# New Lineup of V-Series IGBT Modules

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**ABSTRACT**

Fuji Electric is developing a series of products that use the latest generation "V-Series" IGBTs. V-Series IGBT modules realize lower chip loss and improved package heat dissipation to achieve a smaller IGBT module size and higher power density. The chip and package characteristics have also been improved to enhance reliability and guarantee the maximum temperature of 175˚C. For these high power density and highly reliable V-Series IGBTs, Fuji Electric has developed new packages, such as a large capacity 2-in-1 package and a small sized PIM (Power Integrated Module) package. The product lineup will be expanded up to 1,700 V.

## 1. Introduction

Energy savings and the reduction of $CO_2$ emissions have been seen as important challenges for the industrial sector in recent years. As a result, the demand for inverters is continuing to increase. In consideration of power dissipation, switching capability, drive circuit design and the like, the power semiconductors used most commonly in inverters are IGBTs (insulated gate bipolar transistors).

Fuji Electric developed a line of commercial IGBTs in 1988, and since then has responded to market needs by steadily releasing successive generations of new models that realize low loss and a compact size. Recently, Fuji Electric has realized even lower levels of loss and a more compact size with its lineup of "V-Series" IGBT modules that incorporate the latest generation of IGBTs. Also, the V-Series of IGBT modules feature enhanced chip and package characteristics that improve reliability and enable the guarantee of (non-continuous) operation at chip junction temperatures of $T_j$=175 °C when the inverter is in an emergency operation.

This paper discusses the reliability and product lineup of Fuji Electric's V-Series of IGBT modules.

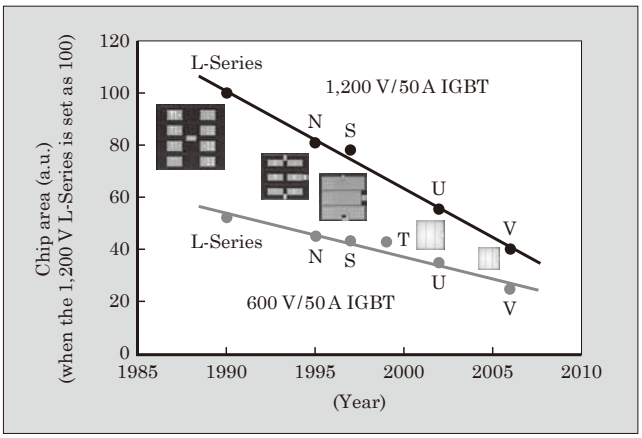
## 2. IGBT V-Series Characteristics[1]

Figure 1 shows the changes in chip size for successive generations of the IGBT chips installed in commercially available IGBT modules. Fuji Electric has reduced the chip size by 50% over 10 years, and the V-Series further shrinks the die size by an additional 30% compared to the U-Series. With the V-Series, the use of a silicon nitride substrate (SiN) having good thermal conductivity as the insulating substrate, in addition to chip improvements, improves the heat dissipation performance and increases the power density of the IGBT module. These improvements contribute significantly to reducing the size and lowering the cost of the entire inverter system. Also, with the V-Series, the optimization of the MOS (metal-oxide-semiconductor) gate structure facilitates control of the abrupt behavior of the IGBT current and FWD (free-wheeling diode) voltage during turn-on switching, which is a cause of EM (electromagnetic) noise[2]. Accordingly, the V-Series of IGBT modules facilitate EM noise reduction and inverter design.

## 3. Reliability of V-Series of IGBT Modules

Not only are the V-Series of IGBT modules compact in size and have good noise controllability, but they are also highly reliable. With the V-Series, non-continuous operation is guaranteed during instantaneous emergency operation at temperatures of up to

Fig.1 Reduction of IGBT chip size

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175 °C, and continuous operation is guaranteed during normal operation conditions at temperatures of up to 150 °C. Compared to the U-Series, this is an increase of 25 °C for each operating state. To make this possible, Fuji Electric improved the reliability and switching capability of the IGBT chip during high-temperature operation, and also improved the package reliability, including the solder and Al bond wires. Details of these accomplishments are described below.

To guarantee operation during instantaneous emergency conditions at temperatures of up to 175 °C, reverse blocking capacity must be maintained even at high temperatures and the chip must be capable of stable switching even at large currents. We have verified that with the V-Series, an IGBT with no lifetime killer and a FWD that uses electron irradiation as carrier lifetime control enables a stable breakdown voltage to be maintained, without thermal runaway, at temperatures of up to 200 °C. Also, to verify the high-temperature switching capability, we have verified IGBT switching and FWD switching at 200 °C. Figure 2 shows IGBT turn-off waveforms for a chip junction temperature $T_j$=200 °C at twice the rated current. Based on these results, the V-Series is able to guarantee operation during instantaneous emergency conditions at temperatures of up to 175 °C.

