Chapter 2 Precautions for Use

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The 7th generation X-series IGBT modules contains the same Field Stop (FS) and trench gate structure that had been introduced for the 5th generation U-series and 6th generation V-series, respectively. Beside that the overall characteristics have been improved by thinning the wafer thickness and optimizing the trench structure.

This chapter explains how to use the 7th generation X-series IGBT modules.

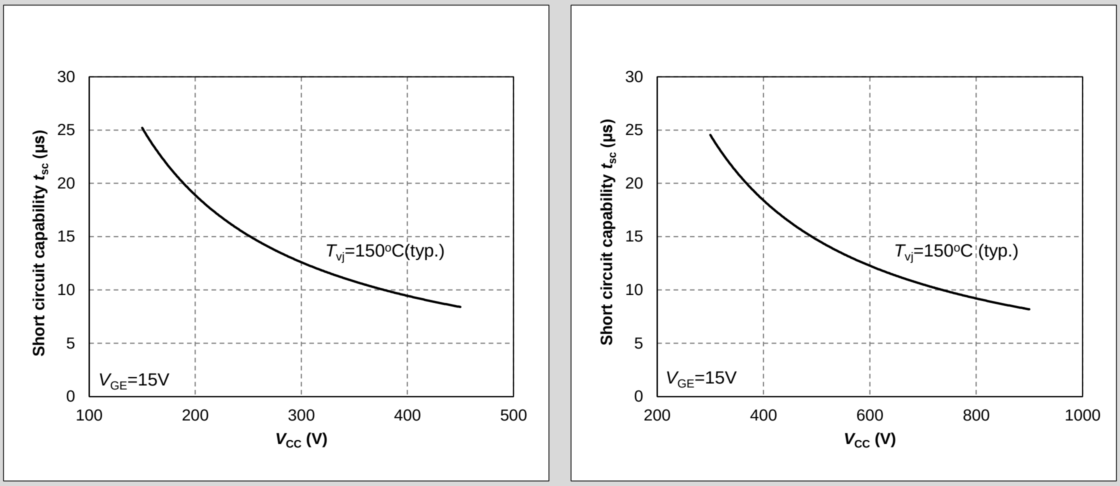
1. Maximum Junction Temperature T_{vj}, T_{vjop}

The Characteristics of the 7th generation X-series modules have been improved to provide a continuous operation junction temperature T_{vjop} of maximum 175℃. Operating conditions must never be defined to exceed the maximum junction temperature. Please be aware using these products beyond the maximum temperature may result in a reduction of the product life time, such as power cycle endurance.

2. Short-Circuit (Overcurrent) Protection

If a short-circuit occurs, the IGBT collector current I_C will increase. If I_C reaches a specified value, the voltage between collector and emitter (V_{CE}) will rapidly increase. Because of this behavior the collector current during short circuit is suppressed to a certain level. The short circuit condition has to be removed immediately as high voltage and high current is applied to the IGBT at the same time.

Fig. 2-1 shows the relation between the applied voltage V_{CC} and the short-circuit withstand capability (short circuit time) for the 650V and 1200V X-series modules. Please define the short circuit detection time and protection intervention time in order to not exceed the withstand capability. This has to be applied according to the operating requirements of the application.



(a) 650V (b) 1200V module

Figure 2-1 Short circuit capability of X-series IGBT modules as function of the applied voltage V_{CC} (V_{GE}=15V).

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3. Overvoltage Protection and Safe Operating Area

3.1 Overvoltage protection

Due to fast switching speed of IGBTs, a high d*i*/d*t* is generated during the IGBT turn-off and the IGBT turn-on / FWD reverse recovery. This high d*i*/d*t* causes a high surge voltage due to the external wiring stray inductance. If the surge voltage exceeds the module's maximum rated voltage (V_{CES}), it can lead to the destruction of the module. There are several methods to avoid high surge voltages like adding a snubber circuit, adjusting the gate resistance R_G, or reducing the inductance of the main circuit.

Fig. 2-2 shows a schematic diagram of turn-off and reverse recovery waveforms as well as the specific definition of surge voltage. The surge voltage which arises between collector and emitter during the IGBT turn-off is called V_{CEP}. V_{AKP} defines the surge voltage which occurs between the anode and the cathode of the FWD during the reverse recovery phase.

