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HV-IGBT Module for High-Performance Inverter Design

This article provides an overview of Mitsubishi Electric's newly developed XB-Series High Voltage Insulated Gate Bipolar Transistor (HV-IGBT) modules. The series achieves lower switching losses and enhanced reliability through the adoption of 7th-generation Si IGBT (CSTBT™) and Relaxed Field Cathode (RFC) diodes compared to the previous series. During development, particular focus has been placed on both loss reduction and robustness, contributing to improved inverter efficiency and longer thermal cycling lifetime. These modules are suited for large industrial systems such as railways and medium-voltage drives.

By Victor Tolstopyatov, and Nils Soltau, Mitsubishi Electric Europe B.V., Germany and Shuhei Saito, Hironaka Yoichi, Mitsubishi Electric Corporation, Japan

To meet growing demands for energy-efficient and reliable inverter systems in traction applications, Mitsubishi Electric has introduced the XB-Series high-voltage IGBT modules, engineered for use in harsh environments such as railway systems and medium-voltage drives [1].

The XB-Series represents the latest generation of HVIGBT modules from Mitsubishi Electric. While the X-Series targets applications requiring the highest power density and performance, the XB-Series was specifically engineered as a value-optimized solution focused on both reliability and efficiency. It is designed for converter systems that require high switching speed or utilize earlier generations of IGBTs, such as the R- and H-Series. The current ratings of the XB-Series are optimized to serve as a practical and efficient replacement for these legacy HVIGBT modules.

This article presents the key advantages of adopting the XB-Series, particularly in terms of improving the reliability and overall performance of high-voltage power converters.

Lineup overview

The product lineup includes a range of modules with rated blocking voltages of 3.3 kV, 4.5 kV, and 6.5 kV with package isolation voltages of 6.0 kV and 10.2 kV, and current ratings up to 1500 A – covering a wide spectrum of traction inverter applications (Table 1). Both package types, offering 6.0 kV or 10.2 kV isolation voltages, are illustrated in Figure 1 [2]. The external dimensions of the new XB-Series remain identical to those of the previous R-Series. As a result, isolation voltage, physical footprint, and maximum junction temperature are consistent with the conventional 3.3 kV R-Series.

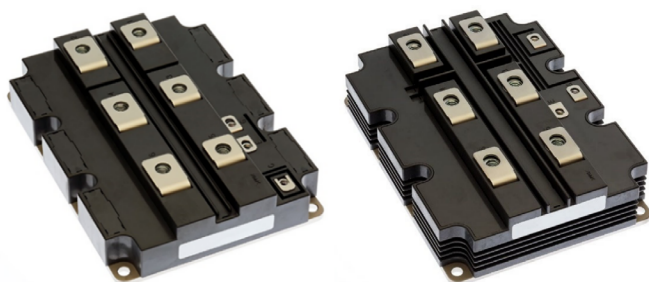


Figure 1: XB-Series HVIGBT modules in 6.0kV and 10.2kV isolation packages

This design allows seamless replacement without the need for modifications to the interface, such as busbars or mounting configurations.

Type name	Rated voltage	Rated current	Isolation Voltage	Maximum junction temperature
CM1500HC-66XB	3.3 kV	1500 A	6.0 kV _{rms}	150 °C
CM1200HC-90XB	4.5 kV	1200 A	6.0 kV _{rms}	150 °C
CM1200HG-90XB	4.5 kV	1200 A	10.2 kV _{rms}	150 °C
CM750HG-130XB	6.5 kV	750 A	10.2 kV _{rms}	150 °C

Table 1: Lineup of XB-Series HV-IGBT

Electrical performance

Switching and static losses are among the most critical performance parameters of IGBT modules, as they directly impact inverter efficiency and thermal management. With each new generation of HVIGBTs, Mitsubishi Electric aims to incorporate cutting-edge technologies into chip design to minimize these losses. As shown in Figure 2, the XB-Series achieves approximately 15% lower total power losses [3] in acceleration mode (power factor PF = 0.85) compared to the previous R-Series. According to simulation the same result of 15% reduction of power losses may be expected for braking mode.