To guarantee during normal operation at temperatures of up to 150 °C, long-term reliability of the chip's breakdown voltage, and reliability of the package, including solder and wire bonding, are essential. The long-term reliability of a chip's breakdown voltage is usually verified with an accelerated aging test in which a DC voltage is applied to a chip while being heated

Fig.2 High-temperature switching waveform of 1,200 V "V-Series" IGBT

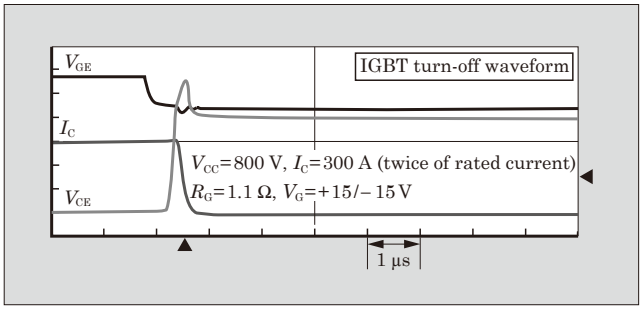



Fig.3 Breakdown voltage reliability test results for 1,200 V "V-Series" FWD

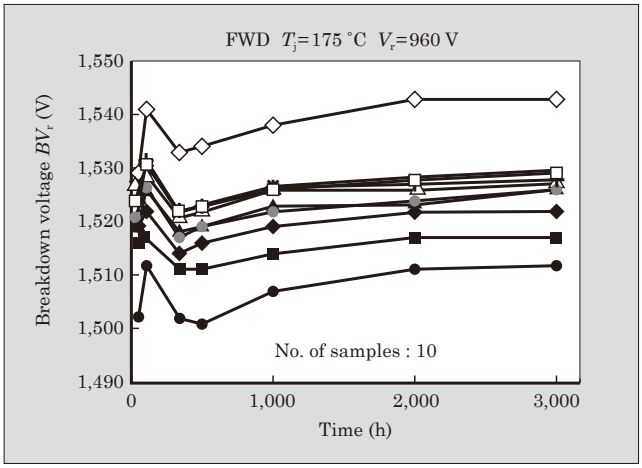



Fig.4 1,200 V "V-Series" power cycle test results

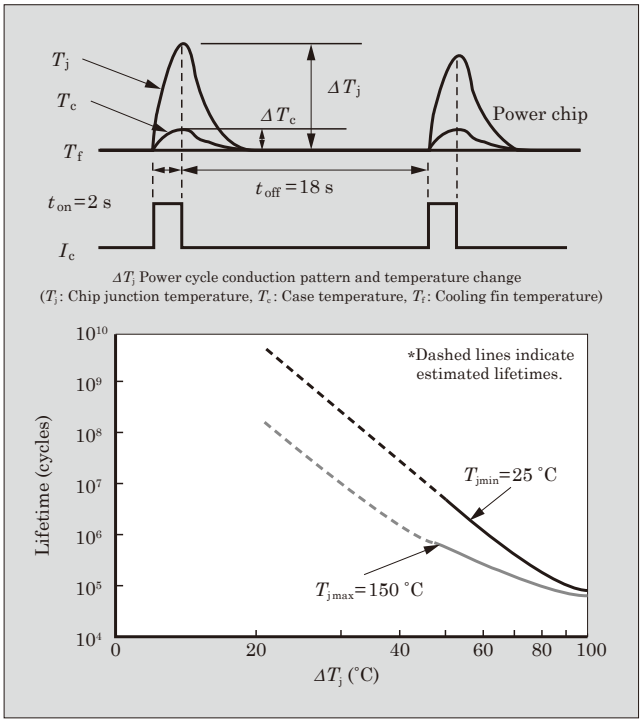



