

Development of A 3-level ANPC 800kW-class Power Stack based on 1200V IGBT Module for Renewable Energy Application

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3L-ANPC Power Stack Design

- Layout
- Loss and thermal simulation
- Ls analysis for DC busbar

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- Zero state control
- Turn-off sequence

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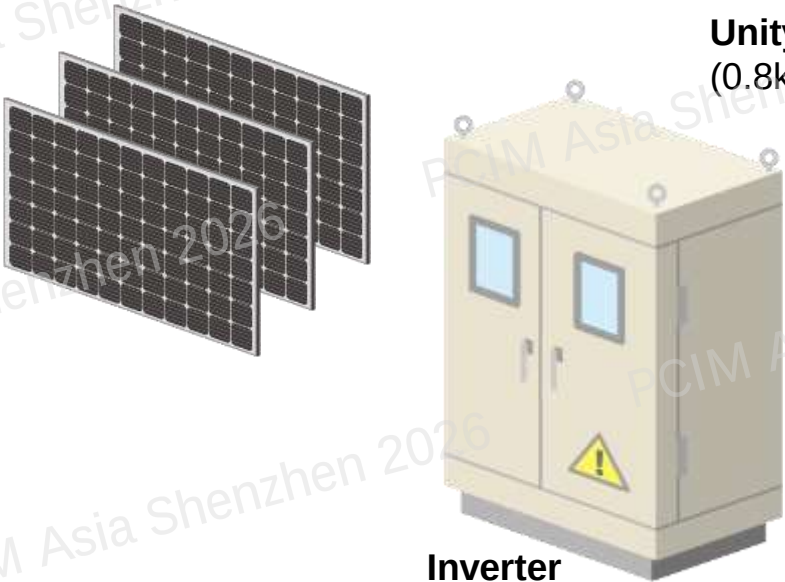
Inverter System in Renewable Energy Application

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The mainstream design of high-power inverter for central PV application could be separated into two cabinet types: **Unity-scale** and **Large-scale cabinet**, which causes the design challenge of power stack and components layout.

Example: Central PV MW system



Inverter

Unity-scale cabinet
(0.8kW~1.2MW/ per stack)

Large-scale cabinet
(1.2MW~2.5MW/ per stack)

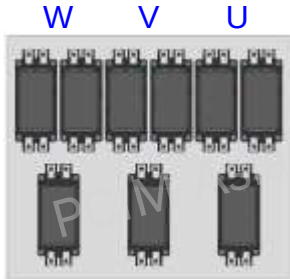
Single IGBT system (no-paralleled)

- Easy maintenance
- Simple cooling system

W

V

U



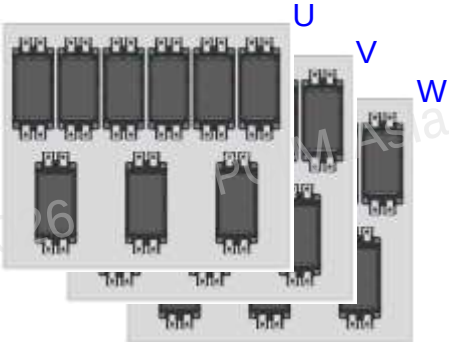
3-paralleled IGBT system

- High output power (single cabinet)
- Flexible layout for components

U

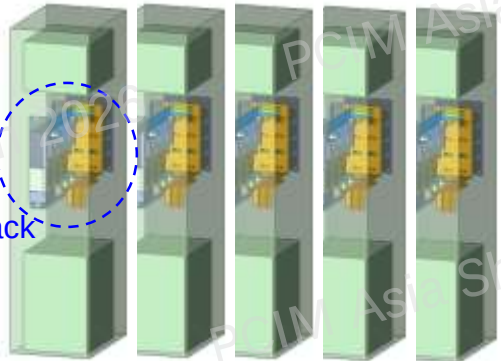
V

W



Paralleled-cabinet for achieving higher output power

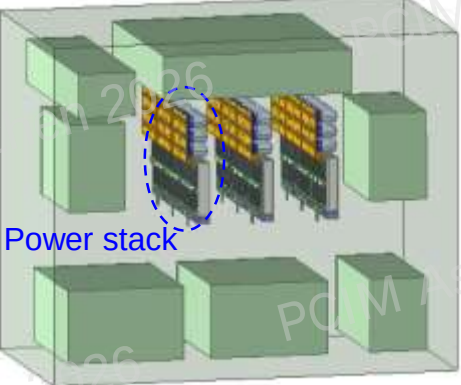
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Power stack