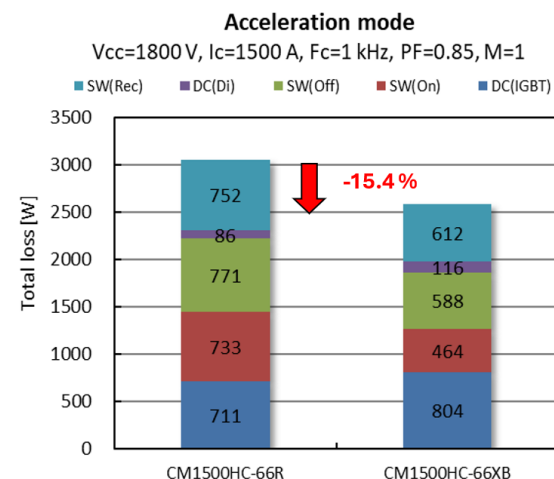


Figure 2: Total inverter loss calculation result



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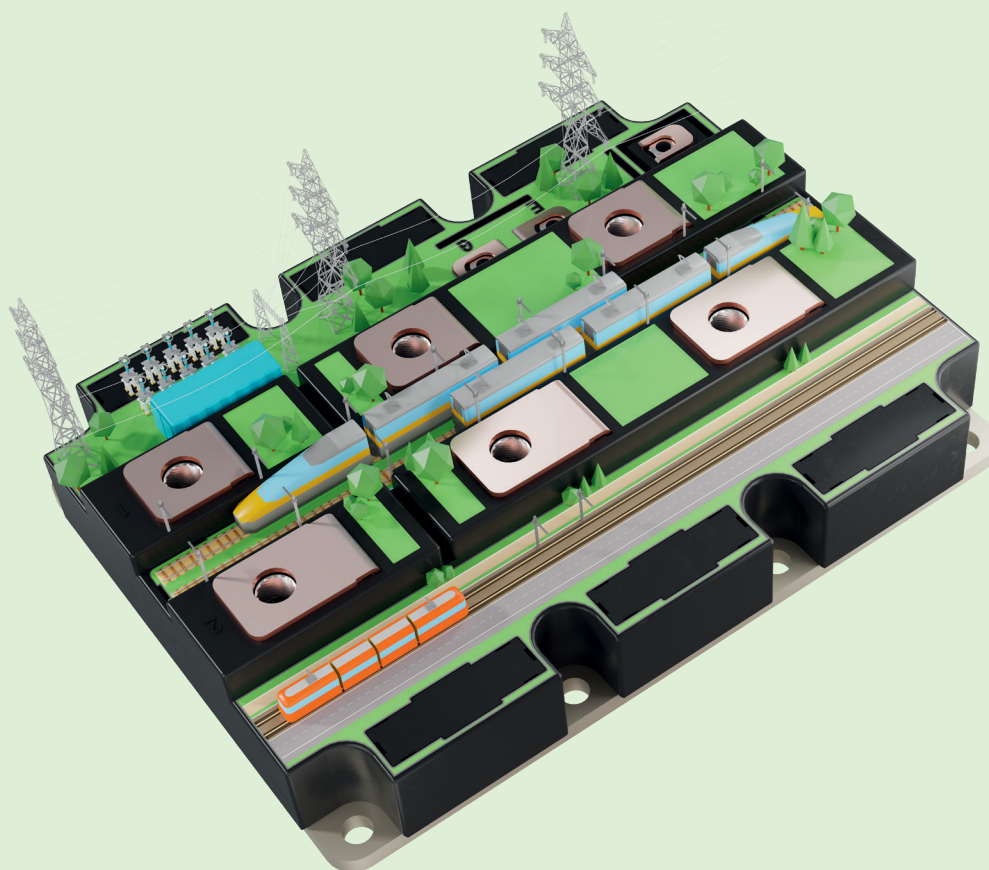
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mining or grid infrastructure

X- and XB-Series for High-Performance Inverter Design

- // Standardized and field-proven packages with 6 kV and 10.2 kV insulation voltage
- // IGBT chips with latest generation CSTBT™ technology and robust RFC diodes
- // High robustness/resistance against environmental influences due to the newly developed SCC (Surface Charge Control) process
- // Increased current rating for applications with maximum power density (X-Series)
- // Increased switching speed, current ratings compatible to previous R-Series (XB-Series)
- // Package compatible to previous H- and R-Series for simplified design and easy replacement
- // High robustness and 150 °C maximal operation temperature

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This significant improvement is primarily achieved by optimizing gate structure, which reduces the reverse transfer capacitance (C_{res}). While the conventional 3.3 kV R-Series utilized a planar gate design, the new XB-Series employs a trench gate, resulting in a more favorable distribution of hole density in the collector region – both at the top and bottom surfaces of the IGBT chip. That allows XB-Series to have a 77% reduction in input capacitance (C_{ies}) and a 49% reduction in reverse transfer capacitance (C_{res}) compared to the R-Series. Additionally, the total gate charge (Q_G) is reduced by approximately 51%, which not only contributes to lower switching losses but also facilitates the miniaturization and energy efficiency of the gate driver unit.

Reliability of IGBT and diode chips

Since the primary target applications of HVIGBTs are traction systems and railway converters, reliability and robustness are top priorities. These systems operate under high voltage, variable load, and harsh environmental conditions where unexpected faults or overloads may occur. A traditional measure of IGBT robustness is the Safe Operating Area (SOA), which defines the limits under which the device can safely operate without failure. Although the maximum specified turn-off current is typically twice the nominal current, the new XB-Series IGBT chip is capable of safely turning off more than 6.5 times its nominal current (9750 A), as demonstrated on the CM1500HC-66XB example in Figure 3.

