“High Speed V-Series” of Fast Discrete IGBTs

Taketo Watashima † Ryu Araki †

ABSTRACT

Fuji Electric has developed and commercialized the “High Speed V-Series” of discrete IGBTs (insulated gate bipolar transistors) rated at 600 V/35-75 A and 1,200 V/15-40 A for improving power conversion efficiency and downsizing of mini UPSs (uninterruptible power supplies) and photovoltaic power conditioners. IGBT chips combining low on-voltage with high-speed switching characteristics and high-speed FWD chips are mounted in a small discrete package. In simulations of application to a UPS full-bridge circuit, lower loss by about 15% with the 600 V product and about 30% with the 1,200 V product was achieved in comparison with conventional series.

1. Introduction

In response to recent wide-ranging environmental problems such as global warming and environmental destruction, there has been a heightened awareness of global environmental protection, and against this backdrop there has been a growing movement for energy savings. Meanwhile, as a result of the rapid spread of digital consumer electronics and the network capability of various electronic products, the amount of digital data transmitted through networks has increased explosively and as a result, the environment around us is changing greatly.

In the past, so that digital data on a network would be available at all times and in order to guarantee the reliability of that data, a large-size UPS (uninterruptible power supply) of 100 kVA or more was typically installed in the power supply area of a data center. Recently, however, in order to accommodate the higher densities of server equipment installations in data centers, a method of parallel redundant operation is becoming popular, whereby the installation of small-size UPSs is implement with a distributed architecture, and is combined with mini-UPS devices of approximately 10 kVA in order to improve the reliability of the power supply lines.

Further, in order to conserve resources and reduce CO_2 emissions, renewable energy is also being

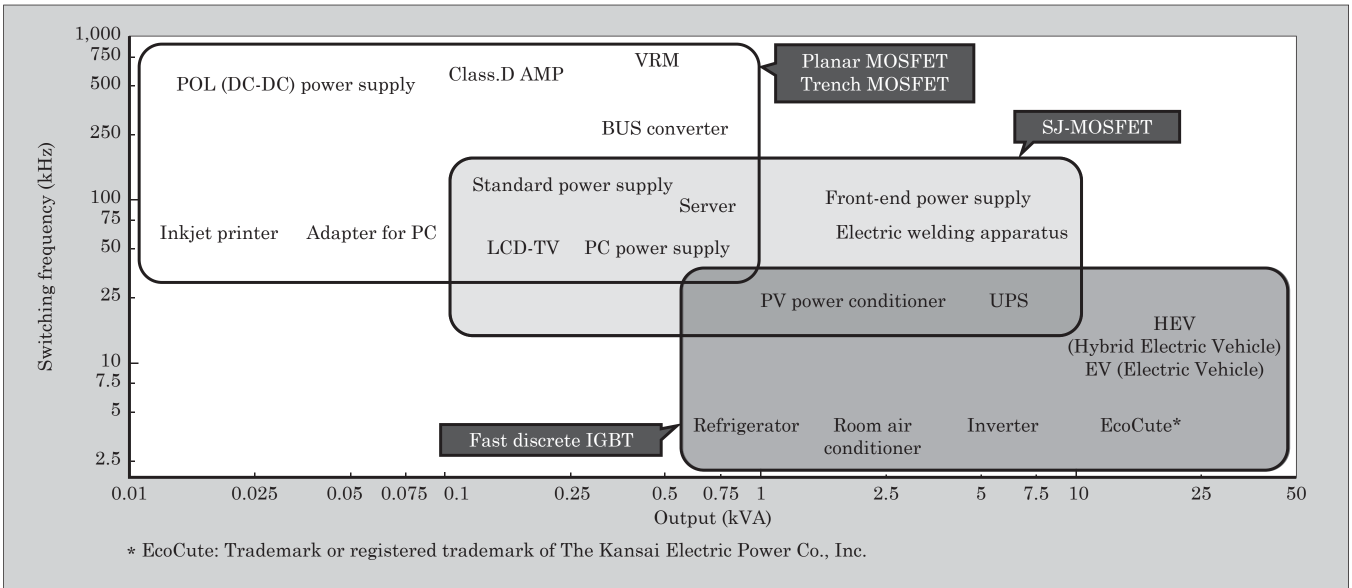

Fig.1 Major switching semiconductor devices and specifications of power supplies to which they are applied

† Fuji Electric Co., Ltd.

introduced. Among government supported initiatives for renewable energy, photovoltaic power generation systems are spreading rapidly. In these photovoltaic power generation systems, the DC power generated by solar cells must be converted into AC power, and 3 to 5 kVA power conditioners are being used as home-use power converters.

