“XS Series” 650-V Discrete IGBTs

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ABSTRACT

Fuji Electric has developed and launched the “XS Series” 650-V discrete IGBTs as a product line-up for UPSs and photovoltaic power generation PCSs that operate at a switching frequency of approximately 20 kHz. These devices are improved in a trade-off between conduction loss and switching loss. The series has a rating of 650 V/30 to 75 A, and its conduction loss and switching loss are lower than previous products by 20% or more. When Incorporated in a UPS, the device showed higher efficiency than previous products for all load ranges, increasing by up to 0.12 points. It also showed that the rise in device case temperature becomes smaller.

1. Introduction

Recently, utilization of the Internet of Things (IoT), big data and artificial intelligence (AI) is progressing and data usage is globally on the rise. In this situation, servers and data centers that handle data have high demands for energy saving and efficiency improvement is progressing for uninterruptible power systems (UPSs) intended for these types of equipment requiring high-quality power.

Meanwhile, the spread of renewable energy including photovoltaic and wind power generation has led to more energy decentralization, which has increased demand for power conversion. With power conditioning systems (PCSs), which convert direct-current power generated by photovoltaic systems into alternating-current power, device efficiency has been improving as with UPSs.

To improve efficiency of UPSs and PCSs, there is very high demand for switching devices with a lower loss.

Fuji Electric has developed and launched the “XS Series” 650-V discrete insulated gate bipolar transistors (IGBTs) as a product line that improves the on-state voltage and switching loss trade-off characteristic so as to improve the efficiency of UPSs and PCSs. This paper outlines the product series and describes the effect of its application.

2. Outline of “XS Series”

Figure 1 shows major applications of discrete IGBTs. The 650-V XS Series that Fuji Electric has developed targets UPSs and PCSs that operate at a switching frequency of approximately 20 kHz. IGBT and free wheeling diode (FWD) chips with a rated current of 30 to 75 A are mounted in the TO-247, a standard package for discrete products, as show in Fig. 2. Table 1 shows the major maximum ratings and electrical characteristics of the XS Series. It provides wide-ranging options according to the equipment power supply capacity.

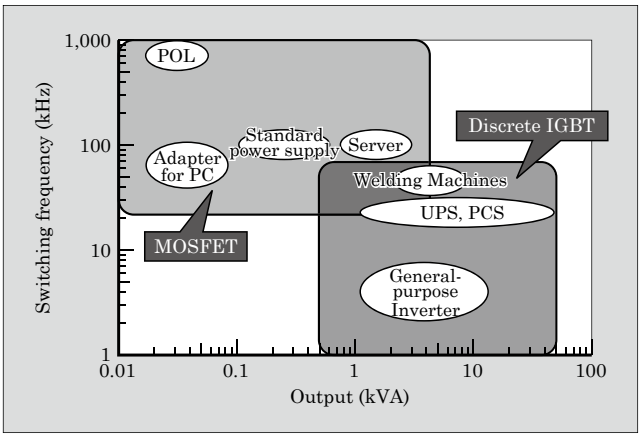

Fig.1 Major applications of discrete IGBTs

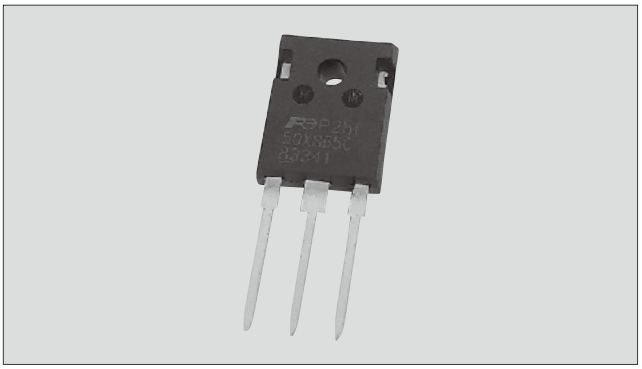

Fig.2 “XS Series” (TO-247 package)

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Table 1 Major maximum ratings and electrical characteristics of “XS Series”