Fig.5 1,200 V "V-Series" PIM series and New Dual series

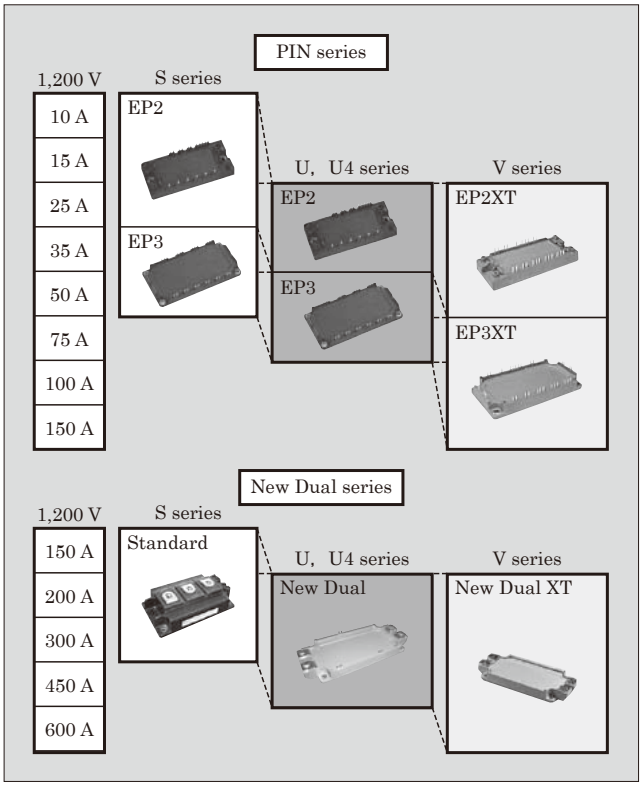
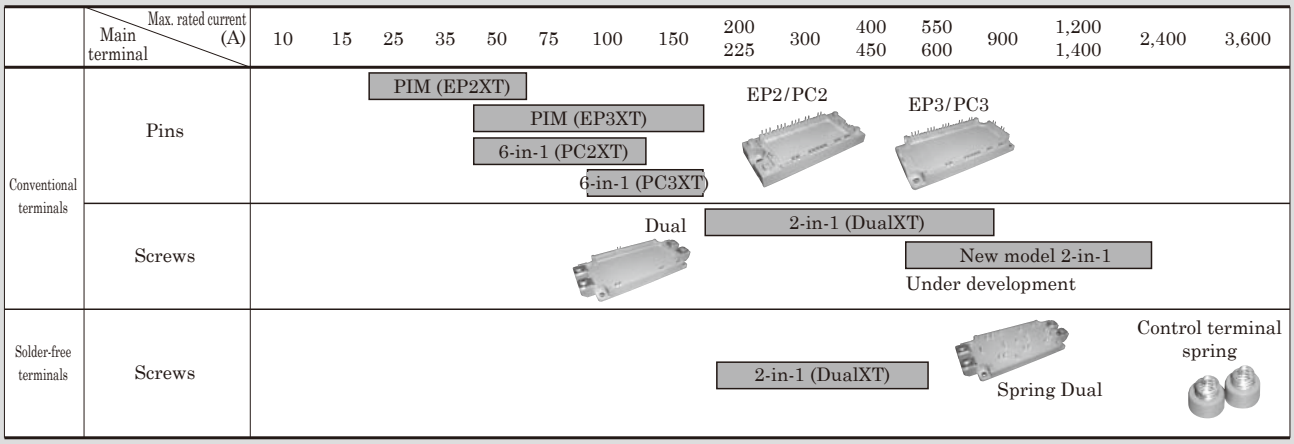
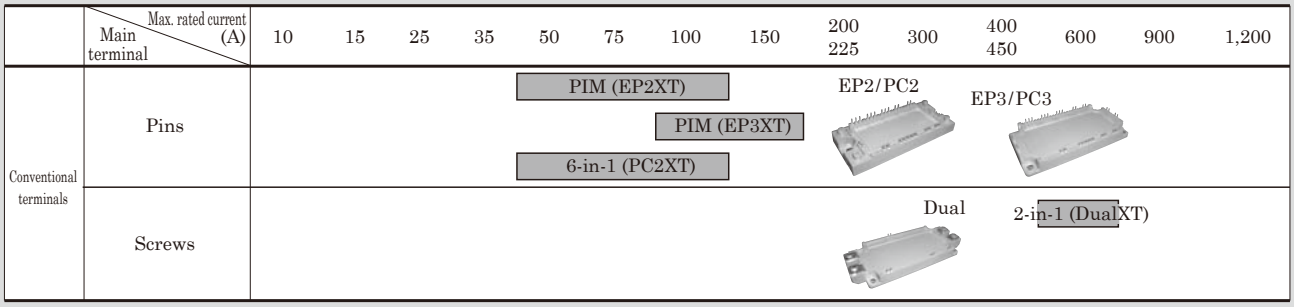


Fig.6 Future expansion of the “V-Series” lineup




(a) 1,200 V series




(b) 600 V series

in an electronic oven. Figure 3 shows the results of a FWD reliability test. For a $T_j$ (chip temperature) of 175 °C, we verified that sufficient reliability is exhibited, without degradation of the breakdown voltage, even after 80% of the rated voltage had been applied for 3,000 hours. An IGBT having a similar junction termination as the FWD was found to have the equivalent reliability.