As they increase in popularity, these devices will be made inevitably with higher efficiency and smaller size as measures to counter global warming, and there is a great need for low-loss switching devices that are necessary for improving power conversion efficiency and realizing smaller size devices.

Mini-UPSs and power conditioners use discrete IGBTs (insulated gate bipolar transistors).

To improve the trade-off relation between low on-voltage characteristics and high-speed switching characteristics, and to realize higher performance and greater ease of use of mini-UPSs and power conditioners, Fuji Electric has developed a "High Speed V-Series" of fast discrete IGBTs, which are introduced herein.

2. Product Overview

Fig. 1 shows the main types of switching semiconductor devices and the specifications of power supplies to which they are applied. Major applications of the newly developed high-speed discrete IGBTs are shown in Fig. 1 and their appearance is shown in Fig. 2. Additionally, Table 1 lists the product lineup of the High Speed V Series,

The 600 V series, consisting of 35 to 75 A IGBT chips and 15 to 35 A FWD (free wheeling diode) chips, and the 1,200 V series, consisting of 15 to 40 A IGBT chips and 12 to 30 A FWD chips, are each housed in a single compact package (TO-247 package of dimensions 15.5 (W)×21.5 (H)×5 (D) (mm)), are provided with an

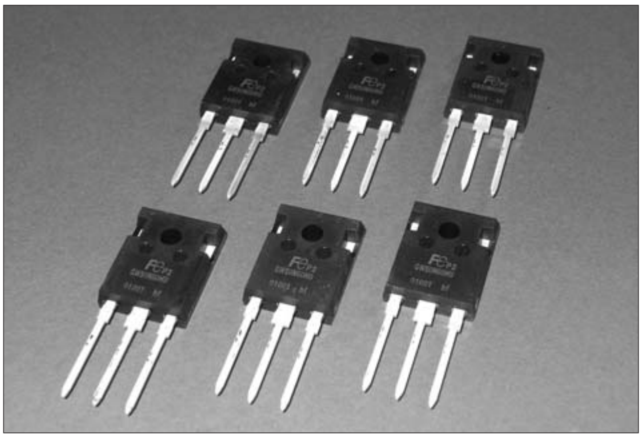

Fig.2 Appearance of "High Speed V Series" of fast discrete IGBTs

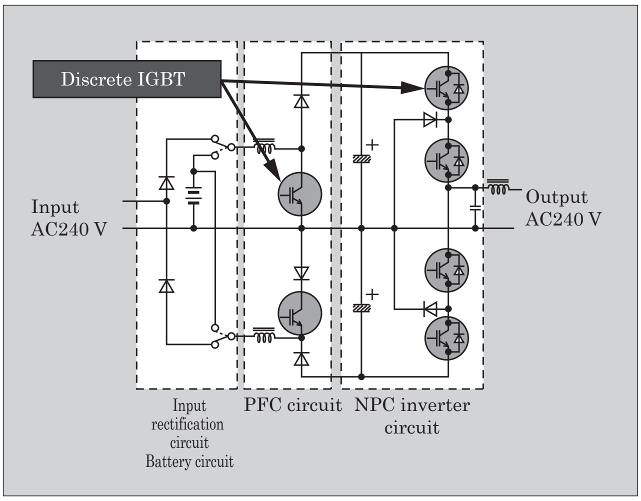

Fig.3 Typical circuit example of mini-UPS (3-level power conversion circuit)

Table 1 Major maximum ratings and electrical characteristics of "High Speed V Series"

