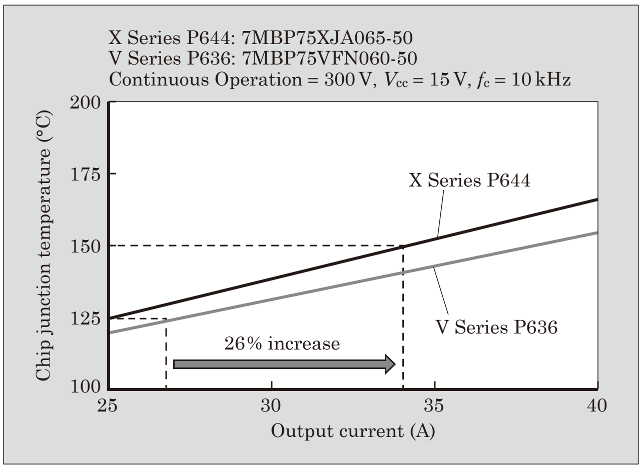

Fig.9 Output current and junction temperature of the power converter

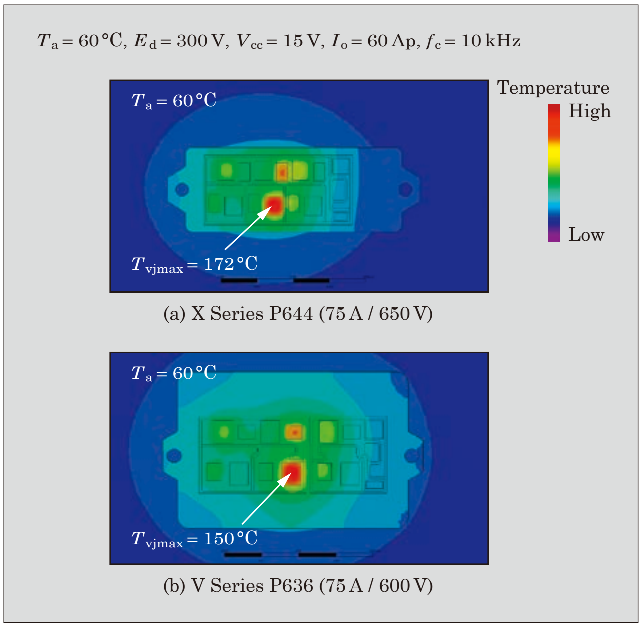

Fig.10 Comparison of temperature distribution during the motor lock operation (results of transient heat transfer analysis)

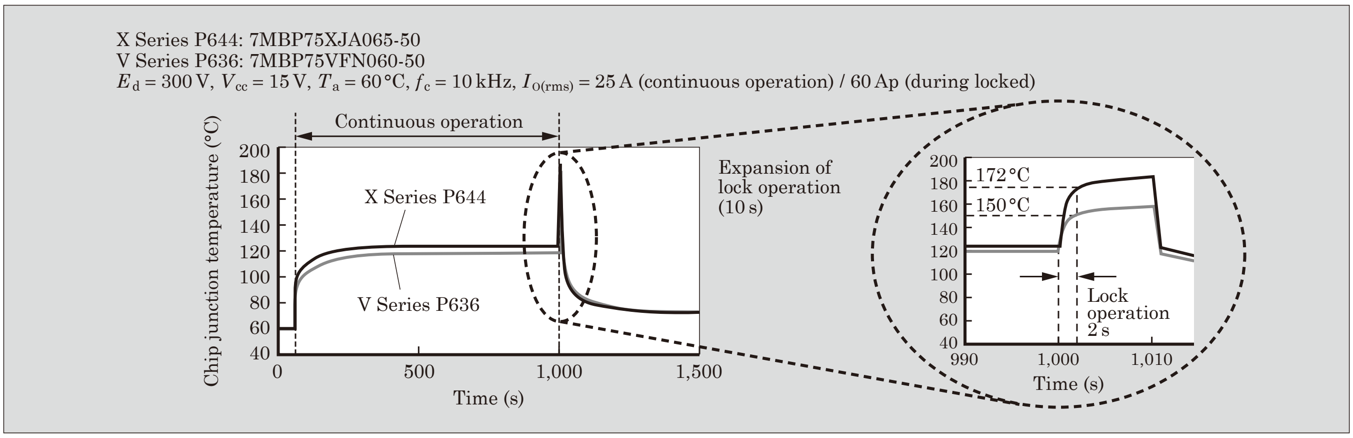

Fig.11 Comparison of junction temperature increase (transient heat transfer analysis results)

Figure 10 shows a comparison of the temperature distribution between X-P644 and V-P636 under the situation that the motor state became lock-operation from the continuous-operation in Fig. 8. Under the same motor-lock operating conditions as the V-P636, the X-P644 has a higher junction temperature of T_{vj} = 172 °C due to miniaturization of the package. However, it is lower than the maximum junction temperature of T_{vjmax} = 175 °C, therefore, it can be used under the same conditions as conventional V-P636. Figure 11 shows a comparison of the junction temperature waveforms during the series of operations described above. These results show that replacing the V-P636 with the X-P644 not only reduces the footprint area of the power conversion system module by approximately 12% but also allows for higher output power.

7. Postscript

The new developed 7th-generation "X Series" IGBT-IPM based on the compact "P644" package is described.

With the addition of the P644, the industry's smallest class 7-in-1 IGBT-IPM with a built-in 3-phase inverter circuit and brake circuit, to our product line-up, we believe that it will contribute to a wider range of applications by making future power conversion systems higher efficient, smaller size and more cost-effective.

We will continue to promote further technological innovation and contribute to solving global energy and environmental problems through the development of IGBT modules.

References

(1) Minagawa, K. et al. 7th-Generation "X Series" IGBT-IPMs. FUJI ELECTRIC REVIEW. 2019, vol.65, no.4, p.210-214.

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(3) Kawabata, J. et al. "The New High Power Density 7th Generation IGBT Module for Compact Power Conversion Systems". Proceeding of PCIM Europe 2015.

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