Model	Built-in FWD	Package	Maximum rating				Electrical characteristic			
			IGBT			FWD	IGBT		FWD	
			V_{CES}	I_C T_{vj}=100 °C	I_{CP}	I_F T_{vj}=100 °C	$V_{CE(sat)}$ T_{vj}=25 °C (typ.)	$V_{CE(sat)}$ T_{vj}=125 °C (typ.)	V_F T_{vj}=25 °C (typ.)	V_F T_{vj}=125 °C (typ.)
			(V)	(A)	(A)	(A)	(V)	(V)	(V)	(V)
FGW50XS65D	Provided	TO-247	650	50	200	30	1.35	1.50	1.70	1.78
FGW75XS65D	Provided	TO-247	650	75	300	30	1.35	1.50	1.70	1.78
FGW30XS65C	Provided	TO-247	650	30	120	30	1.35	1.50	1.70	1.78
FGW40XS65C	Provided	TO-247	650	40	160	40	1.35	1.50	1.70	1.78
FGW50XS65C	Provided	TO-247	650	50	200	50	1.35	1.50	1.70	1.78
FGW75XS65C	Provided	TO-247	650	75	300	75	1.35	1.50	1.70	1.78
FGZ75XS65C	Provided	TO-247-4	650	75	300	75	1.35	1.50	1.70	1.78
FGW30XS65	None	TO-247	650	30	120	–	1.35	1.50	–	–
FGW40XS65	None	TO-247	650	40	160	–	1.35	1.50	–	–
FGW50XS65	None	TO-247	650	50	200	–	1.35	1.50	–	–
FGW75XS65	None	TO-247	650	75	300	–	1.35	1.50	–	–

3. Issues with Discrete IGBTs

For UPSs and PCSs with a few kilovolt ampere or larger capacity, 3-level inverters are generally adopted for improving the power conversion efficiency of the inverter unit. Figure 3 shows circuit diagrams of the I-type and T-type 3-level inverters.

UPS and PCSs often have discrete IGBTs operating at a switching frequency of approximately 20 kHz. Figure 4 shows breakdowns of the loss of discrete IGBTs in T1 and T2 of the I-type and AC switches (T3 and T4) of the T-type, for which products rated at 650 V are used. With the I-type, T1 requires a reduction in all of the conduction loss P_{sat}, turn-on loss P_{on} and turn-off loss P_{off} and T2 requires a reduction in P_{sat}. With the T-type, a reduction in the IGBT and FWD conduction loss P_{sat} + P_f and the FWD recovery loss of P_{rr} is important.

To improve device efficiency, minimizing this power loss in inverter circuits is important and the XS Series has its focus on reducing the conduction loss and switching loss of both IGBTs and FWDs.

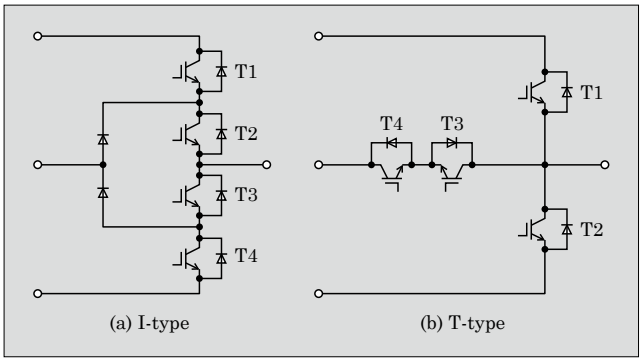

Fig.3 3-level inverter circuit diagrams

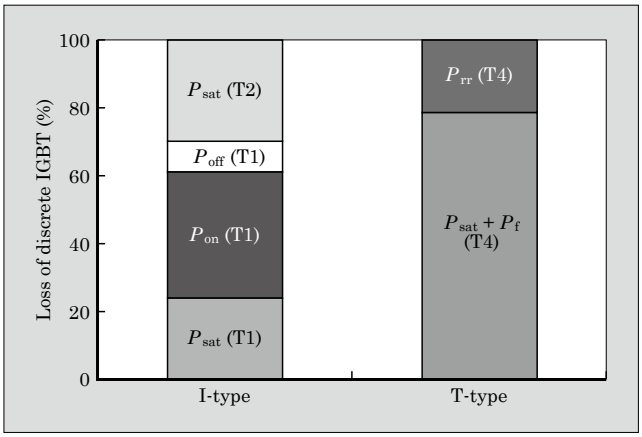

Fig.4 Result of device loss analysis (f_c=20 kHz)

4. Features of “XS Series”

The 650-V XS Series is based on the IGBT and FWD chip technologies of the 7th-generation “X Series” and has the optimum design for discrete products used at a switching frequency of approximately 20 kHz.

