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2.5 kV IGBT Module in LV100 Package with Enhanced SLC+ Technology for Superior Power Cycling Performance

Mitsubishi Electric Introduces advanced 2.5 kV IGBT Module with Enhanced SLC+ Technology for Superior Power Cycling Performance. Engineered as optimal solution for 1000 Vac / 1500 Vdc 2-level inverters systems in wind, solar, hydrogen and energy storage applications. This new module sets a benchmark in reliability, tackling power and thermal cycling stress to ensure long-term stability and reduced maintenance costs."

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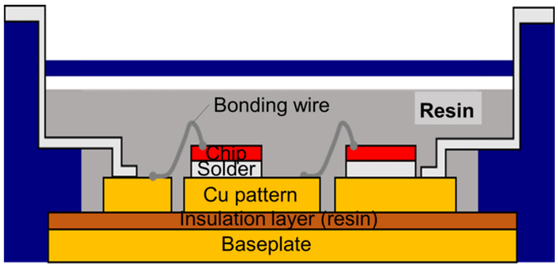
Introduction

The global shift towards renewable energy sources like wind power, energy storage, hydrogen production, and photovoltaic (PV) systems is driving the need for power electronics that can deliver both high performance and exceptional reliability. Mitsubishi Electric is addressing these demands with a new generation of power modules that combine advanced packaging technology with cutting-edge chip design.

At the heart of this innovation is the Solid Cover+ (SLC+) structure, a significant update from the previous Solid Cover (SLC) technology [3]. The newly developed SLC+ structure is engineered to enhance power cycling capabilities, a critical factor in ensuring the long-term reliability of power modules under demanding operating conditions. This updated SLC+ structure is integrated with Mitsubishi Electric's latest low-loss 7th-generation 2.5 kV chipset, offering an ideal combination of performance and durability.

The 2.5 kV voltage rating has been specifically selected as the optimal solution for 1000 Vac and 1500 Vdc systems. This choice represents a carefully considered compromise between long-term DC stability (LTDS) and power losses, ensuring that the module provides both high efficiency and reliable performance in renewable energy applications. These new modules are tailored to meet the stringent requirements of high-performance applications in wind power, energy storage, hydrogen production, and PV systems.

Figure 1: LV100 module with 2.5 kV IGBT and SLC+ technology



Structure name	Solid Cover (SLC)	Solid Cover + (SLC+)
module types	LV100	LV100
Sealing material	Resin	Resin
Substrate	Insulating metal substrate (IMS)	Insulating metal substrate (IMS)
Bond wire matrial	Al	Al-alloy
Chip surface	Metallization layer	Hard metallization layer

Figure 2: SLC and SLC+ technology

With these innovations, Mitsubishi Electric is setting a new standard in power modules, focusing on maximizing both efficiency and reliability, even in the most challenging renewable energy environments.

Technical Innovation: The SLC+ Structure for higher reliability

Central to the enhanced performance and reliability of Mitsubishi Electric's new module is the Solid Cover+ (SLC+) structure. The well-known SLC structure [3] [2] has been update to for power cycling capability improvements.

New Al-alloy Bond Wire:

The SLC+ structure introduces an advanced aluminum alloy bond wire that offers significantly higher yield strength compared to conventional bond wires. This enhancement is crucial as it directly addresses one of the primary causes of SLC module power cycle failure "bond wire cracking". Under power cycling, the repeated expansion and contraction of materials can lead to mechanical

