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Mega-Watt-Level Power Stack Design with LV100 Package

Mitsubishi Electric introduces the reference design of power stack, assembled with 3-parallel IGBT modules (1.7kV/ 1200A) in LV100 package. The solution for 690 Vac / 1100 Vdc 2-level inverters systems in wind power application is designed by electrothermal simulation, and the experimental results support the effectiveness of the design methodology. The information in this article about the power stack and some design concepts may support power-device users.

By Zheng-Feng Li, Nobuya Nishida, Mitsubishi Electric Corporation, Fukuoka, Japan
Koichi Masuda, Nils Soltau, Mitsubishi Electric Europe B.V., Ratingen, Germany

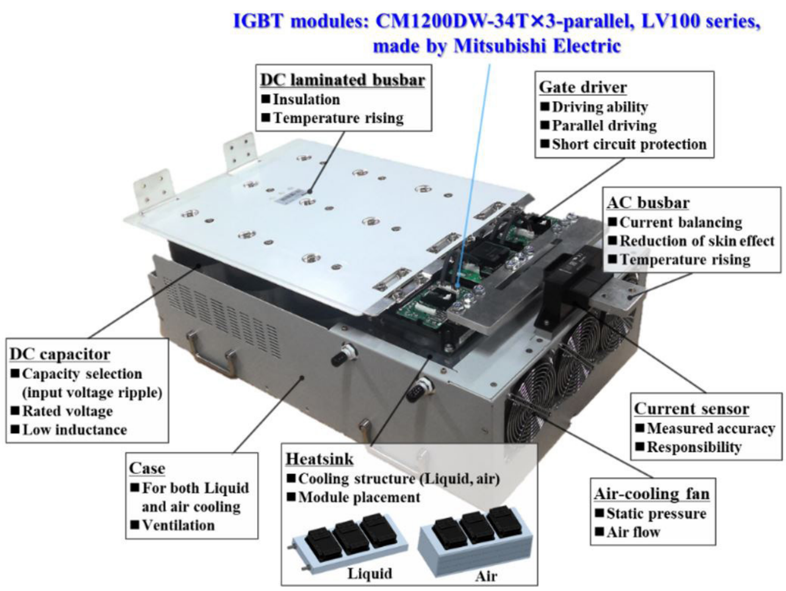


Figure 1: Illustrate of power stack and technical points.

Introduction

In recent years, demands for power semiconductors, key devices for contributing to realize a decarbonized society, have been rapidly expanding. The reason is that the path toward renewable energy grids involve significant integration of inverter-based resources (IBRs), which are composed with a huge number of small IBRs to adjust frequency and voltage for obtaining higher system performance [1]-[2]. Therefore, the significant growth of wind power (WP), photovoltaics (PV), hydrogen and energy storage system are expected [3]. The power rating of a large inverter for WP or central PV inverters could be somewhat below 10 MW approximately [4]. Wherein, the key manufactures design the utility-scale solutions using 1.5 MW to 2.5 MW with paralleled-connections to achieve the required output power. In order to reduce customers' developed workload, Mitsubishi Electric starts to provide data about a power stack, which is a single-phase inverter solution composed of 3 paralleled industrial IGBT modules in LV100 package.