4.1 IGBT chip

Figure 5 shows a cross-sectional structure of the IGBT chips. The “High-Speed W Series,” a conventional product line, uses the 6th-generation “V Series” IGBT for modules as the basis and is designed with the focus on high-speed switching characteristics. It achieves this by adopting a surface structure with the parasitic capacitance significantly reduced, optimizing the field stop (FS) layer, controlling the hole injection into the collector layer and thinning the Si substrate[1]. With the XS Series, in comparison, on the basis of the 7th-generation X Series IGBT technology that has improved the trade-off characteristic of $V_{CE(sat)}$-E_{off} from the 6th generation, we have adopted design measures

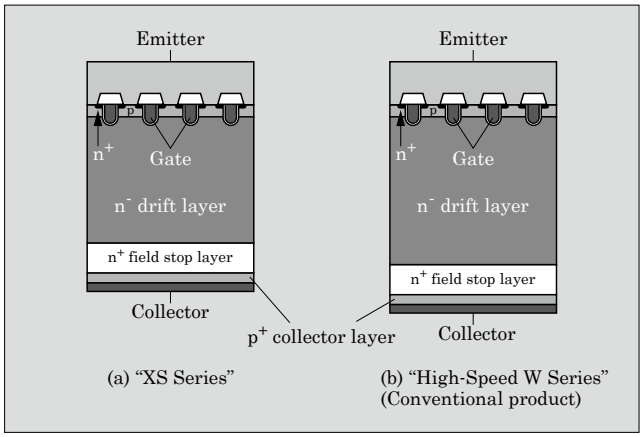

Fig.5 IGBT chip cross-sectional structure

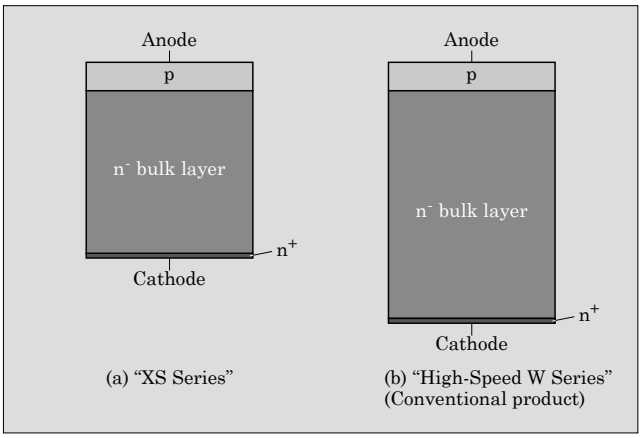

Fig.7 FWD chip cross-sectional structure

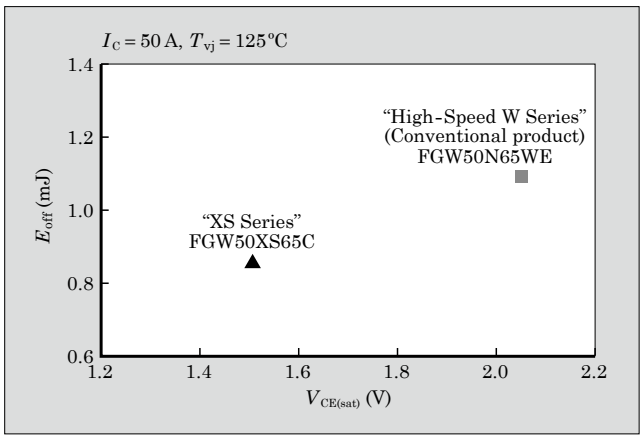

Fig.6 Trade-off characteristic (IGBTs)