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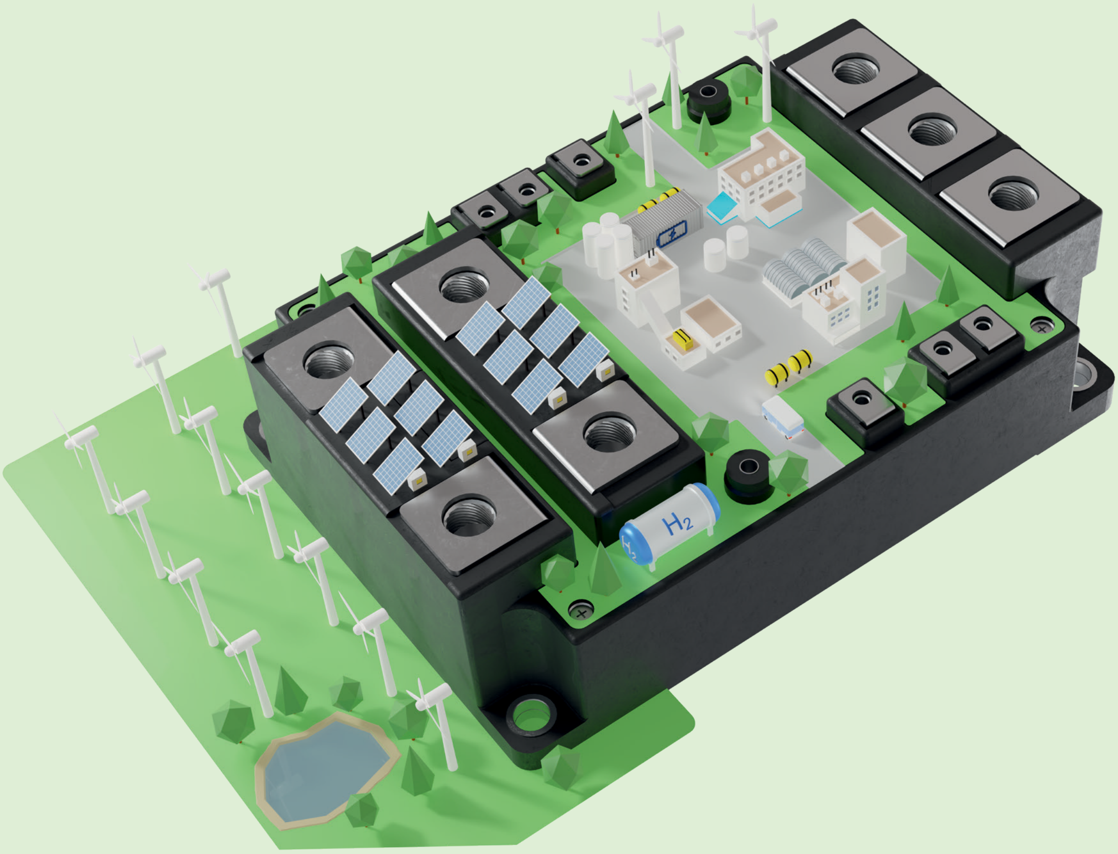

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// High current capability by 3 AC-output terminals
// High thermal cycle capability by SLC-Technology
// Pre-applied PC-TIM available
// New 2000V class available enabling 2-level for $1500V_{dc}$ inverter systems
// High temperature operation with $T_{vj\,max}$ = 175°C junction temperature at overload events
// 2.5kV class and 1800A/1.2kV are under development

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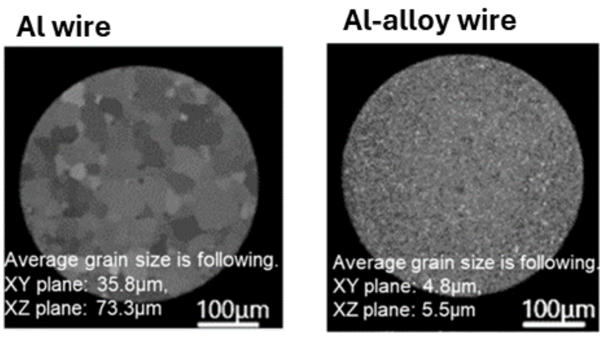
stress that eventually causes bond wires to crack. The new Al-alloy wire in the SLC+ structure is designed to withstand these stresses more effectively, increasing power cycling capability. This improvement not only extends the operational lifespan of the module but also enhances its reliability under the fluctuating temperature conditions typical e.g. in wind converter application. Especially the enhanced characteristics of the aluminum alloy wire in combination with the hard resin encapsulation of the SLC technology resulting in a significant improvement of power cycling capability.



Wire material	Yield Str. (MPa)
Al	32
Al-alloy	87

Figure 3: Comparison of Al and Al-alloy wire

Hard Metallization Layer on Chip Surface:

Another critical feature of the SLC+ structure is the hard metallization layer applied to the chip surface. In traditional power modules, the chip electrode is susceptible to cracking due to mechanical stress and thermal expansion. Such cracks can lead to catastrophic module failures, rendering the entire system inoperative. The hard metallization layer in the SLC+ structure acts as a protective shield, preventing the formation of cracks and maintaining the integrity of the chip electrode. This innovation complements the improved bond wire, creating a synergistic effect that significantly enhances the overall robustness of the module.