Power stack



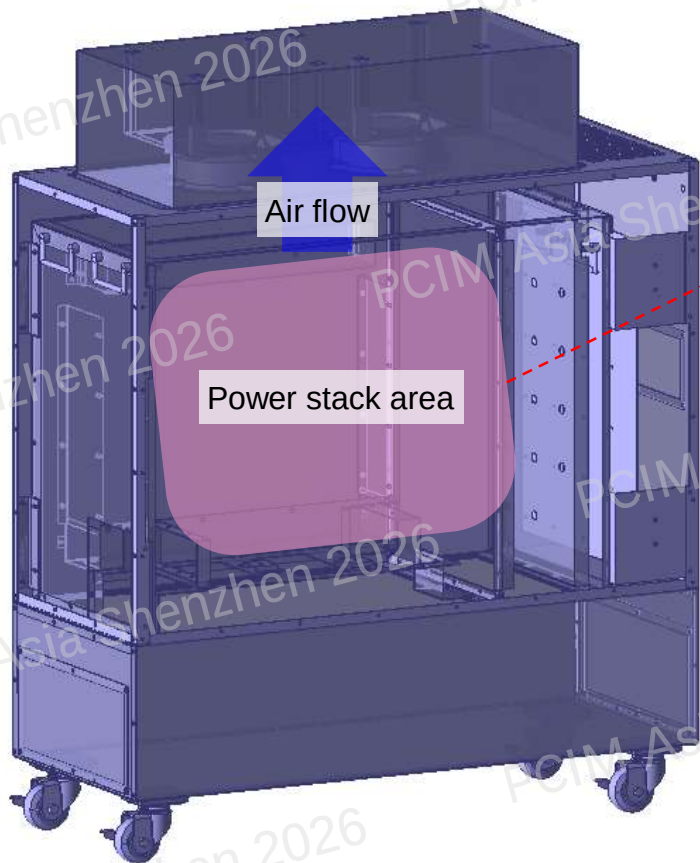
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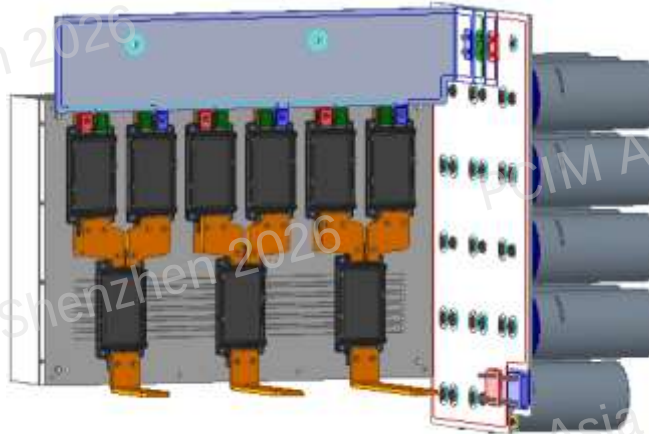
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Research Background of Proposed Power Stack

To find the stack characteristic under the same cabinet design concept and direction of air-flow, this paper compared performance between two types of power stacks including component layout, stray inductance and temperature rise of chip.



