Bodo´s Power Systems®

Increasing Power Density of 4.5 kV IGBT Power Modules

The requirements of future power-electronic converters are increasing constantly. Power density and converter efficiency have to increase further. Output power shall be adaptable for various projects and end customers. And yet, the converter still needs to be cost competitive. This article demonstrates how a new 4.5 kV power module can fulfil these converter requirements in applications such as railway, medium-voltage drives or electric power systems.

By Kazuto Mikami and Kenji Hatori, Mitsubishi Electric Corporation, Fukuoka, Japan
Victor Tolstopyatov and Nils Soltau, Mitsubishi Electric Europe B.V., Ratingen, Germany

Introduction

In 2020, Mitsubishi Electric has announced the availability of HV100 power modules with X-Series chipset and a voltage rating of 3.3 kV [1]. The HV100 package, as shown in Figure 1, offers high flexibility by easy parallel connection, low commutation stray inductance and 10.2 kV isolation voltage. Offering such features, this package has been originally designed to fulfill the requirements of future railway converters [2]. Most recently, Mitsubishi Electric further released another HV100 power module, which is rated for 4.5 kV and achieves a nominal current rating of 450 A. This article introduces this new device with the type name CM450DE-90X, explains the advantages compared to previous power modules and shows key features for applications like railway, medium-voltage drives or electric power systems.

Figure 1: Power Module in HV100 Package

Inside CM450DE-90X, Mitsubishi Electric uses its latest 4.5 kV X-Series chip generation including CSTBTTM (III) and RFC diode. This ensures low losses, smooth switching waveforms and high robustness in case of over-current.

The structure of the HV100 package is shown in Figure 2. The two DC terminals are located at one side of the power-module, whereas two AC terminals are located at the opposite side. It allows low-inductive connection of the DC-link capacitor and a clean converter setup. In its center, the HV100 offers space for the gate-driver board. When HV100 power modules are connected in parallel, terminals are still easy to access and well sorted. For the gate driver in parallel connection, a PCB may be mounted just on top of the paralleled modules and control all of them. Also such design can be easily scalable by increasing (or decreasing) the number of paralleled modules to adjust the output power.

The HV100 package uses the famous MCB baseplate (Metal Casting direct Bonding). It allows lower thermal conductivity for remarkable power density. Compared to a classical package structure with AlSiC baseplate, the thermal resistance from junction to case is about 30% lower with MCB baseplate. Moreover, the MCB baseplate avoids substrate solder, which was originally a limiting factor of thermal-cycling lifetime in conventional power-module packages.

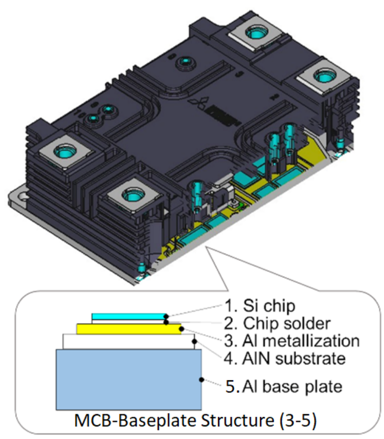

Figure 2: Cross section view of HV100 power module including MCB baseplate structure

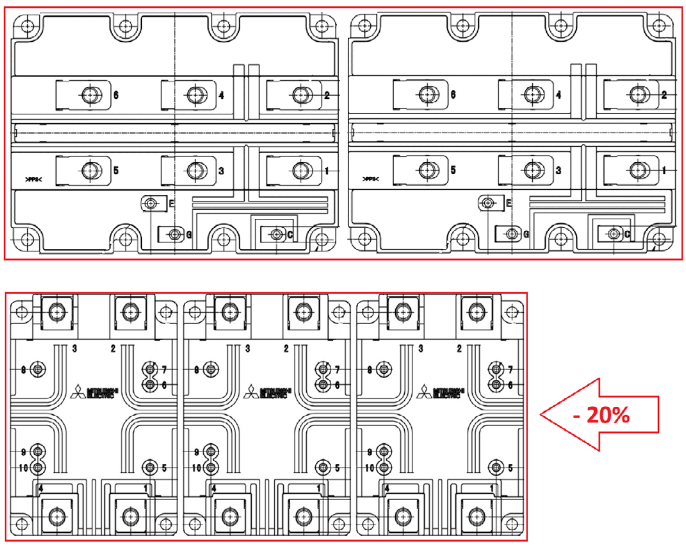

Figure 3: Size comparison for one half bridge with HV100 and conventional packages at same nominal current rating

Increased Power Density

In the following, the achievable output power of CM450DE-90X is compared with conventional 190 x 140 mm² power modules. The comparison considers for example two CM1350HG-90X single modules in conventional packages with three paralleled CM450DE-90X dual modules, which corresponds to the same nominal current rating for one half-bridge. Even though the nominal current rating is same, Figure 3 shows that the HV100 power modules occupy about 20% less area on the heatsink.