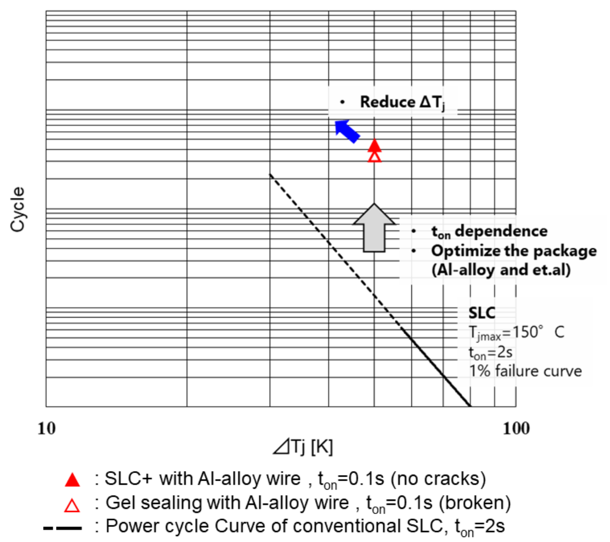


Figure 4: SLC+ power cycle test

Power Cycle Performance Improvement

The actual benefits of the SLC+ structure are demonstrated through power cycling tests conducted by Mitsubishi Electric. These tests target is to reproduce the harsh operating conditions that power modules face in renewable energy systems, particularly the thermal cycling that occurs in wind turbine converters on generator side [1]. The 2.5 kV LV100 module with SLC+ structure exhibited a power cycling capability exceeding 40 million cycles under conditions of ton=0.1 s, Tjmax=150 °C, and ΔTj=50 K. Notably, this performance was achieved without any failures and demonstrate the effectiveness of the improved SLC+ structure design.

This represents a significant advancement over conventional power modules, which typically show signs of degradation or failure under similar conditions. The enhanced power cycling capability of the SLC+ module ensures that it can operate reliably over extended periods, even in the most demanding applications. This reliability is particularly critical in renewable energy systems, where unplanned maintenance or downtime can lead to substantial financial losses and disrupt energy production.

2500V for low LTDS FIT rate

The 2.5 kV IGBT and diode chip-set used in this module have been optimized to meet the requirements of 1500 Vdc / 1000 Vac systems. This optimization involves achieving a delicate balance between minimizing power loss, controlling junction temperature, and enhancing long-term DC stability (LTDS) robustness. These factors are crucial in determining the module's efficiency and reliability. Also the chip sizes, the conduction and switching loss characteristics has been tuned to fit for converters in renewable application such as wind power and storage system. One of the key challenges in designing high-voltage modules is ensuring their robustness against cosmic rays, which can induce failures, especially in environments with long-term exposure to high DC voltages and or high altitudes. Cosmic ray-induced failures, though rare, can have catastrophic consequences, leading to sudden and unpredictable module failures. The 2.5 kV module's enhanced LTDS capability is the result of the 2.5kV chip design and , resulting in a outstanding lower FIT rate, making it an ideal choice for applications that demand long-term reliability and stability in combination with high efficiency.

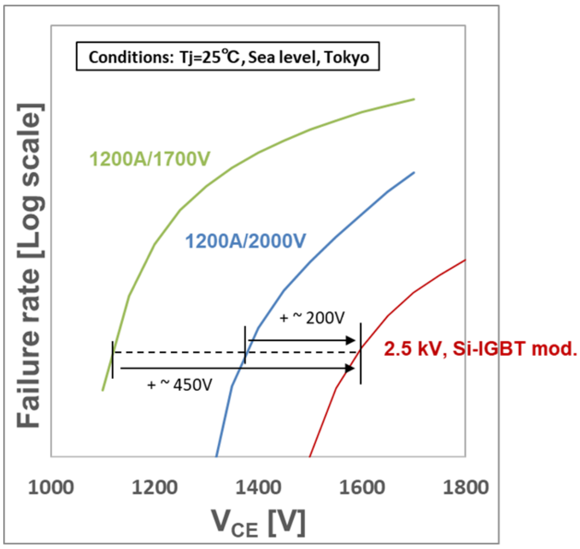


Figure 5: Estimation of LTDS failure rate

Module loss and thermal performance

The actual advantages of the 2.5 kV module with SLC+ structure are evaluated under typical application conditions from renewable applications. Simulations comparing the new 2.5 kV module with a standard 1.7 kV (CM1200DW-34T), module showing several key benefits particularly in wind power applications.