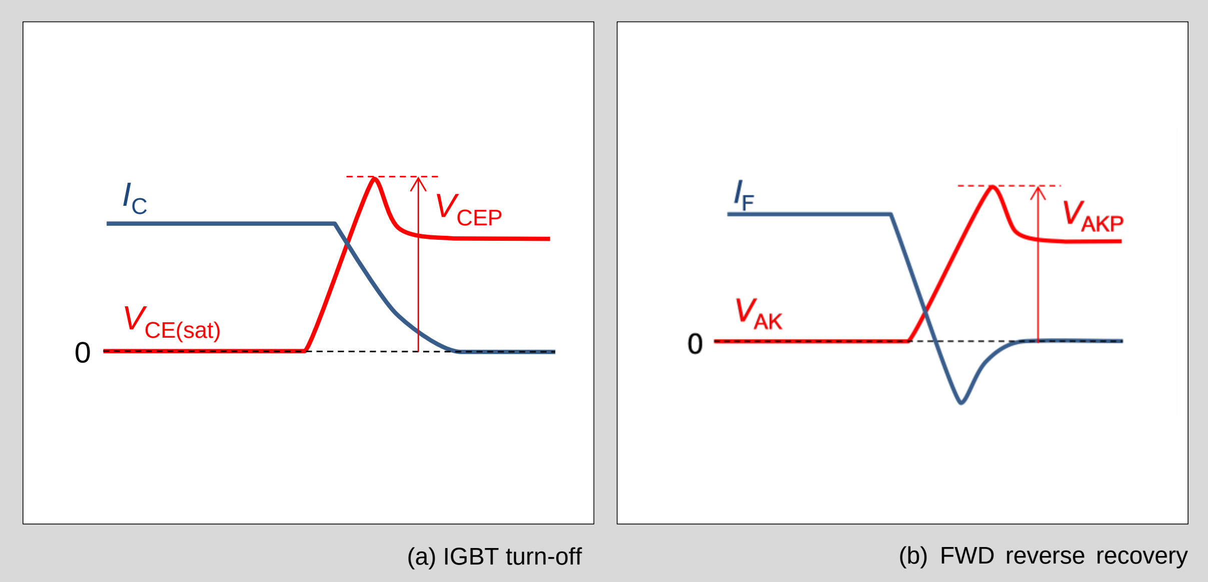

Figure 2-2 Schematic diagram of waveforms and surge voltages for (a) IGBT turn-off and (b) FWD reverse recovery.

Surge voltage characteristics are described below using the following two modules serving as example: 7MBR100XRA065-50 (650V/100A) X-series and 7MBR100XNA120-50 (1200V/100A) X-series.

Fig. 2-3 shows an example of the relation between the main circuit stray inductance (L_s) and the surge voltage V_{CEP} when the IGBT is switched off. It is obvious that V_{CEP} increases with increasing L_s. Due to this coherence, the main circuit has to be designed with the lowest possible inductance. Fuji recommends the use of laminated bus bars for reducing the external inductance value.

Fig. 2-4 shows an example of the relation between the applied voltage V_{CC} and the surge voltages V_{AKP} and V_{CEP}. As one can easily see from this figure, by increasing V_{CC} the surge voltages V_{CEP} and V_{AKP} will increase as well.