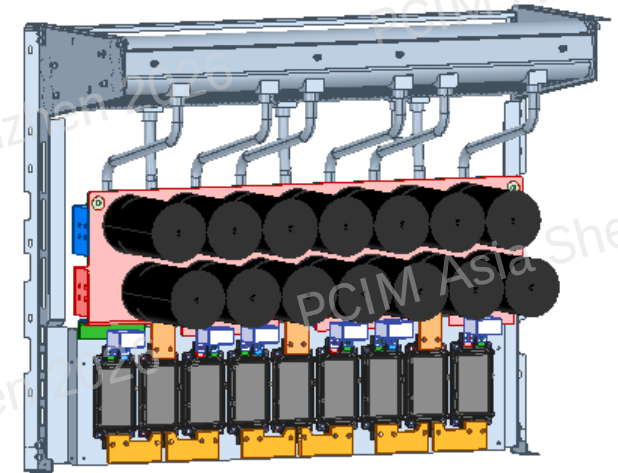
Type A: lower heatsink cost



- Triangular IGBTs
- Heat-pipe (HP) heatsink

Current work: **performance verification**, some results are shown in this Paper.

Type B: higher power density



- One-row IGBTs
- Loop heat-pipe (LHP) heatsink

Current work: manufacturing, the prototype is demonstrated in **Mitsubishi Electric booth**.

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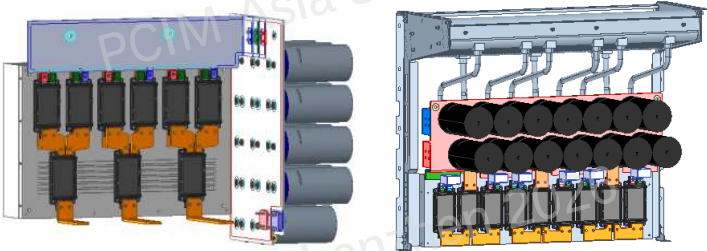


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Characteristic Comparison between Two Stacks



Type A has the merit in lower heatsink cost and layout flexibility, and Type B excels in high power density and lower stray inductance (Ls).



	Type A	Type B
IGBT placement	Triangular	One-row
Heatsink	HP	LHP
TCC between IGBTs	Lower	Higher
Ls	Higher	Lower
Heatsink cost	Lower	Higher
Stack size	Larger	Smaller
Layout flexibility	Higher	Lower

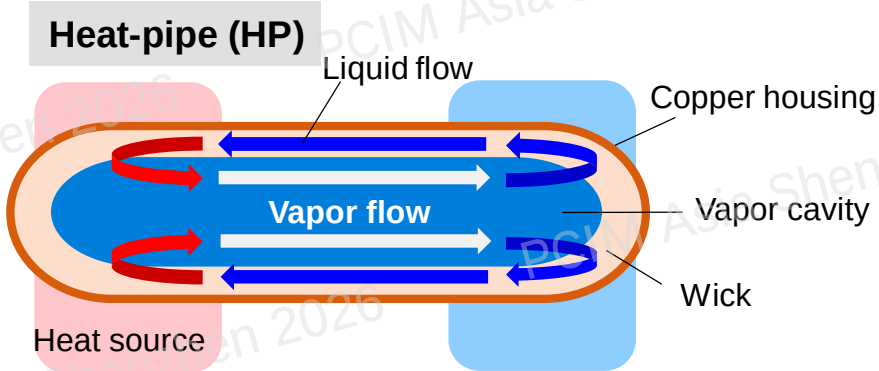
※TCC: Thermal cross-coupling

IGBTs concentrates within smaller area

Spike voltage could be suppressed by snubber capacitors

The cooling fin of LHP should be set above IGBTs

Heat-pipe (HP)