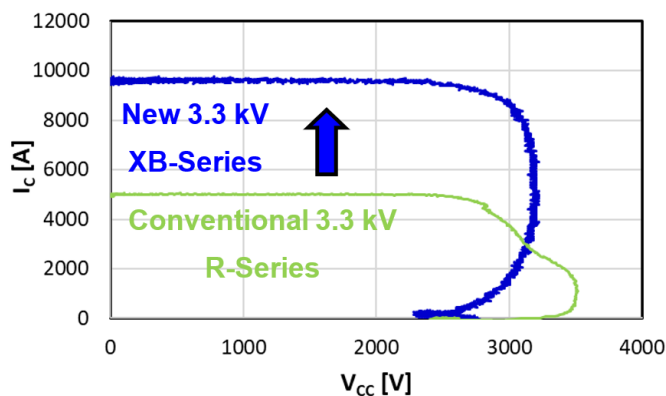


Figure 3: Comparison of I-V plots

The conventional 3.3 kV R-Series used a Field Limiting Ring (FLR), which caused high electric field concentration at the edge during turn-off, risking avalanche breakdown. In contrast, the XB-Series uses a Linearly-narrowed Field Limiting Ring (LNFLR) that gradually narrows the P-type region, reducing hole injection and current crowding. This helps to relax the electric field at the termination and improves switching robustness.

The diode chip structure in the XB-Series was also optimized by implementing Relaxed Field Cathode (RFC) technology, which effectively suppresses snap-off effect during reverse recovery – even under high turn-on di/dt conditions [4]. As a result, the XB-Series demonstrates approximately 3.9 times higher reverse recovery peak power (P_{rr}) than the specified datasheet limit, significantly enhancing diode robustness and system reliability.

Lifetime Improvement

One of the primary aging mechanisms that limits the lifetime of power semiconductor modules is mechanical stress induced by thermal cycling. Due to the differing coefficients of thermal expansion (CTE) among materials, each heating and cooling cycle causes incremental degradation of internal connection joints. In the conventional R-Series, the solder joints beneath the power terminals were identified as the key failure point. As thermal fatigue leads to crack propagation in these joints, electrical resistance increases, resulting in uneven current distribution across the module and a corresponding rise in collector-emitter saturation voltage ($V_{CE(sat)}$).

To enhance the mechanical durability of these joints, a high-strength solder alloy was introduced in the XB-Series. This solder offers improved fatigue resistance under shear stress, significantly extending the module's thermal cycling lifetime. The results of the thermal cycling test are presented in Figure 4, where the failure criterion was defined as a 5% increase in $V_{CE(sat)}$. As shown, the normalized number of cycles before failure is more than twice as high for the XB-Series compared to the 3.3 kV R-Series, demonstrating substantial improvement in long-term reliability.

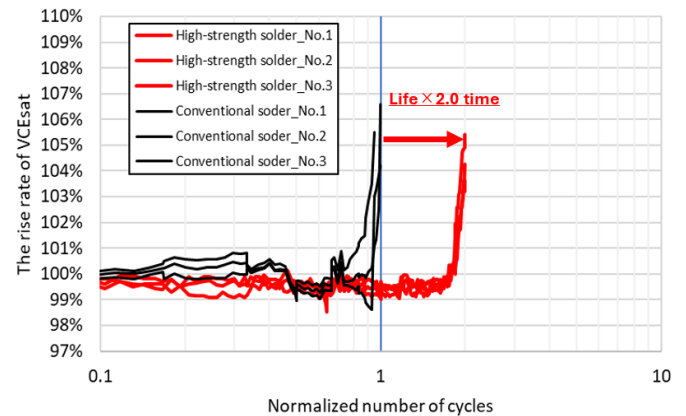


Figure 4: Thermal Cycling Lifetime Comparison

Conclusion

The newly developed XB-Series HV-IGBT modules by Mitsubishi Electric provide a highly reliable and efficient solution for traction and medium-voltage inverter applications. Featuring advanced chip and packaging technologies, the XB-Series achieves approximately 15% lower switching losses and significantly improved robustness compared to previous generations.

Enhanced Safe Operating Area (SOA), improved diode recovery behavior, and extended thermal cycling lifetime make the XB-Series well-suited for demanding environments. The modules also maintain full mechanical compatibility with legacy products, enabling easy system upgrades.

Together, the XB-Series and X-Series form a comprehensive HVIGBT product family that supports a broad range of applications. The XB-Series targets high switching speed systems and offers current ratings aligned with previous HVIGBT generations, making it ideal for upgrades. In contrast, the X-Series provides higher current capability and is optimized for applications requiring maximum power density. This flexibility enables Mitsubishi Electric to support both legacy system modernization and next-generation power electronics development.

References

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