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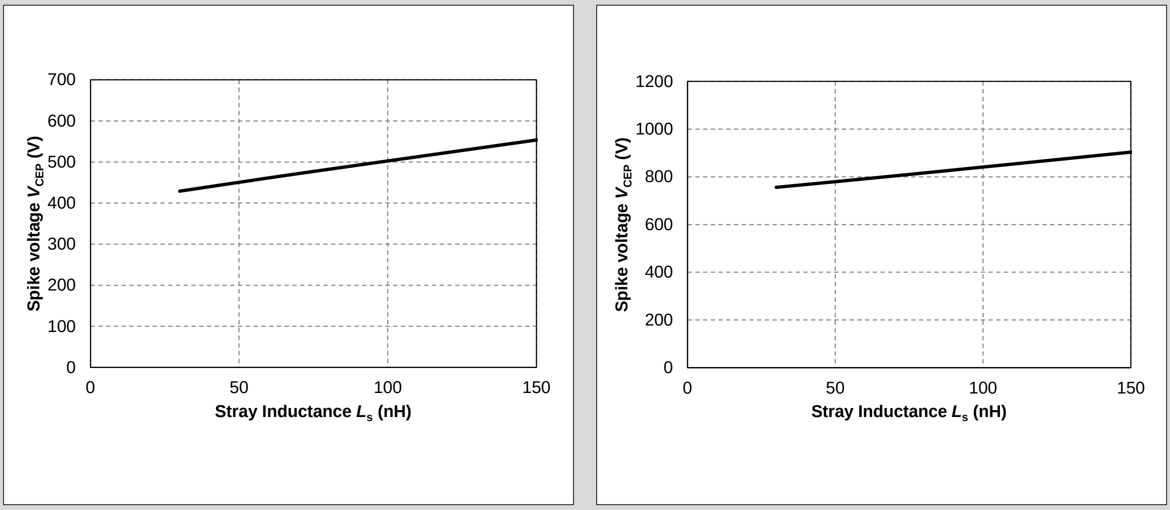
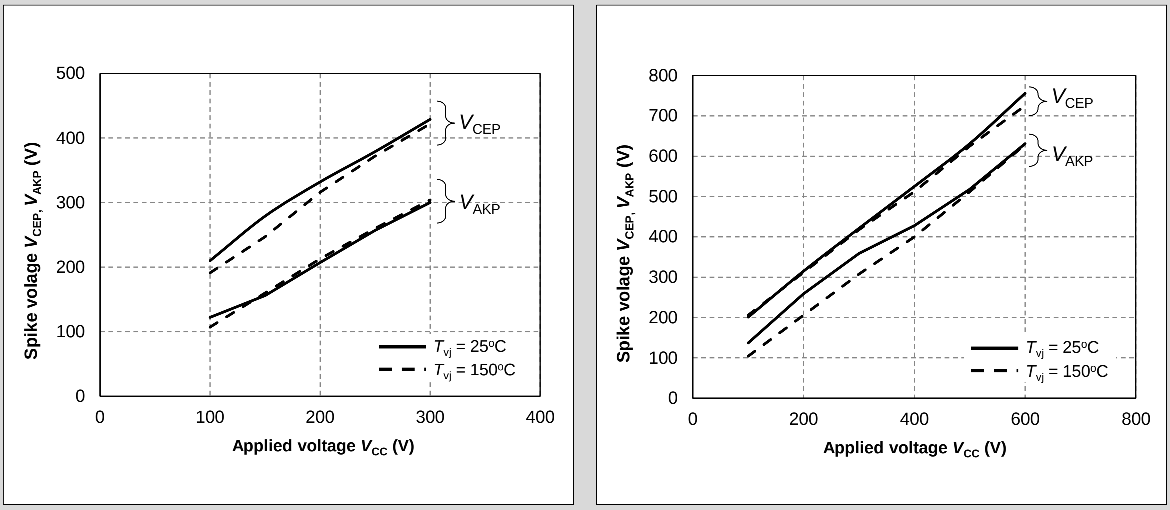


(a) 7MBR100XRA065-50 (650V/100A)
V_{CC}=300V, I_C=100A, R_G=27Ω

(b) 7MBR100XNA120-50 (1200V/100A)
V_{CC}=600V, I_C=100A, R_G=5.1Ω

Figure 2-3 Example of the relation between stray inductance L_s and IGBT turn-off surge voltage.



(a) 7MBR100XRA065-50 (650V/100A)
V_{CC}=300V, I_C,I_F=100A, R_G=27Ω

(b)7MBR100XNA120-50 (1200V/100A)
V_{CC}=600V, I_C,I_F=100A, R_G=5.1Ω

Figure 2-4 Example of the relation between the applied voltage V_{CC} and the surge voltages in IGBT turn-off and FWD reverse recovery.

Fig. 2-5 shows an example of the relation between the collector current I_C and the surge voltage V_{CEP} and relation between I_F and V_{AKP}, respectively. V_{CEP} is increasing with increasing I_C. On the other hand, V_{AKP} tends to be larger for smaller values of the I_F currents. The largest value for V_{AKP} occurs for values smaller than one tenth of the rated current. During design phase it is therefore necessary to evaluate and take into account the surge voltage for the actual used current.