Liquid flow

Copper housing

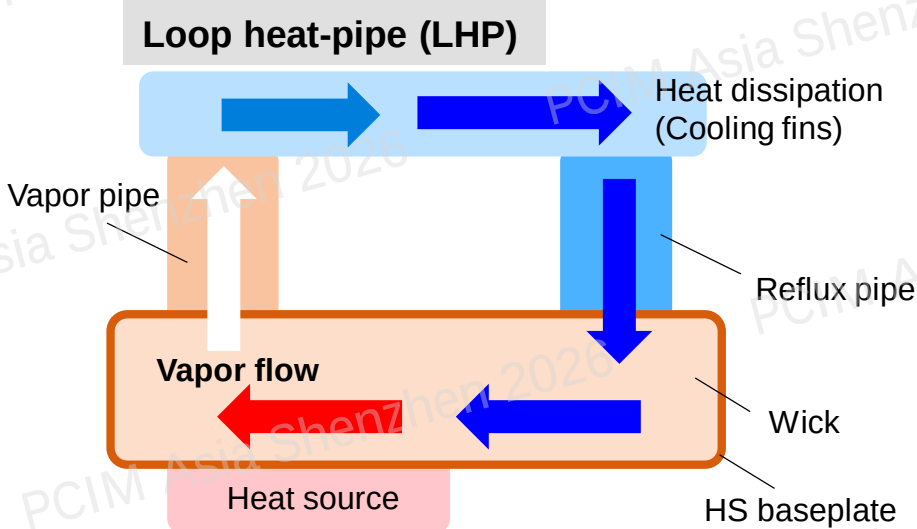
Vapor flow

Vapor cavity

Wick

Heat source

Loop heat-pipe (LHP)



Heat dissipation (Cooling fins)

Vapor pipe

Reflux pipe

Vapor flow

Wick

Heat source

HS baseplate

Cooling fins should set above power device

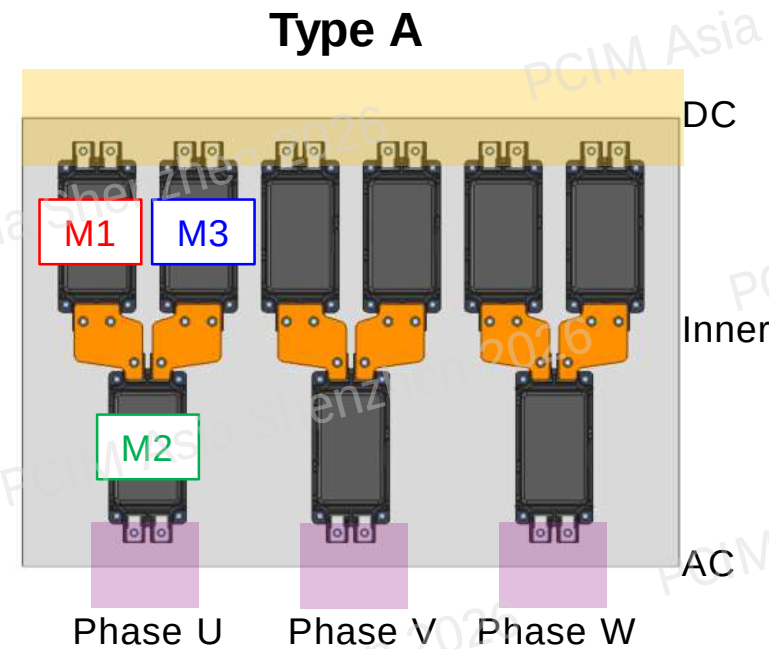
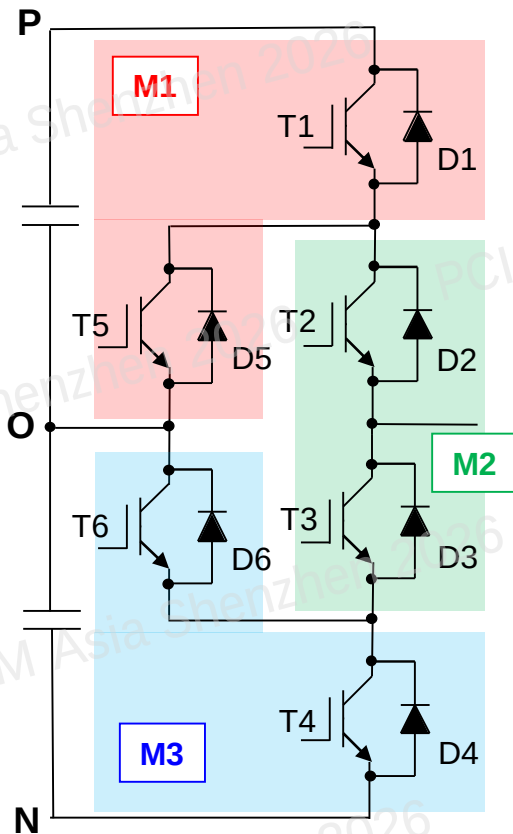
→ Liquid returns wick by **gravity** in reflux pipe