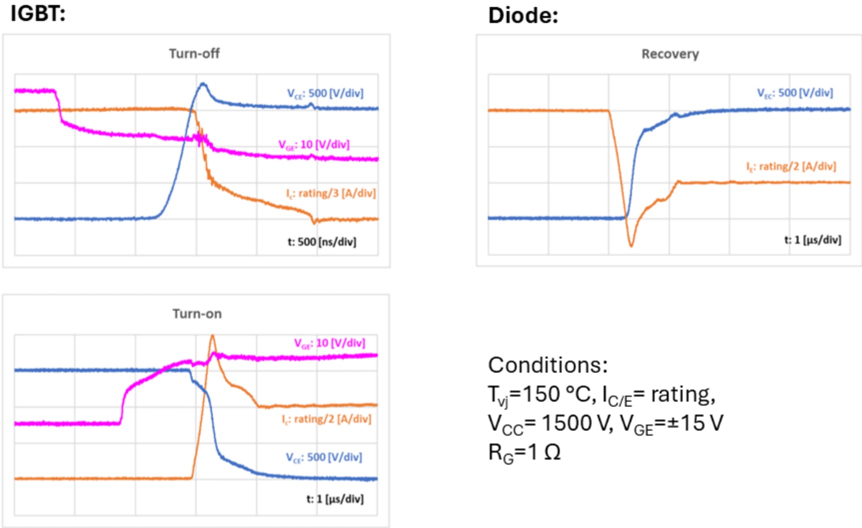


Figure 6: Switching waveforms

	1.7 kV module	2.5 kV module
Conditions		
V_{cc}	1000 V	1500 V
V_{out}	690 Vrms	1000 Vrms
$T_{vj(top)}$	150℃	
cosφ	-0.8	
f_c	1.5 kHz	
f_{out}	6 Hz	
Modulation method	3rd harmonic injection	
Modulation index	0.25	
Results		
P_{out}	1.1 MW	1.26 MW
ΔT_j (IGBT)	32.3 K	45.8 K
ΔT_j (diode)	53.7 K	44.2 K

Table 1: Thermal simulation results at wind converter operating conditions

An excellent low loss switching performance has been achieved, as demonstrated in waveforms at 150 °C. Thanks to the LV100 package's reduced built-in stray inductance, the 2.5 kV module experiences low turn-off and recovery surges, resulting in smooth and rapid switching. This reduced inductance allowing a chip optimization towards loss reductions.

By keeping the same system output power while operating at higher voltage enabled by the 2.5kV module, the actual current can be reduced. The reduction of output current in the is enabling a slight increase in on state voltage without encroachment of overall performance. The 2.5 kV IGBT shows just about 15% higher on-state voltage compared to the 1.7 kV version, while the 2.5 kV diode only has a 5% higher forward voltage. The strong diode performance has been designed because diode losses are critical in rectifier converters for wind s and hydrogen applications.

When comparing power losses and junction temperatures between the 2.5 kV and 1.7 kV modules, the 2.5 kV module delivers about 15% higher output power at the same junction temperature (150 °C). This is particularly beneficial in wind power systems, where the new module can achieve higher power output without exceeding thermal limits.

Moreover, thermally the 2.5 kV module has the improvement that the temperatures of IGBTs and diodes under typical operating conditions are very similar, which leading to efficient device usage and extended power cycling life-time since no device is causing a thermal or lifetime bottleneck while the other device is not fully. The reduced temperature swing (ΔTj) in the 2.5 kV module minimizes the diode as a bottleneck in negative power factor operating conditions and contributing to an extended power cycling lifetime

Conclusion

Mitsubishi Electric's new 2.5 kV IGBT module in LV100 housing, featuring the innovative SLC+ structure, represents a major leap forward in the design of power electronics for renewable energy applications. By addressing the key challenges of thermal and power cycling, power density, high efficiency and cosmic ray-induced failures, this module offers a reliable and efficient solution for renewable applications with 1500 Vdc or 1000 Vac inverter system.

The module's enhanced power cycling capability, coupled with high LTDS robustness and high efficiency features, makes it particularly well-suited for demanding renewable energy systems. As the industry continues to push towards higher efficiency and greater reliability, innovations like the SLC+ structure will play an important role in ensuring that power electronics can meet these demands. Mitsubishi Electric remains at the forefront of this technological evolution, committed to delivering advanced solutions that support the global transition to sustainable energy sources.

Reference

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