Fig. 2-6 shows an example of the relation between the gate resistance R_G and the surge voltage V_{AKP}.

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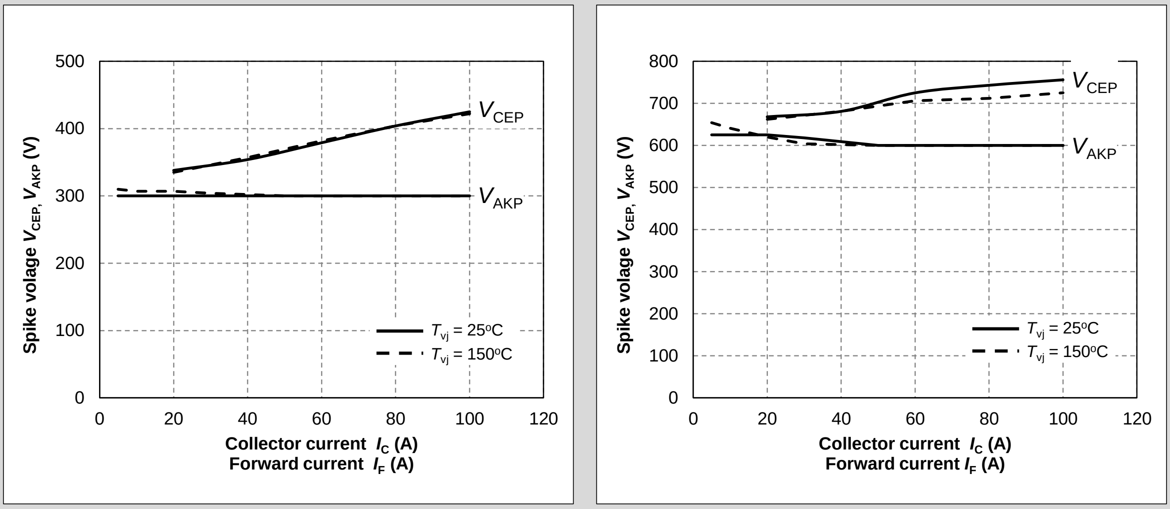
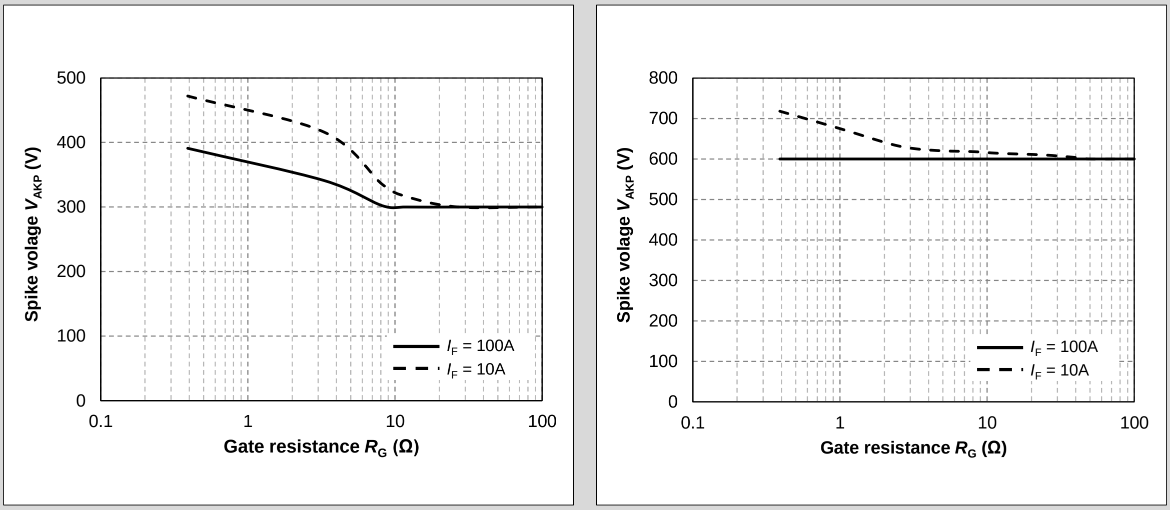
In each subfigure two curves are displayed. One represents the rated current 100A and the other one one tenth of the rated current, 10A. It has to be highlighted that V_{AKP} is increasing with decreasing R_G and I_F values.