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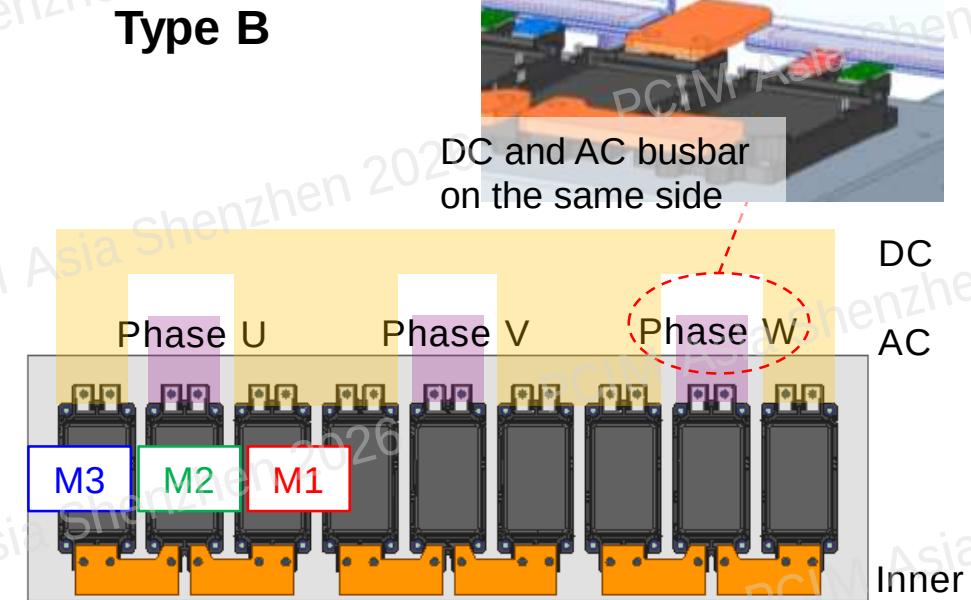
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- In high power application, the 3-level topology is usually composed by **2 in 1 power modules** with considering the loss density on chips and heat-dissipation area of IGBT base plate.
- The heatsink selection has highly relative to IGBT placement due to **TCC** level.



Wide heatsink area
➡ Lower TCC, but larger size



Smaller heatsink area
 ➔ **Larger TCC**, the heatsink with higher cooling ability is necessary.

-
- The figure consists of two parts. The left part is a schematic diagram of a three-phase inverter. It shows three legs (red, green, blue) and three motor phases (M1, M2, M3). The red leg has transistors T1, T2, T5, T6 and diodes D1, D2, D5, D6. The green leg has transistors T3, T4 and diodes D3, D4. The blue leg has transistors T1, T2, T5, T6 and diodes D1, D2, D5, D6. The right part is a layout diagram showing the physical arrangement of the inverter modules (M1, M2, M3) and their connection to the inner busbar. The modules are labeled M1, M2, and M3. The busbar is labeled 'Inner busbar'. The layout shows the connection of the modules to the busbar and the distribution of the motor phases (M1, M2, M3) across the modules.

➔ High Ls

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Loss and Thermal Simulation

- Under the similar temperature rise of IGBT chips (about 150°C), it is necessary to use stronger cooling solution (with higher HTC) under one-row IGBT layout.

		Type A	Type B
		Triangular layout HP heatsink	One row layout with LHP heatsink
Assumed inverter design	Pitch distance between IGBTs	20 mm	10 mm
	Estimated HTC	1100 W/(m²·K)	1600 W/(m²·K)
	Heatsink surface (under IGBT)	512 mm × 358 mm	680 mm × 208 mm
PV mode	Normal (PF=1, Ta=45°C)	150.0°C	150.5°C
	115% rated load (PF=1, Ta=22°C)	149.8°C	151.8°C
ESS mode	100% rated load (PF=-1, Ta=45°C)	145.5°C	149.1°C