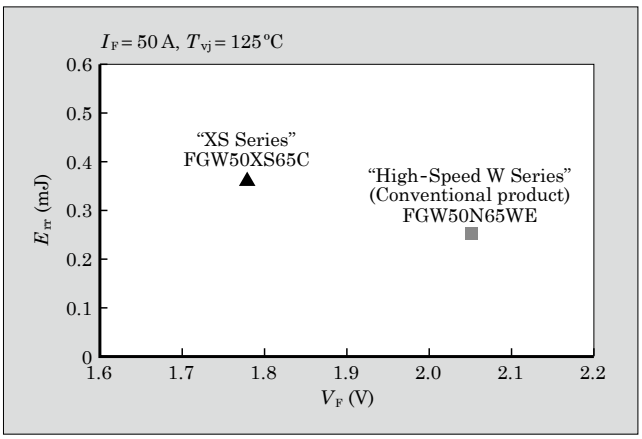

Fig.8 Trade-off characteristic (FWDs)

to improve the trade-off characteristic of $V_{CE(sat)}$-E_{off}. They include adopting a surface structure that is optimum for discrete IGBTs for UPSs and PCSs, optimizing the FS layer, controlling hole injection into the collector layer and thinning the Si substrate. This has achieved a significant improvement in the trade-off characteristic from that of the conventional products with a 0.5-V reduction in $V_{CE(sat)}$ and, at the same time, an approximately 20% reduction in E_{off}, as shown in Fig. 6.

4.2 FWD chip

Figure 7 shows a cross-sectional structure of the FWD chips. The FWD is based on the 7th-generation X Series FWD, which has the most advanced V_F-E_{rr} trade-off characteristic, with the Si substrate thinned and the amount of lifetime killers optimized. In addition to improving the trade-off characteristic of V_F-E_{rr} in this way, we have given the focus on the low V_F characteristic for optimization to suit UPS and PCS applications and successfully reduced V_F by approximately 0.3 V from that of the High-Speed W Series, which is shown in Fig. 8.

4.3 Package

The industry standard TO-247 package has been adopted. For connection between the chip and lead frame, lead-free solder is used, which conforms to the RoHS Directive*1 (EU2011/65/EU).

For products with a 75-A rating, a larger current rating, we also offer a line-up that uses the TO-247-4 package with a sub-emitter terminal added. Reducing the wiring inductance of the gate-emitter loop by lowering the emitter common inductance improves the gate response, which significantly reduces the switching loss in large-current operation.

5. Effect of Application of "XS Series"

5.1 Result of device loss simulation

Figure 9 shows the result of calculating the generated loss of the discrete IGBT of the I-type 3-level inverter. As compared with the High-Speed W Series, the XS Series has less loss in T1 and T2 by improving the $V_{CE(sat)}$ and E_{off} trade-off characteristic.

Figure 10 shows the result of calculating the generated loss of the IGBT and FWD in the AC switch (T4) of the T-type 3-level inverter. As compared with

*1: RoHS Directive: A European Union (EU) directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment

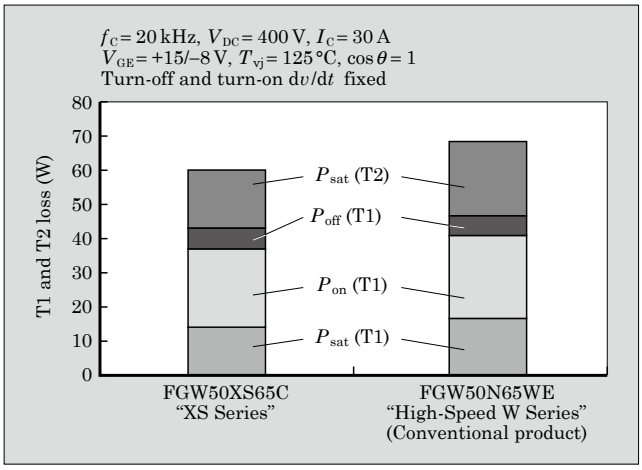

Fig.9 Device loss (3-level I-type)