(a) 7MBR100XRA065-50 (650V/100A)
V_{CC}=300V, R_G=27Ω

(b) 7MBR100XNA120-50 (1200V/100A)
V_{CC}=600V, R_G=5.1Ω

Figure 2-5 Example of the relation between collector current I_C and surge voltage V_{CEP} and forward current I_F and surge voltage V_{AKP}.



(a)7MBR100XRA065-50 (650V/100A)
V_{CC}=300V, T_{vj}=25°C

(b)7MBR100XNA120-50 (1200V/100A)
V_{CC}=600V, T_{vj}=25°C

Figure 2-6 Example of the relation between gate resistance and surge voltage V_{AKP} of FWD reverse recovery.

As described above, the value of the surge voltage generated in IGBT modules varies greatly depending on the used driving conditions, main circuit stray inductance L_s and the switching conditions.

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Besides this, external parts like snubber circuits, capacitor values and gate drive capability also have an influence on the surge voltages.

When using IGBT modules, please make sure that the surge voltage will stay within the Reverse Bias Safety Operating Area (RBSOA) for all operating conditions in all various devices such as inverter systems where the IGBT will be used in. If the surge voltage exceeds the guaranteed RBSOA, please take countermeasures like changing the gate resistance, reducing the stray inductance or adding a snubber circuit. In addition, it could be appropriate to use different gate resistances for turn-on and turn-off in order to optimize the driving condition.

3.2 Gate resistance influence on surge voltage during turn-off

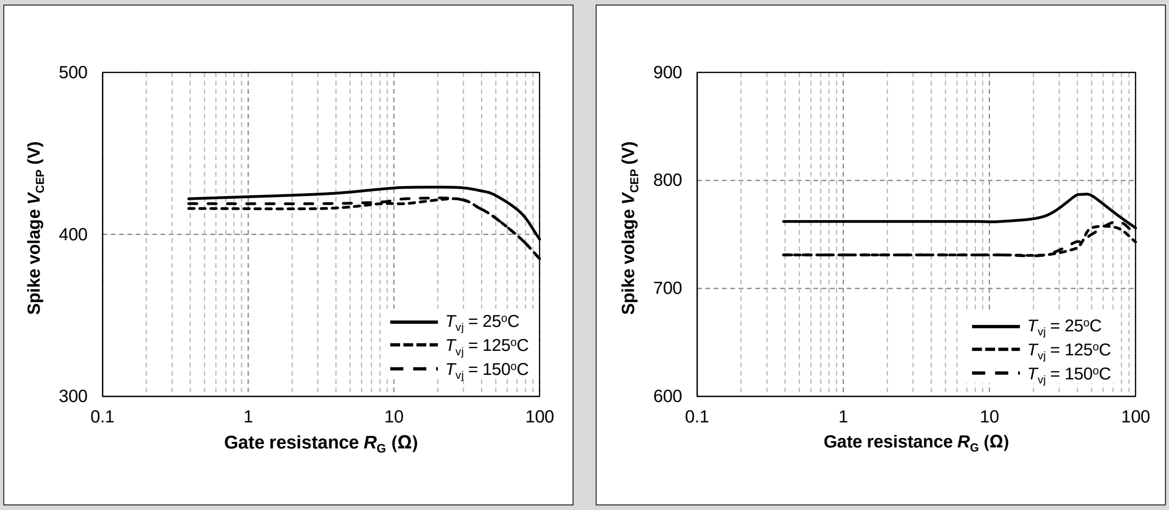
In order to properly design the overvoltage protection, Fig. 2-7 shows the relation between the gate resistance R_G value and the turn-off surge voltage V_{CEP} for X-series 1200V IGBT module.

Be aware that the IGBT modules belonging to the 4th generation (S-series) or even older ones show a different relation. In order to suppress the surge voltage usually an increase of R_G has been a suitable countermeasure.

Now, since the carrier injection efficiency has been improved starting with 5th generation (U-series) the general relation between R_G and the surge voltage has been changed.

Due to this change increasing R_G value may cause now increasing surge voltage V_{CEP} values in contrary to the behavior of old generation products.

Therefore, please select the gate resistance value carefully during the design phase to match the requirements and parameters of the actual device where the IGBT module will be used in.