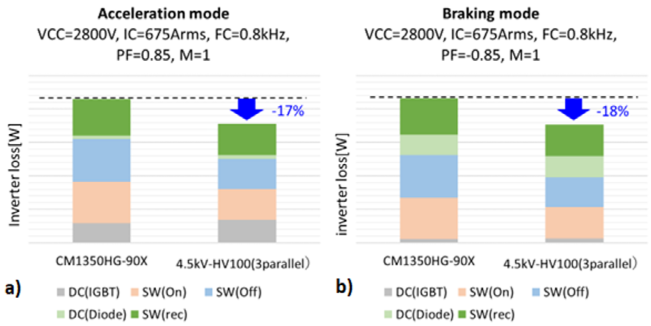

Figure 4: Inverter Loss Calculation Result

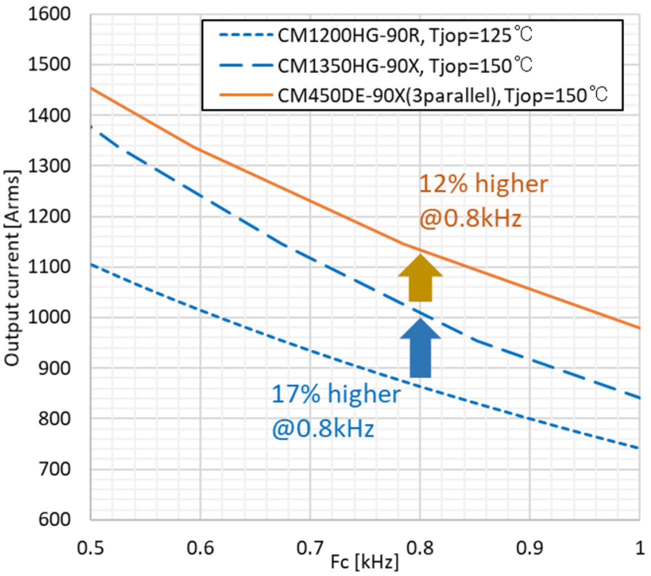

Figure 5: Relationship between output current and carrier frequency for R series HVIGBT, X series HVIGBT and 4.5kV HV100 (Condition: Sinusoidal, V_{CC}=2800 V, P_F=+0.85, M=1, T_S=80°C, T_j = T_{jop})

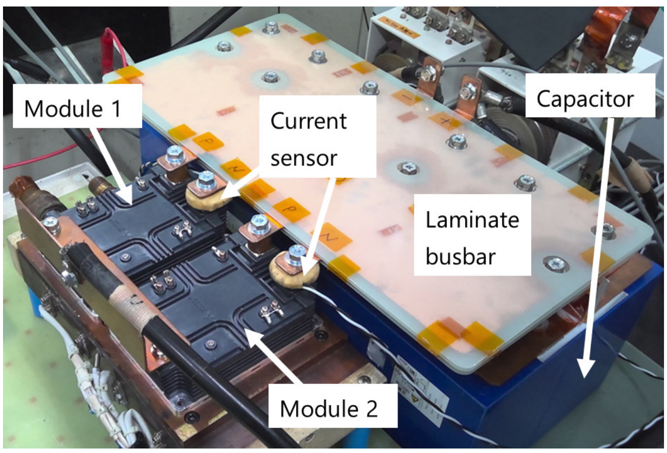

Figure 6: Test setup to measure the current sharing between two CM450DE-90X connected in parallel

Stray inductance between the dc-link and the semiconductor chips is one of the main characteristics of a power module, which can influence significantly its switching behavior. High parasitic inductance protracts turn on and off processes as well as leads to higher overvoltage spike during turn-off. Both mentioned phenomena overall increase switching losses of the module. Since the HV100 achieves lower stray inductances, faster switching speeds and lower switching losses are enabled. Compared to the conventional package, the 4.5kV HV100 can reduce total inverter losses by 17% in acceleration mode (i.e. positive power factor Figure 4a) and 18% in braking mode (i.e. negative power factor Figure 4b) [3].