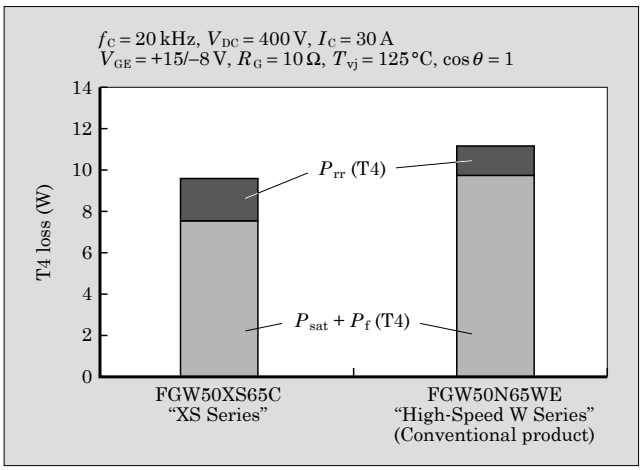

Fig.10 Device loss (3-level T-type)

the High-Speed W Series, the XS Series has been confirmed to have lower loss with the T-type as well achieved by reducing the IGBT $V_{CE(sat)}$ and FWD V_F.

5.2 Result of UPS evaluation

Figure 11 shows the result of measuring the efficiency with the XS Series applied to a UPS that uses the I-type 3-level inverter. The output capacity of the UPS used for the evaluation is 3 kW and the switching frequency of the IGBT is 24 kHz.

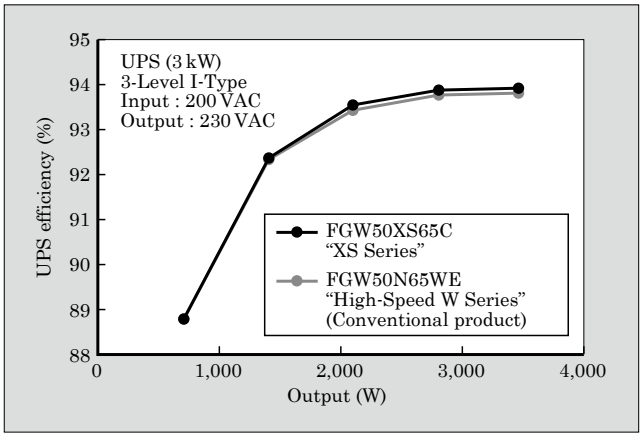

Fig.11 Comparison of UPS efficiency

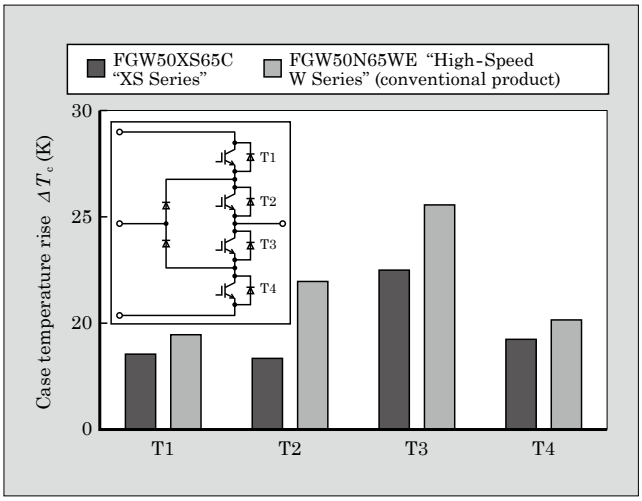

Fig.12 Comparison of IGBT case temperature rise

The XS Series offers higher efficiency than the High-Speed W Series, a conventional product, in all load ranges, increasing by up to 0.12 points. It has also been confirmed that the rise in device case temperature is smaller with the XS Series than with the High-Speed W Series in all of T1 to T4, as shown in Fig. 12.

6. Postscript

This paper has described the "XS Series" 650-V discrete IGBTs. We have developed this product mainly for UPSs and PCSs but it can also be widely applied to the PFC circuit of switching power supplies and industrial devices. We also plan to develop 1,200-V rated products of the "XS Series" discrete IGBTs intended for the main switches of T-type 3-level inverters used for UPSs and PCSs and 2-level inverters.

Fuji Electric intends to continue to contribute to energy saving and improvement of power conversion efficiency by working on further loss reduction of devices and offering products that meet the market needs.

References

(1) Hara, Y. et al. High-Speed Discrete IGBT "High-Speed W-Series". FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.280-284.

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