(a)7MBR100XRA065-50 (650V/100A) V_{CC}=300V (b)7MBR100XNA120-50 (1200V/100A) V_{CC}=600V

Figure 2-7 Example of the relation between gate resistance R_G and turn-off surge voltage V_{CEP}

Reference

1) Y. Onozawa et al., "Investigation of carrier streaming effect for the low spike fast IGBT turn-off", Proc. ISPSD, pp. 173-176, 2006.

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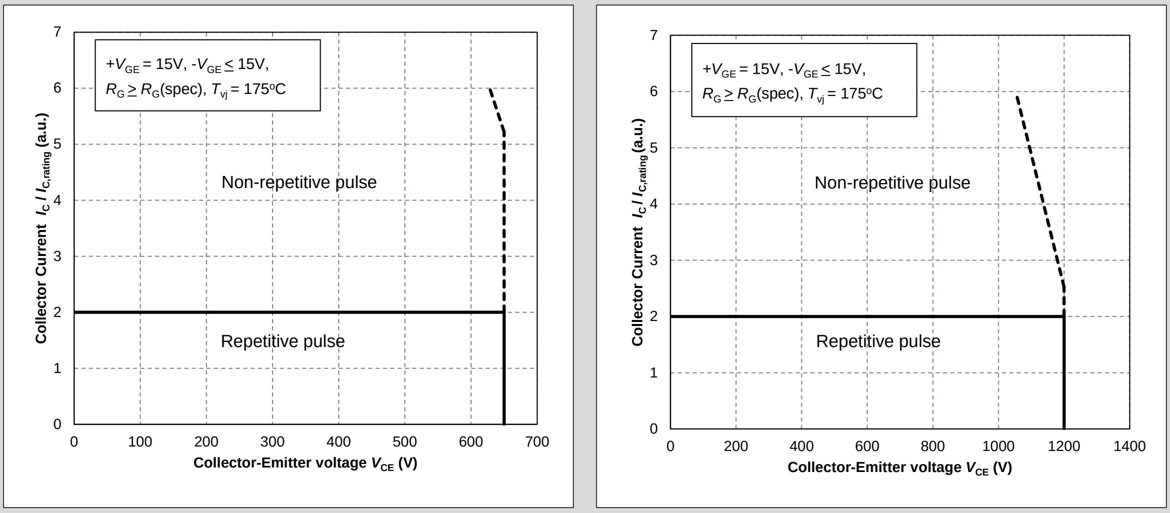
3.3 Overvoltage Protection under short circuit condition

When a short circuit occurs, the IGBT collector current I_C sharply increases. In this case a larger current I_C has to be cut off compared to a normal operation during turn-off. Thus, there is an additional RBSOA (Reverse Bias Safe Operating Area) for non-repetitive pulse is defined for the short circuit condition.

Fig. 2-8 shows RBSOA (repetitive pulse) and RBSOA (non-repetitive pulse) for the 650V and 1200V 7th generation X-series modules. The V_{CE}–I_C locus has to stay within the RBSOA (non-repetitive pulse) during a short circuit condition until it will be turned off. Unless stated otherwise the voltage V_{CE} of RBSOA is the voltage measured at the main terminals of the module.



(a) 650V rated module

(b) 1200V rated module

Figure 2-8 RBSOA for IGBT

3.4 Safe Operating Area for FWD

In the design phase, SOA (Safe Operating Area) for FWD, which exists similar to RBSOA for IGBT, has to be carefully considered. As shown in Fig. 2-9 the SOA for FWD is indicated as the area which is limited by the maximum power (P_{max}) during reverse recovery. The maximum power is defined as the product of current I_F and voltage V_{AK}. Therefore, it is mandatory to ensure that the V_{AK} – I_F locus of the FWD always stays within the SOA. Unless stated otherwise the voltage V_{AK} of SOA is the voltage measured at the main terminals of the module.

Fig. 2-9 shows an example of SOA for the FWD for 2MBI600XNE120-50 (600A/1200V). In this case, P_{max} is given as 420 kW.