Using MelcoSim ver.5.4.1 [4], the achievable output current is calculated for three CM450DE-90X in parallel compared to CM1350HG-90X and CM1200HG-90R (previous R-Series). The results are shown in Figure 5. Compared to the previous R series HVIGBT modules, the X series can contribute to lower losses, improved thermal resistance and increased maximum allowed operating temperature to Tj=150°C. By those mentioned factors the possible output current in CM1350HG-90X module might be increased by around 17% in comparison to CM1200HG-90R. A further 12% increase may be achieved by using new HV100 dual modules CM450DE-90X (three in parallel). This is achieved by the lower switching losses and the improved thermal resistance due to the MCB baseplate.

Parallel Operation

As previously mentioned, the HV100 package is designed for simpler parallel connection. Hence, even for parallel connections, the terminal layout allows straight forward connection of the dc-link capacitors and the AC output. In the following, the current sharing among two parallel-connected CM450DE-90X is measured. Figure 6 shows the test setup. With it, the individual currents of the N-side IGBTs are measured. The tests have been performed at room temperature, V_{CC} = 2800 V, a total current of $I_{C,total}$ = 900 A (450 A per power module), and a gate voltage of V_{GE} = ± 15 V.

Figure 7 (a) and (b) show the current sharing between the two power modules during turn-off and turn-on respectively. The measurements show that the current is distributed evenly between the two power modules, leading to a very good utilization of available chip area.

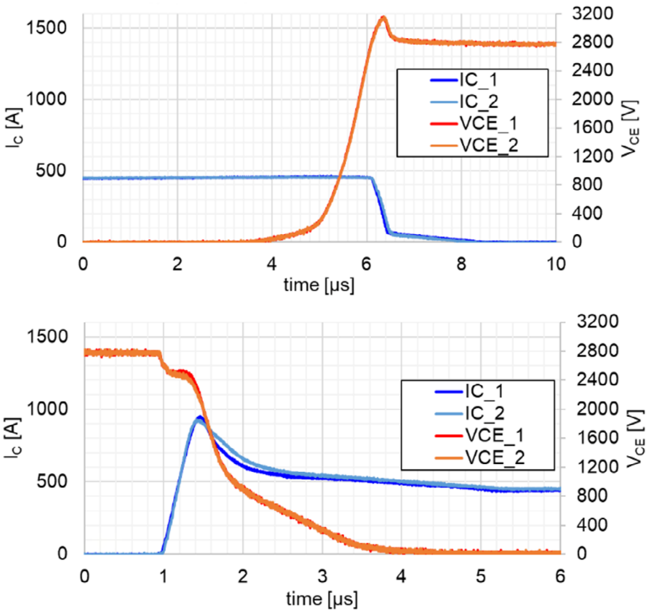

Figure 7: Current sharing of two parallel-connected CM450DE-90X (Conditions: V_{CC}=2800V, $I_{C,total}$=900A, V_{GE}=±15V, T_j=25°C, N-side)

It should be noted that the two modules used in the evaluation have been selected to have small differences in their individual characteristics. Regarding the influence of power module parameter variations on the parallel connections, please refer to [5].

Switching with High Stray Inductance

Switching with low DC-link stray inductance LS is recommended to reduce switching losses and overvoltage during turn-off switching. However, converter design with low LS might not always be possible. In some cases, for example in multi-level converters, the power module should also be able to operate safely even under higher LS conditions. Figure 8 shows a comparison of switching waveforms at LS=100nH and 400nH for 4.5kV HV100 during turning-off. As it can be seen, even at LS high as 400nH the maximum VCE voltage reaches only around 3600V. For further measurement results at high stray inductance, please see [3]. In summary, CM450DE-90X can operate even with high stray inductance having enough margin to VCES and without oscillations.