PF=1, Power loss on T1-T4, D5, D6

PF=-1, Power loss on T5,T6, D1-D4

Coolable power loss for each module

Type A: M1/M3 (800 W), M2 (1100W~)

Type B: 900 W for all modules

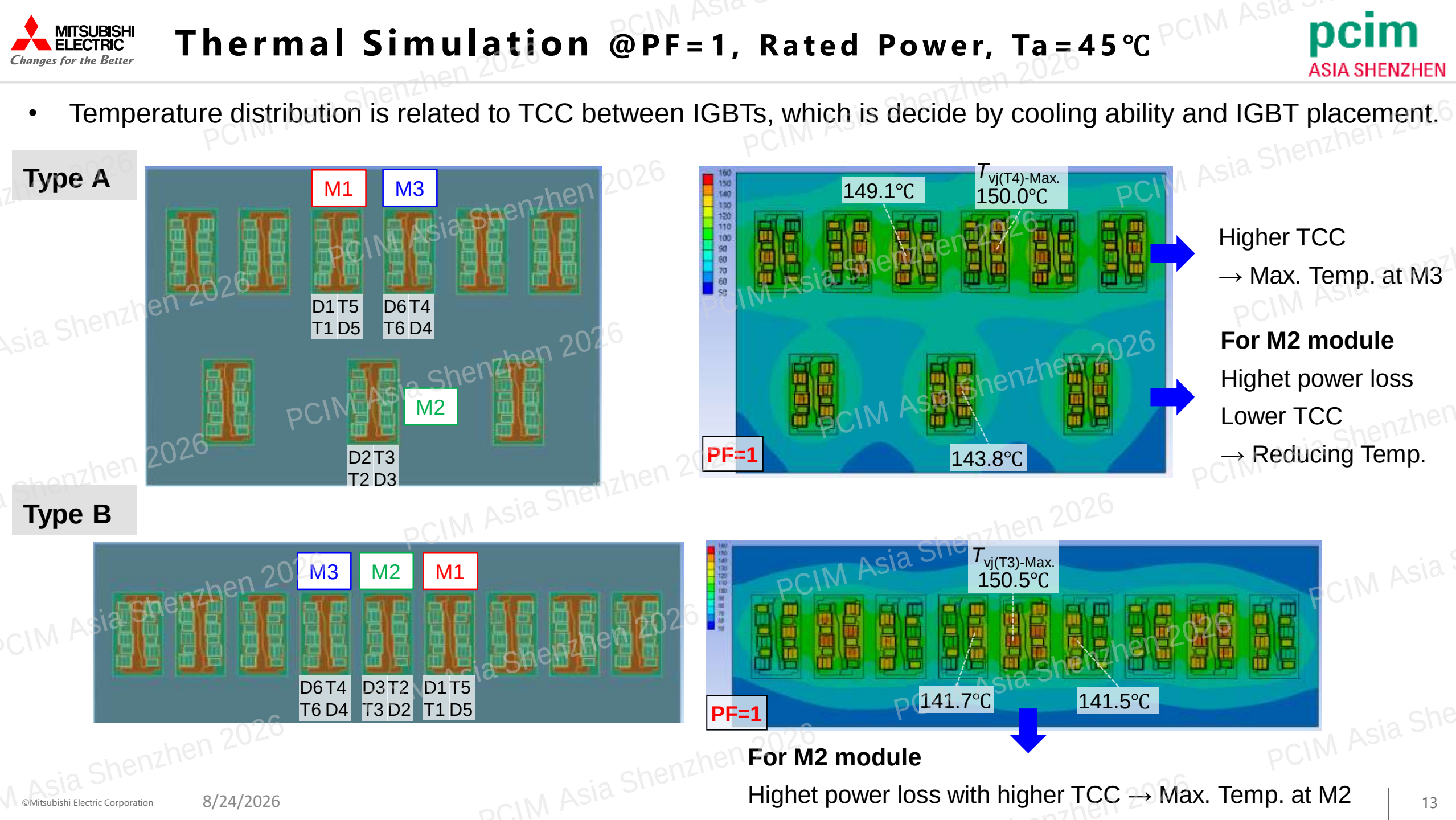
Smaller TCC

※HTC: Thermal transfer coefficient

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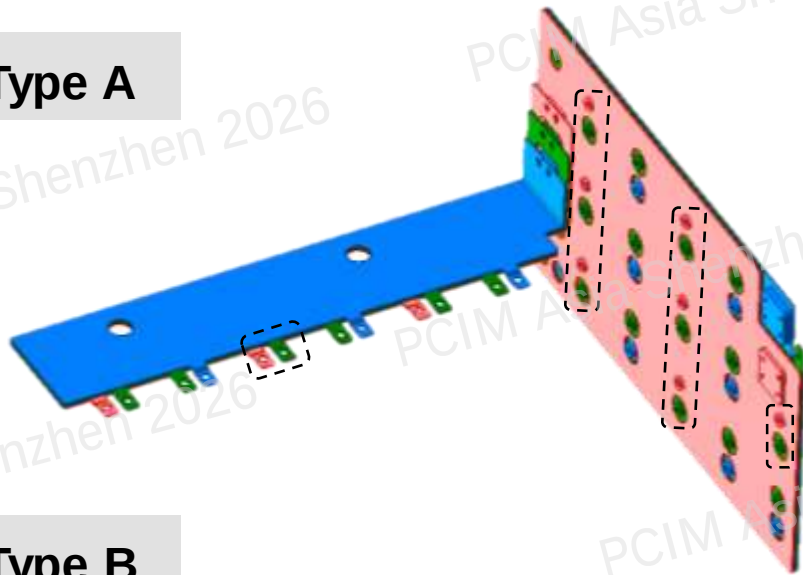