Typically, in a power module, the package reliability is affected by repeated thermal cycles, wherein a chip becomes hot while in the on-state and then becomes cool during the off-state, and as a result, the solder and wire bonding contact underneath the chip are stressed by thermal expansion and contraction. Sufficient capacity to withstand this stress is necessary. Figure 4 shows the results of a V-Series power cycle test. The $T_{jmin}$=25 °C line indicates the chip's lifetime (number of cycles) when the cooling fin temperature is held constant and the maximum chip junction temperature is varied during the load cycle. For example, $\Delta T_j$=30 °C represents a load cycle in which the cooling fin temperature is 25 °C and the maximum chip temperature is 55 °C. The $T_{jmax}$=150 °C line indicates the chip's lifetime when the maximum chip temperature is held constant and the cooling fin temperature is varied during the load cycle. For example, when $\Delta T_j$=30 °C, the cooling fin temperature is 125 °C and the maximum chip temperature is 150 °C during the load cycle.

As shown in the graph, even if $\Delta T_j$ is the same, higher cooling fin and chip temperatures result in shorter lifetimes. In other words, the $T_{jmax}$=150 °C line represents the worst case operating conditions, but even under these conditions, it was still possible to verify that the V-Series provides sufficient reliability with a lifetime of more than 50,000 cycles at $\Delta T_j$=100 °C. Based on these results, the improvements to the chip and package reliability guarantee the normal operation of the V-Series at temperatures of up to 150 °C.

Thus, the reliability of the V-Series during high-temperature operation has been improved significantly, and this improved reliability contributes greatly to enhancing the inverter reliability and the degree of freedom in the thermal design.

## 4. Lineup of V-Series IGBT Modules

At present, the V-Series is available in PIM (power integrated module) and New Dual models as shown in Fig. 5.

The PIM models integrate upper and lower arm IGBTs and FWDs for 3 phases, a converter diode and a brake IGBT (7-in-1), enabling a 3-phase AC inverter to be configured from a single module. As a result, an

inverter system can be made more compact in size and the design can be streamlined. For the V-Series, the lineup of PIM models was expanded up to a rated current of 150 A.

The New Dual models are provided for use with rated currents of 200 A and above. These modules integrate upper and lower arm IGBTs and FWDs for 1 phase (2-in-1). Three chips are used in parallel inside the module. When power semiconductors are used in parallel, there is a concern that a current imbalance will occur in which current is concentrated in some chips. The New Dual models feature an innovative internal interconnect pattern that results in an extremely easy-to-use device with almost no current imbalance among chips. For the V-Series, the lineup of New Dual models was expanded up to a rated current of 600 A.

## 5. Future Outlook

Fuji Electric plans to continue to expand the V-Series lineup. Future plans for expansion of the lineup are shown in Fig. 6. Development of the following new packages is being advanced.

(1) High-power modules (Econo PACK+*1, new 2-in-1)
(2) Compact module (MiniSKiiP*2)

Presently, the market for high-power inverters for electric power transformer applications such as wind power generators, traction applications and the like is expanding, and Fuji Electric plans to develop high-power modules to meet the needs of these markets. We plan to develop a line of EconoPACK+ models up to rated values of 550 A and 1,200 V, and a new 2-in-1 model up to rated values of 1,400 A and 1,200 V. Also, for low-power applications, Fuji Electric is developing the MiniSKiip, which is solder-free, is easy to assemble and has equivalent functions as the PIM models but with a significantly smaller size. We plan to develop a line of MiniSKiip models rated at 8 to 100 A and 1,200 V.

Additionally, Fuji Electric is also developing a 1,700 V chip, and plans to deploy this chip in successive high-power applications such as the new 2-in-1 and New Dual models.

*1: Econo PACK is a trademark or registered trademark of Infineon Technologies AG.
*2: MiniSKiiP is a trademark or a registered trademark of SEMIKRON.

## 6. Postscript

This paper has described the features and lineup of Fuji Electric's "V-Series" IGBT modules that use the latest generation IGBT chips. Through improved chip technology and package heat dissipation performance, the V-Series achieves a smaller size and will significantly aid in the production of more compact inverters. Moreover, improved reliability of the chip and package enables the operation to be guaranteed at temperatures up to 175 °C. Consequently, the V-Series makes an important contribution to enhancing the inverter reliability and the degree of freedom in the thermal design.

In the future, Fuji Electric plans to deploy the V-Series technology in 1,700 V high-power modules and compact modules, and will to continue to support the needs of our customers.

### References

(1) Onozawa, Y., et al. "U-Series IGBT Modules (1,200 V)," Fuji Electric Journal. 2002, vol.75, no.10, p.563-566.
(2) Igarashi, S., et al. "Analysis and Reduction Methods of EMI Radiation Noise from Converter Systems," IEEJ Transactions on Industry Applications. 1998, vol.118-D, no.6, p.757-766. (Japanese).