Model	FWD type	Package	Maximum rating				Electrical characteristics			
			IGBT			FWD	IGBT		FWD	
			T_j=100 °C			T_j=100 °C	T_j= 25 °C typ	T_j= 125 °C typ	T_j= 25 °C typ	T_j= 125 °C typ
			V_{CES} (V)	I_C (A)	I_{CP} (A)	I_F (A)	$V_{CE(sat)}$ (V)	$V_{CE(sat)}$ (V)	V_F (V)	V_F (V)
FGW35N60HD	Ultra Fast FWD	TO-247	600	35	105	15	1.5	1.8	2.1	1.7
FGW50N60HD	Ultra Fast FWD	TO-247	600	50	150	25	1.5	1.8	2.1	1.7
FGW75N60HD	Ultra Fast FWD	TO-247	600	75	225	35	1.5	1.8	2.1	1.7
FGW35N60H	w/o FWD	TO-247	600	35	105	–	1.5	1.8	–	–
FGW50N60H	w/o FWD	TO-247	600	50	150	–	1.5	1.8	–	–
FGW75N60H	w/o FWD	TO-247	600	75	225	–	1.5	1.8	–	–
FGW15N120HD	Ultra Fast FWD	TO-247	1,200	15	45	12	1.7	2.1	2.3	1.85
FGW30N120HD	Ultra Fast FWD	TO-247	1,200	30	90	20	1.7	2.1	2.3	1.85
FGW40N120HD	Ultra Fast FWD	TO-247	1,200	40	120	30	1.8	2.2	2.3	1.85
FGW15N120H	w/o FWD	TO-247	1,200	12	36	–	1.7	2.1	–	–
FGW30N120H	w/o FWD	TO-247	1,200	20	60	–	1.7	2.1	–	–
FGW40N120H	w/o FWD	TO-247	1,200	30	90	–	1.8	2.2	–	–

expanded array of options so as to support UPSs and power conditioners having various outputs, and were designed in consideration of the trend toward equipment downsizing and to improve the convenience of mounting.

3. Design Policy

3.1 Application trends and device issues

Fig. 3 shows a typical example of a mini-UPS circuit.

In order to reduce power loss in a mini-UPS, an increasing number of commercialized high-efficiency UPSs has used 3-level power conversion technology in their inverters.

Fig. 4 shows a typical example of a power conditioner circuit.

A power conditioner is a device that converts the DC power generated by a photovoltaic module into AC power for home use, and as the DC-AC conversion efficiency increases, a greater amount of power can be generated and the amount of power usable at home increases. In power conditioners as well, examples of the application of 3-level inverters (see explanation on page 108) are appearing in order to achieve even high efficiency.

Fig. 5 shows the analysis results of device loss in a 3.5 kW-class UPS inverter. Of the total loss, it was found that approximately 60% is attributable to the on-voltage loss (V_{on}) and approximately 30% is attributable to the switching loss (E_{on}, E_{off}) of the IGBT. Also, in a FWD, the t_{rr} loss during the reverse recovery mode is dominant.

Therefore, the IGBTs installed in inverters are requested to have low on-voltage and, during high current and high-speed switching operation, to exhibit low loss performance (i.e., an improved tradeoff relation between $V_{CE(sat)}$ and E_{off}). Further, in FWDs, the highest priority issue is to reduce switching loss by shortening t_{rr}.

3.2 Characteristics of 600 V series of IGBT chips

Fig. 6 shows the cross-sectional structures of 600 V IGBT chips of the conventional "E Series" and the recent "High Speed V Series."

The High Speed V Series combines a trench gate structure on the front surface and a field stop (FS) structure on the back surface, and was designed to provide a significant improvement in the tradeoff relation between $V_{CE(sat)}$ and turn-off loss based on Fuji Electric's V Series IGBTs for motor drives.

Fig. 7 shows the $V_{CE(sat)}$ vs. E_{off} characteristics of a conventional 600 V/30 A IGBT and of the High Speed V Series.

For the approximate 20 kHz high-speed switching operation of a mini-UPS, power conditioner or the like, which is the targeted application of the newly developed 600 V IGBTs, the High Speed V Series has improved the high-frequency drive performance through optimizing the chip surface structure to reduce Miller capacitance and achieving a reduction in both $V_{CE(sat)}$ and E_{off} while maintaining the required breakdown tolerance for the application.