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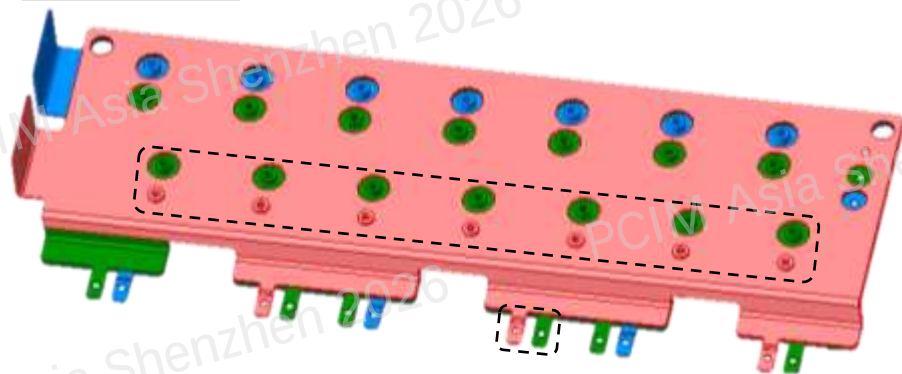


- The V-phase L_{S-DC} busbar at P-O layer are compared for two type power stacks. Although the Type A busbar brings 29% of L_{S-SCL} higher than that of Type B, the spike voltage could be suppressed by snubber capacitors.
 ➡ It is also a reasonable design of Type B busbar.