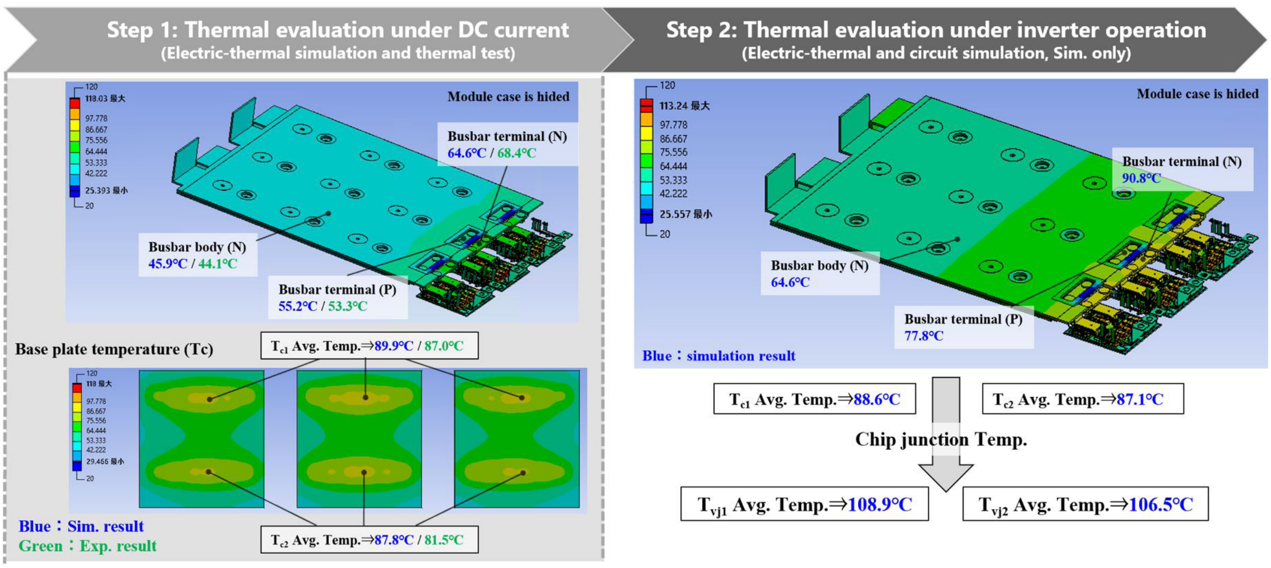


Figure 2: Thermal evaluation methodology of power stack.

The LV100 has a footprint of 100 mm × 140 mm. It has become popular for high-capacity inverter systems as shown in Figure 1. The stack design includes evaluation and selection of various other components. Moreover, current balancing, skin effect, temperature rising, as for example, needs to be considered. Moreover, to verify the electro-thermal design under different cooling condition, both of liquid and forced-air cooling could be suitable to the power stack with changing the heatsink. This paper introduces the performance and key thermal design information of the power stack, and its specification as listed in Table 1. Hence, the maximum current is designed to 1800A for 3-phase connection to achieve 2MW of output power, and the current imbalance ratio could also be controlled within 5%.

Item	Specification
Topology	2 level
Size (L×W×H)	795×423×289 mm
Weight	About 65 kg
Output power	2 MW
DC Voltage	1100 V
Current	AC：1800 Arms @fs: 2.5kHz
Current imbalance ratio	Within 5%
Max. driving fs	2.8kHz

Table 1: Specification of power stack.

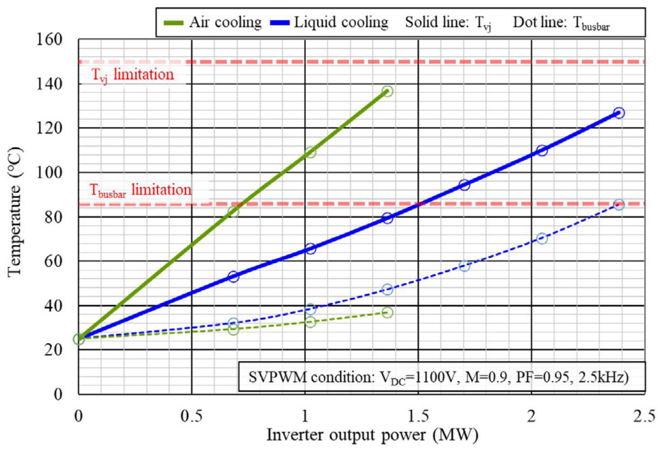


Figure 3: Relationship between T_{vj} and T_{busbar} under different output power and cooling method.

Design Methodology and Output Capacity of Power Stack

The proposed power stack is designed by electro-thermal co-simulation using computer-aided engineering (CAE) software: Q3D and Workbench, Ansys. There are two steps for evaluating the output capacity of power stack as shown in Figure 2, the ambient and water inlet temperature are set at 25°C, and heat generating of DC capacitors is not considered. In step 1, thermal evaluation has been done under 1800 A of DC current and temperatures at DC busbar and IGBT case ($T_{c,x}$) is measured. Wherein, the $T_{c,1}$ and $T_{c,2}$ represent baseplate temperature just under high- and low-side IGBT chip, respectively. Heat-transfer coefficient (HTC) for simulation was adjusted to meet with experimental results for achieving less than 10% error. In step 2, loss of DC busbar and IGBT modules was simulated considering space-vector pulse-width modulation (SVPWM) (by power loss calculator, Melcosim made by Mitsubishi Electric. Condition: V_{DC}=1100V, Modulation index=0.9, Power factor=0.95, 2.5kHz). Wherein, the thermal model is same to Step 1 and chip junction (T_{vj}) was calculated from thermal resistance and simulated T_c. Then the temperature distribution under inverter mode could be estimated.