An example of the reverse recovery waveform is shown in Fig. 2-10(a) whereas in Fig. 2-10(b) SOA for FWD including V_{AK}–I_F locus for the reverse recovery waveforms from Fig 2-10(a) are displayed. The blue line in the latter figure represents the V_{AK}–I_F locus resulting from a circuit using a snubber circuit. The locus is within the SOA for FWD and the circuit will not cause any problem. The red line in the same figure represents a V_{AK}–I_F locus which is exceeding the SOA for the FWD. Hence, the used circuit may lead to the destruction of the FWD. In consequence it is mandatory to take appropriate action for

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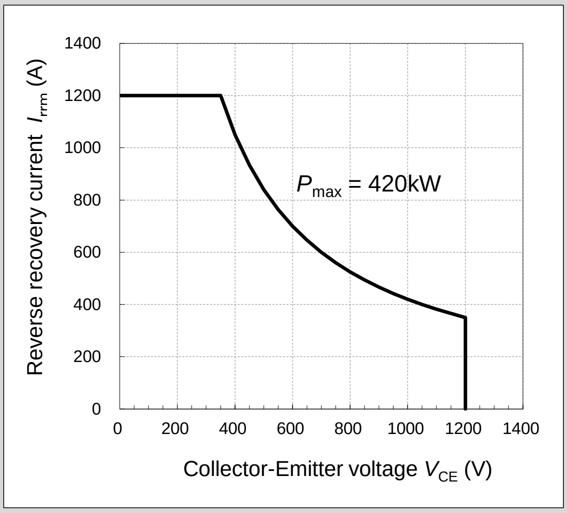
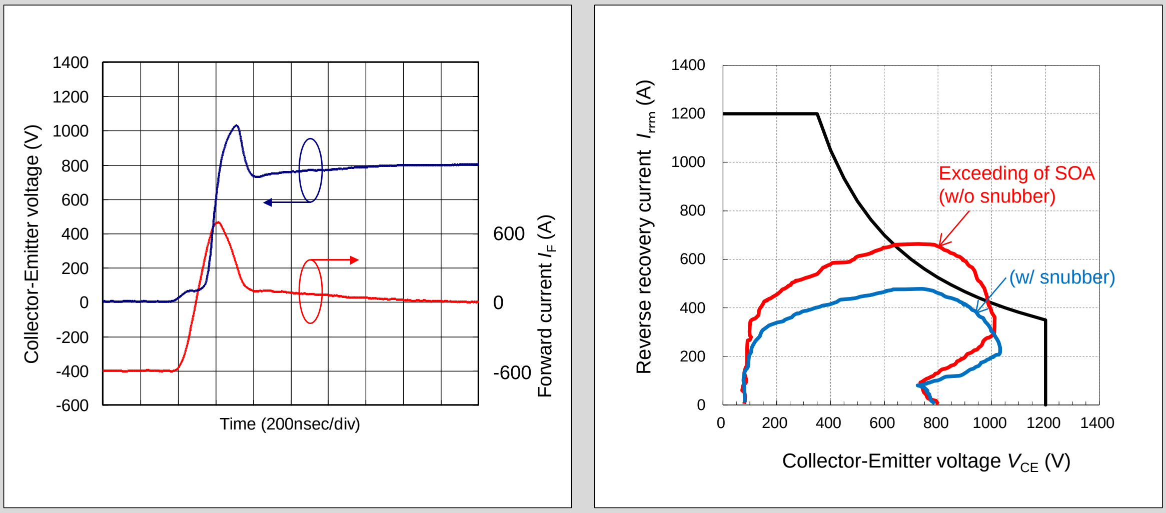


Figure 2-9 Example of Safe Operating Area (SOA) for FWD

keeping the locus within the SOA. For instance, this might be achieved by using a larger gate resistance for the IGBT.

The gate driving condition must be defined and chosen in order to keep the V_{AK}–I_F locus within the SOA for FWD for all operating conditions and all used devices.



(a) Waveform example when reverse FWD was restored

(b) V_{AK}-I_F and SOA for FWD Back Restoration

Figure 2-10 Reverse recovery waveform and V_{AK}-I_F locus for FWD reverse recovery

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4. Parallel Connection

IGBT modules can be connected in parallel for increasing the current capability. This chapter describes the parameters which have to be taken into account when X-series IGBT modules are going to be connected in parallel.