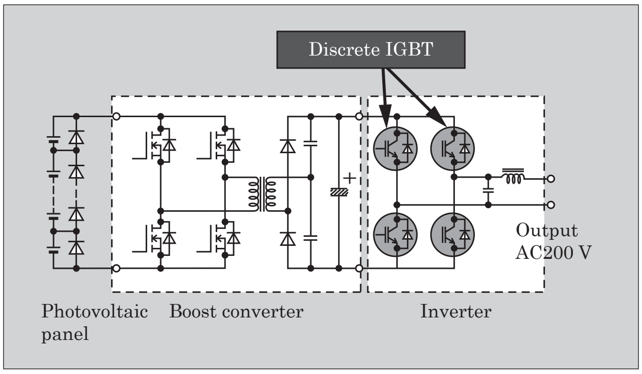

Fig.4 Typical circuit example of power conditioner

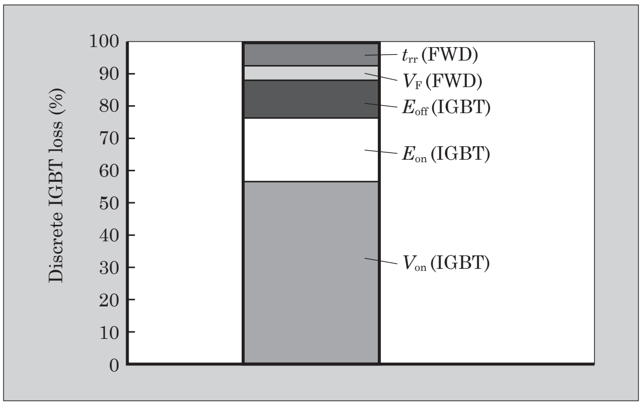

Fig.5 Analysis results of device loss when installed in 3.5 kW-class UPS

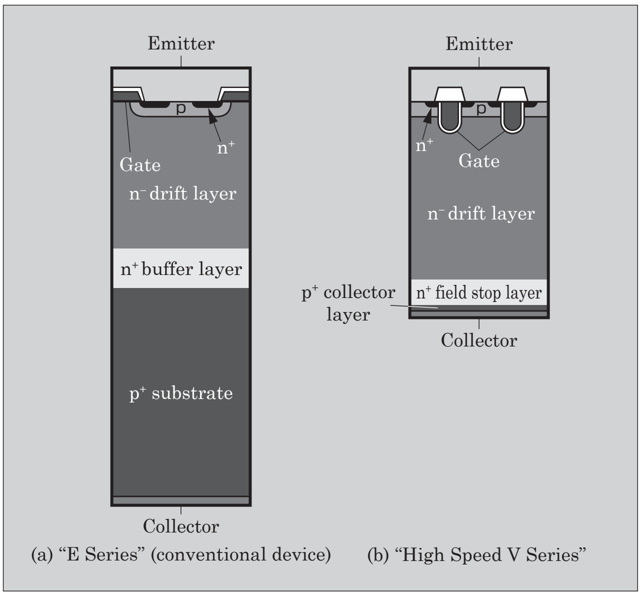

Fig.6 IGBT chip cross-section

3.3 Characteristics of 600 V series of FWD chips

The following characteristics of the 600 V FWD were optimized to reduce switching loss.

(a) Anode region impurity density
(b) Lifetime killer diffusion profile and density
(c) Drift region thickness

As a result of these measures, specifications were established for FWD chips that are faster than conventional devices while having soft recovery characteristics, and that inhibit an increase in VF.

Fig. 8 compares the switching loss in a conventional 600 V/30 A FWD with that of the High Speed V Series. An improvement of approximately 37% less switching loss was achieved.

3.4 Characteristics of 1,200 V series of IGBT chips

The design of the 1,200 V IGBTs for high voltage use, as in the case of the 600 V IGBTs, was based upon the V Series IGBT modules for motor driving, and was optimized for discrete use to realize a significant improvement in the tradeoff relation between $V_{CE(sat)}$ and E_{off}.

Fig. 9 shows the $V_{CE(sat)}$ vs. E_{off} characteristics of a conventional 1,200 V/25 A IGBT and of the High Speed V Series.