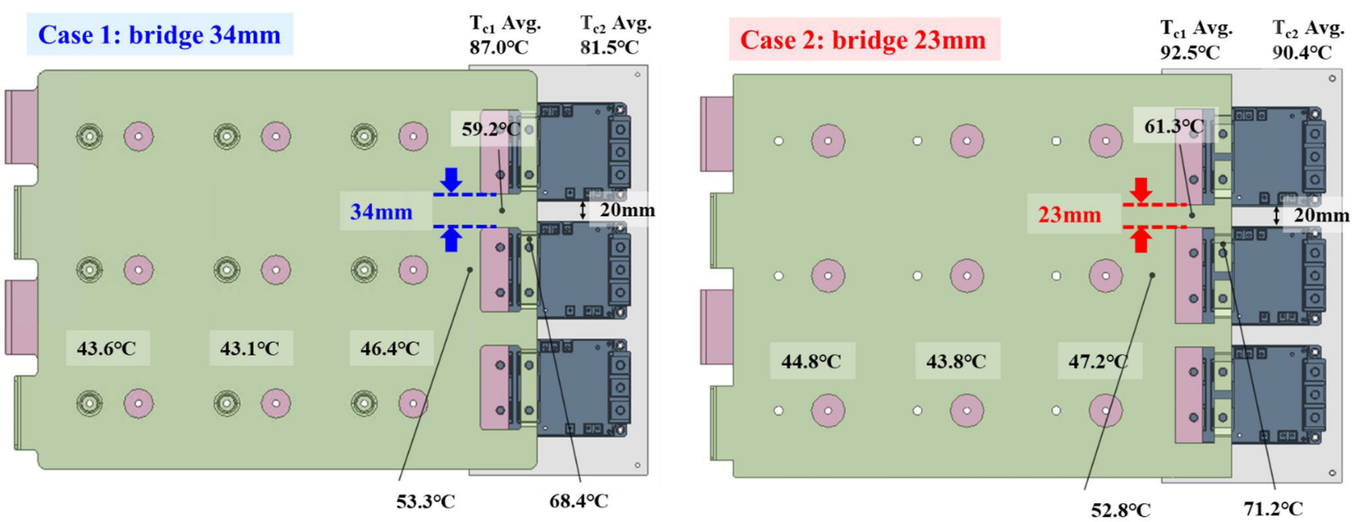
Figure 3 shows the estimated output power under inverter condition for air and liquid cooling by setting different conditions of generating loss and HTC, the solid and dot line represent the Tvj and busbar temperature Tbusbar, respectively. The output power of 2 MW could be achieved for liquid cooling. Air-forced cooling results in output power of 1.4 MW with gentle temperature rising of busbar.

Improvement of Stack Performance

For MW-level power stack design, the power modules are usually used in paralleled connection while considering current balancing, driving synchronization, short circuit protection and temperature rising. Wherein, the design concept of current balancing is to equalize the impedance among parallel paths proposed in [5], this paper focuses on the temperature rise of components with explaining the heat dissipation under different design approach.

1) Bridge width effect of DC busbar:

Figure 4 shows experimental results of temperature distribution with different bridge width of DC busbar under 1800 A of DC current and 3 mm of layer thickness. In doing so, the 20 mm of pitch distance among paralleled IGBTs is fixed. Since IGBT modules dissipate heat via the heatsink and the DC busbar, a narrow bridge width causes higher IGBT temperature due to increase of thermal resistance.



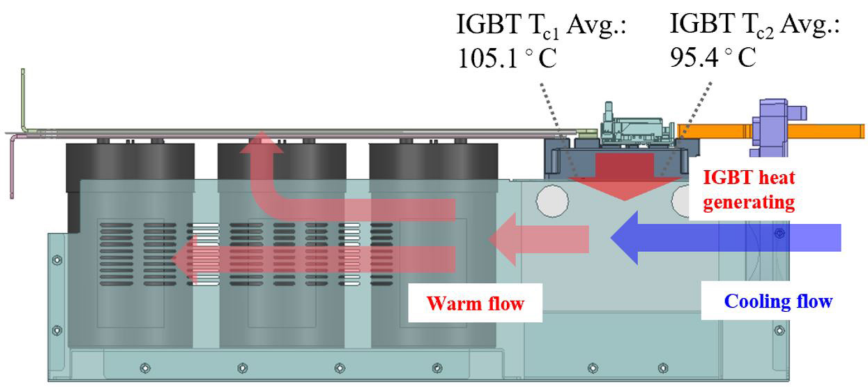
a) Bridge width=34mm

b) Bridge width=24mm

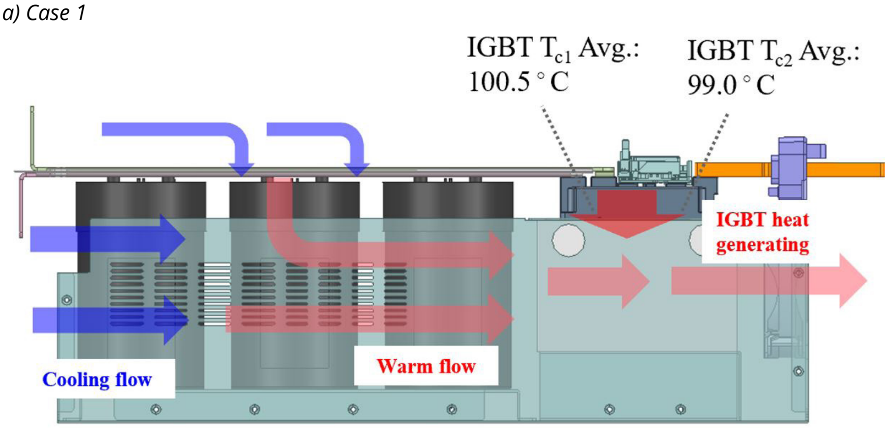
Figure 4: Temperature distribution under different bridge width.