4.1 Junction temperature dependency of output characteristics and current imbalance

The junction temperature (T_{vj}) dependence of output characteristics influences the current imbalance of modules which are connected in parallel significantly. Fig. 2-11 shows typical output characteristic of 7th generation X-series IGBT modules ($V_{CE(sat)}$-I_C relation). As shown in Fig. 2-11, the X-series IGBT has a positive temperature coefficient which means that increasing T_{vj} leads to larger $V_{CE(sat)}$ values. Due to the positive temperature coefficient the current imbalance will be automatically regulated because the collector current I_C will decrease when T_{vj} increases.

As all output characteristics have a positive junction temperature coefficient, the X-series IGBT modules have suitable characteristics for parallel operation. According to historical data the positive temperature coefficient has been achieved by Fuji Electric starting from the 4th IGBT generation (S-series).

4.2 $V_{CE(sat)}$ variation and current imbalance

The ratio of current sharing between IGBT modules in parallel connection is called current imbalance

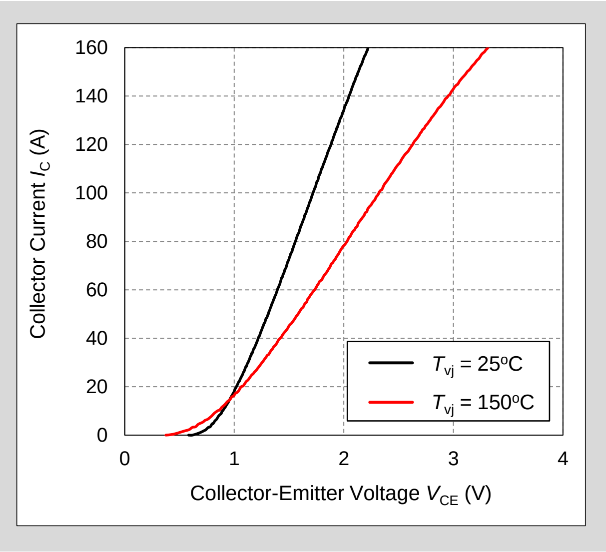

Figure 2-11 Relation between T_{vj} (1200V/100A) and IGBT output characteristics

ratio α. This ratio is determined by the variation of $V_{CE(sat)}$ of the IGBT itself and the junction temperature dependency of the output characteristics.

The relation between the current imbalance ratio α and variation $\Delta V_{CE(sat)}$ of $V_{CE(sat)}$ for two X-series IGBT modules connected in parallel are shown in Fig. 2-12. The current imbalance ratio α is obtained by

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applying Equation 2-1 with I_{C1} as current value and $I_{C(ave)}$ (=$I_{C1}/2+I_{C2}/2$) as the average current of the two paralleled modules.

As shown in Fig. 2-12, an increase of $\Delta V_{CE(sat)}$ results in a larger current imbalance α. Hence, parallel connection of modules requires a combination of modules which have only slightly different $V_{CE(sat)}$ values.

$$\alpha = \left(\frac{I_{C1}}{I_{C(ave)}} - 1 \right) \times 100 \quad \text{.................................Equation 2-1}$$

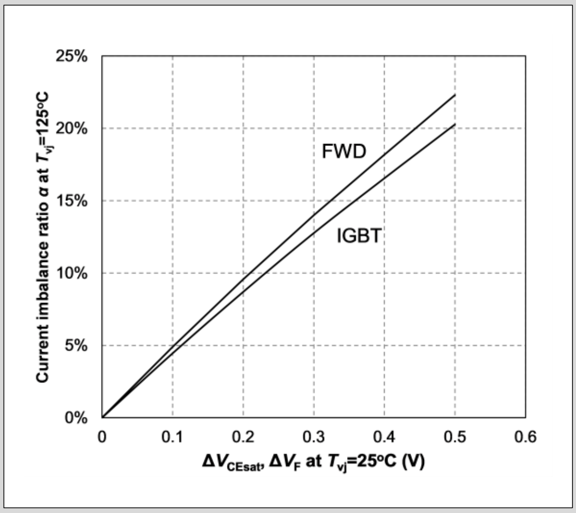

Figure 2-12 $V_{CE(sat)}$ and V_F variation and current imbalance ratio (1200V)

5. Mounting Instruction

Please refer to the WEB site (see URL below) and download the suggested mounting instruction for the concerned package of X-series module.

Fuji Electric Power Semiconductor - Design Support
http://www.fujielectric.com/products/semiconductor/model/igbt/mounting/index.html

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