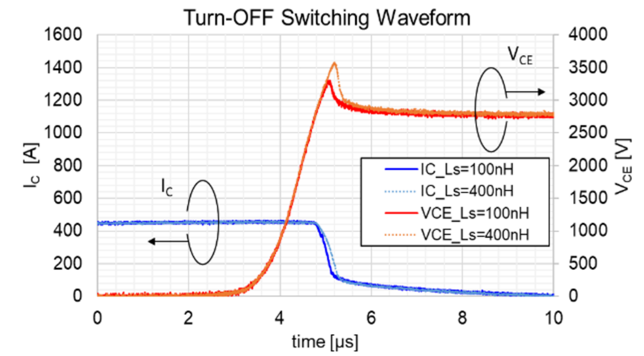

Figure 8: Comparison of switching waveform of 4.5kV HV100 between L_s=100nH and L_s=400nH (Condition: V_{CC}=2800V, I_C=450A, V_{GE}=15 V, T_j =150°C)

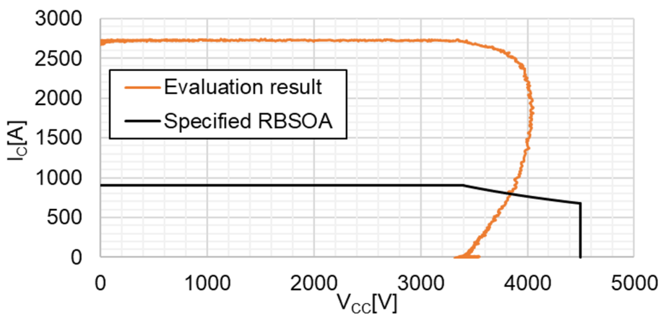

Figure 9: Specified RBSOA and evaluation result (V_{CC}=3400V, T_j=150°C)

Ruggedness in Over-Current Events

Robustness of power modules is one of the main required feature especially for such a responsible applications as railway or electric power systems. Defining RBSOA (Reverse Bias Safe Operation Area) is the typical approach to evaluate the robustness of IGBT module. This characteristic shows the ability of a power module to withstand certain voltage and current during IGBT turn-off. In Figure 9, the specified RBSOA for CM450DE-90X is shown with black color. In same picture, real type-test measurement results are shown with orange. It has been confirmed that the CM450DE-90X sample has not failed even at 2700A which is 6-times rated current. This difference demonstrates the ruggedness of CM450DE-90X and potentially gives additional safety margin to the converter manufacturers and end-users in case of unexpected over-current events.

Conclusion

This article has introduced the new 4.5 kV / 450 A power module in the HV100 package, named CM450DE-90X. The power module provides 10.2 kV isolation voltage and remarkable performance enabled by its MCB baseplate and latest chip generation. It has been shown that CM450DE-90X fulfills future converter requirements. In particular, power-density increase, simple parallel-connection, and high ruggedness in case of over-current have been discussed.

The new CM450DE-90X is extending the line-up of the LV100 / HV100 product family. Besides CM450DE-90X, there are additional power modules for 1.7 kV and 3.3 kV rated voltage available. Table 1 shows the complete LV100 / HV100 line-up.

	LV100		HV100	
Dimensions	100 mm x 140 mm x 40 mm			
Isolation Voltage	6 kV$_{rms}$		10.2 kV$_{rms}$	
Rated Voltage	1.7 kV	3.3 kV	3.3 kV	4.5 kV (new!)
Rated Current	1200 A	450 A, 600 A	450 A, 600 A	450 A
Model	CM1200DA-34X	CM450DA-66X CM600DA-66X	CM450DE-66X CM600DE-66X	CM450DE-90X

Table 1: Line-up of HV100 and LV100 power modules

References

[1] Mitsubishi Electric Corporation, *Mitsubishi Electric to Launch HV100 dual type X-Series HVIGBT Modules,* Tokyo, Japan, 2020.

[2] N. Soltau, E. Wiesner, R. Tsuda, K. Hatori and H. Uemura, “Demands by Future Railway Converters and How They Change Power Semiconductor Modules,” in *Bodo’s Power Systems*, Jul 2021.

[3] K. Mikami, K. Hatori and N. Soltau, “4.5 kV HV100-type HVIGBT Module for Large Industrial Equipment,” in *PCIM Europe*, Nuremberg, Germany, 2023.

[4] Mitsubishi Electric Corporation, “Mitsubishi Electric Power Module Loss Simulator Melcosim,” [Online]. Available: https://www.mitsubishielectric.com/semiconductors/simulator/index.html. [Accessed 19 May 2023].

[5] Y. Ando, J. Sakai, K. Hatori, N. Soltau and E. Wiesner, “Influence of IGBT and Diode Parameters on the Current Sharing and Switching-Waveform Characteristics of Parallel-Connected Power Modules,” in *24th European Conference on Power Electronics and Applications (EPE’22 ECCE Europe)*, Hanover, Germany, 2022.

www.mitsubishielectric.com