3.5 Characteristics of 1,200 V FWD chip

The 1,200 V FWD for high voltage use, owing to an improved impurity density of reqion realizes lower E_{rr}, and at the same time, inhibits oscillation and surge voltage during reverse recovery operation. Additionally, in order to enhance its reverse recovery tolerance, the anode structure that inhibits the concentration of current in the vicinity of the edges of the active region has been optimized.

Fig. 10 compares switching loss for a conventional 1,200 V/25 A FWD device and for the High Speed V Series. An improvement of approximately 26% less switching loss was achieved.

4. Effect of Application of High-Speed Discrete IGBTs

Fig. 11 and Fig. 12 show the results of simulations of generated loss in the case of installing high-speed discrete IGBTs in a general-purpose power supply. The general-purpose power supply simulates a UPS full-bridge circuit ((PWM: pulse width modulation)

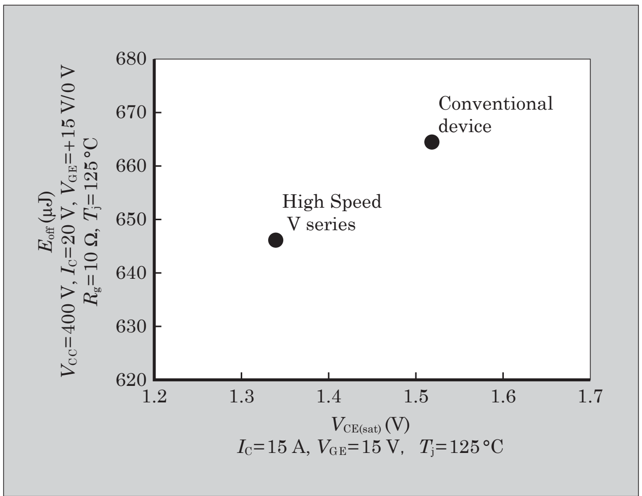

Fig.7 $V_{CE(sat)}$-E_{off} characteristics of 600 V/30 A IGBT

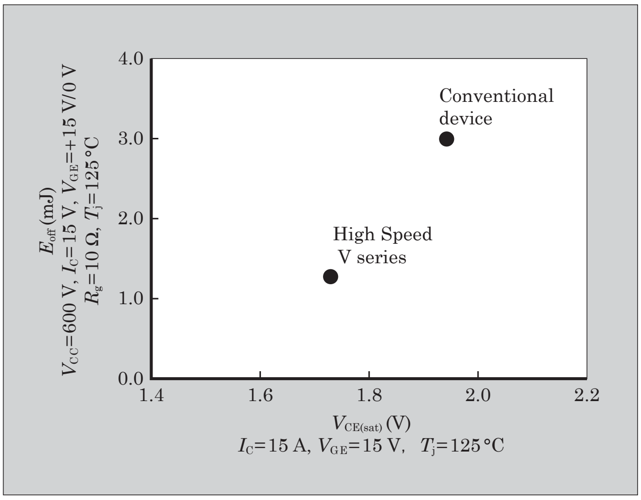

Fig.9 $V_{CE(sat)}$-E_{off} characteristics of 1,200 V/25 A IGBT

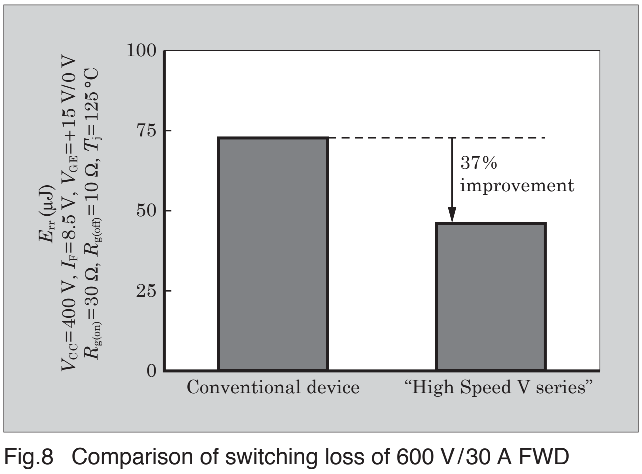

Fig.8 Comparison of switching loss of 600 V/30 A FWD

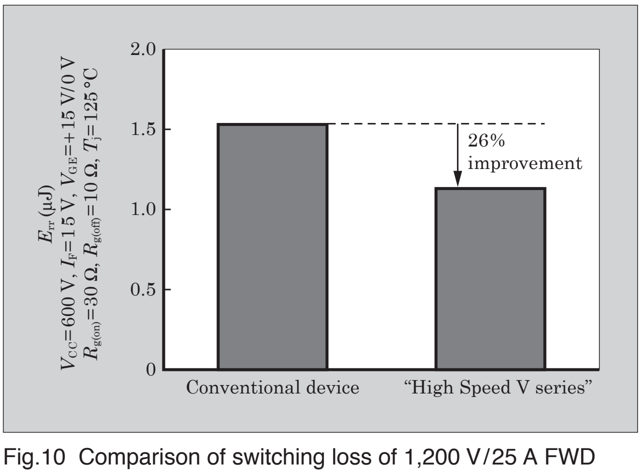

Fig.10 Comparison of switching loss of 1,200 V/25 A FWD

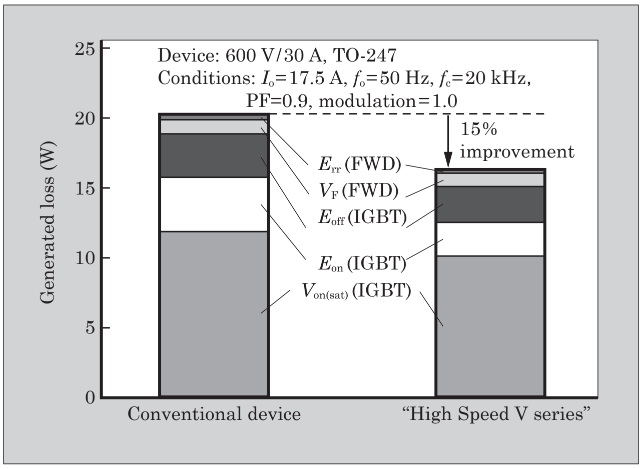

Fig.11 Loss simulation of 600 V series

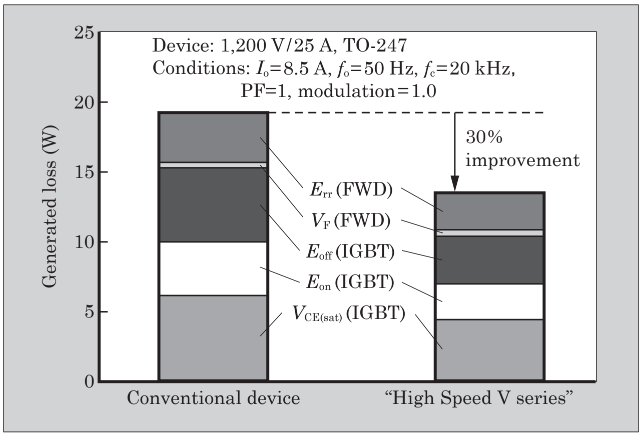

Fig.12 Loss simulation of 1,200 V series

inverter) having a 3.5 kW (200 V/17.5 A) output and 20 kHz switching frequency.

For the 600 V-class device of Fig. 11, application of the High Speed V Series is expected to reduce the total loss by approximately 15%. Moreover, for the 1,200 V-class device of Fig. 12, approximately 30% lower loss is expected. These conduction losses $V_{CE(sat)}$ of the full-bridge circuit account for about 30 to 60% of the total loss, and therefore an improved tradeoff relation between $V_{CE(sat)}$ and E_{off} will contribute to the realization of lower loss. The application of a high-speed V Series IGBT to an actual device will contribute significantly to improving the power efficiency of the overall system.

5. Postscript

These products are used not just in mini-UPSs and power conditioners for photovoltaic power generation systems, but can also be applied widely in the power supplies for small-size, low-noise machine tools such as welding (inverter welding) apparatus and laser processing machines. Fuji Electric intends to contribute to energy savings and global environmental protection through providing the marketplace with products capable of high-speed and large current switching so as to realize low loss.

References

(1) Onozawa.Y, et al. Development of the next generation 1,200 V trench-gate FS-IGBT featuring lower EMI noise and lower switching loss. 19th ISPSD. 2007, p.13-16.