2) Flow direction of forced-air cooling:

In the forced-air cooling, the flow direction affects significantly the system performance. Each IGBT module should receive equal air flow to achieve minimum temperature imbalance in parallel condition. Hence, the air-flow direction of the proposed power stack could be separated into two cases as shown in Figure 5. In the case 1, forced-air flows through the heatsink and gets heated up by the IGBTs. Afterwards, the warm air flows to the DC busbar and the capacitors. The front-side IGBT whose case temperature is the Tc2 receives maximum cooling flow, but the cooling of peripheral components and even the back-side IGBT whose case temperature is the Tc1 become worse due to higher ambient temperature. Whereas, air-flow direction of the case 2 would be better with considering system performance.



a) Case 1



b) Case 2

Figure 5: Different Air-flow direction for power stack. (Side view)

Line-up		LV100 (Industrial)				LV100 (Traction)			HV100	
Application		Renewable, Industrial				Traction, Power transmission				
Footprint		100mm×140mm×40mm								
V_{isol}		4kVrms				6kVrms			10kVrms	
Rated Voltage		1.2 kV	1.7 kV	2.0kV	2.5kV 1)	1.7 kV	3.3 kV		3.3 kV	4.5kV
Rated Current	Si	800A 1200A 1800A 1)	800A 1200A	1200A	1200A 1)	1200A	450A 600A		450A 600A	450A
	Hybrid SiC	-	-			-	600A		-	-
	Full SiC	-				-	750A 375A 185A	800A 2) 400A 2) 200A 2)	-	-

1) Under development
2) SBD-embedded

Table 2: Line-up of IGBT module with LV100 package.

Conclusion

This study indicates influence factors on temperature rising: DC busbar and direction of air flow. The thermal management is a cross coupling issue. Hence, the design and selection of peripheral components should be optimized. The IGBT modules with LV100 package is a suitable solution for such a power stack due to its easy paralleling and low inductance. This reduces design difficulty for achieving better system performance on thermal management, current balancing and lower voltage spike. Especially, the symmetric chip layout simplifies the heatsink design and reduces the thermal cross coupling between IGBT modules. The line-up of LV100 package is shown in Table 2. LV100 for industrial application covers voltage ratings of 1200V, 1700V and 2000V. The package is based on the SLC packaging technology with a thermal cycle failure free packaging technology by matching thermal expansion coefficients [6]. A LV100 package for railway applications is available for 1700V and 3300V and uses MCB baseplate [7].

Reference

1. F. Z. Peng, C. -C. Liu, Y. Li, A. K. Jain and D. Vinnikov, “Envisioning the Future Renewable and Resilient Energy Grids—A Power Grid Revolution Enabled by Renewables, Energy Storage, and Energy Electronics,” IEEE J. Emerging Sel. Top. Ind. Electron., vol. 5, no. 1, pp. 8-26, Jan. 2024.
2. H. Jain, B. Mather, A. K. Jain and S. F. Baldwin, “Grid-Supportive Loads—A New Approach to Increasing Renewable Energy in Power Systems,” IEEE Trans. Smart Grid, vol. 13, no. 4, pp. 2959-2972, July 2022.
3. C. Breyer et al., “On the History and Future of 100% Renewable Energy Systems Research,” IEEE Access, vol. 10, pp. 78176-78218, 2022.
4. F. Blaabjerg, Y. Yang, K. A. Kim and J. Rodriguez, “Power Electronics Technology for Large-Scale Renewable Energy Generation,” Proc. IEEE, vol. 111, no. 4, pp. 335-355, April 2023.
5. Z. -F. Li, N. Nishida, H. Aoki, H. Shibata, C. -C. Liao and M. -S. Huang, “Simulation-Assisted Design of a Power Stack for Improving Static Current Sharing Among Three IGBT Modules Connected in Parallel,” IEEE Access, vol. 10, pp. 10079-10093, 2022.
6. T. Radke, N. Lakshmanan and D. He, “LV100: Smart Solution for 1500 VDC 3-Level Central PV Inverters,” Bodos Power, pp. 22-27, Oct. 2020.
7. N. Soltau, E. Wiesner, R. Tsuda, K. Hatori and H. Uemura, “Demands by Future Railway Converters and How They Change Power Semiconductor Modules,” Bodos Power, pp. 18-22, July 2021.

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