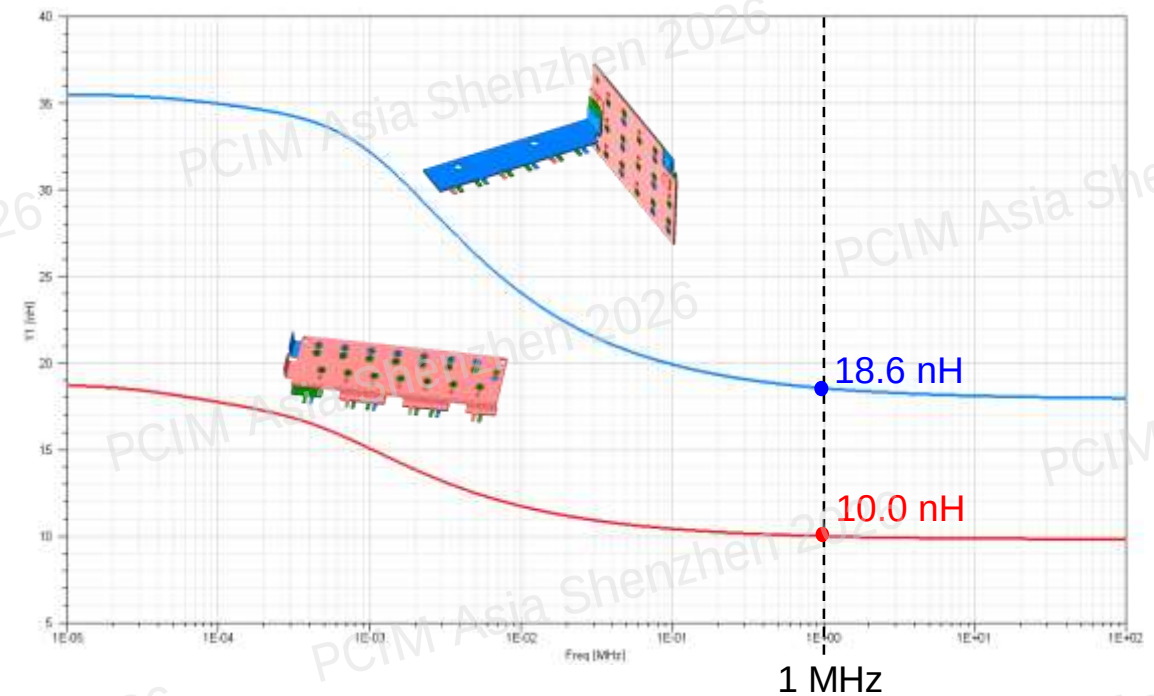
Type A



Type B



$L_{S-DC \text{ busbar}}$ of two DC laminated busbars



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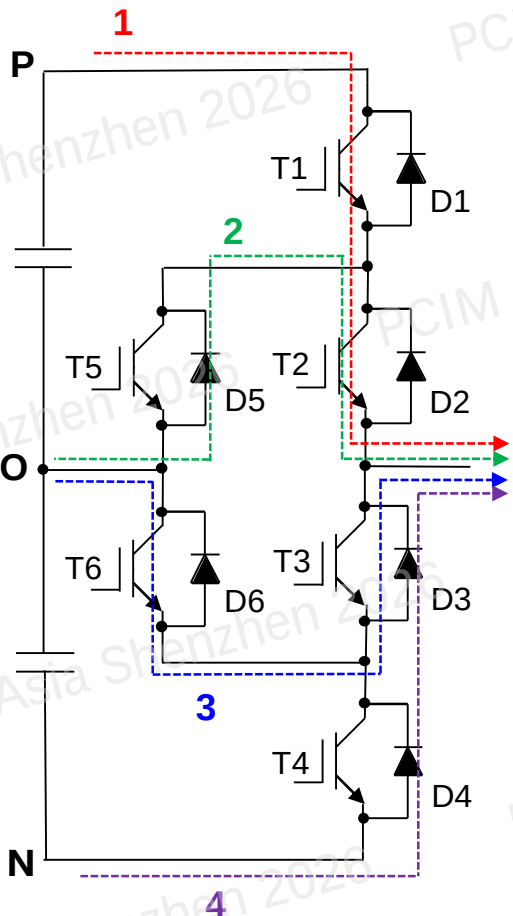
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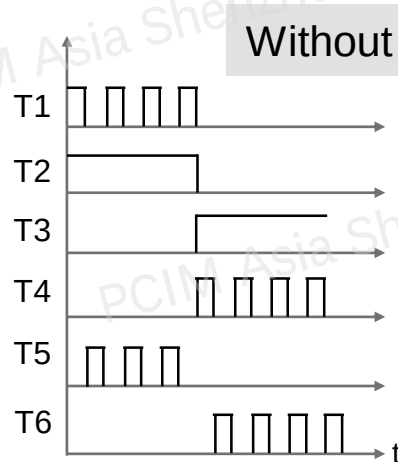
Control Methodology of ANPC-PWM1 with ZSC



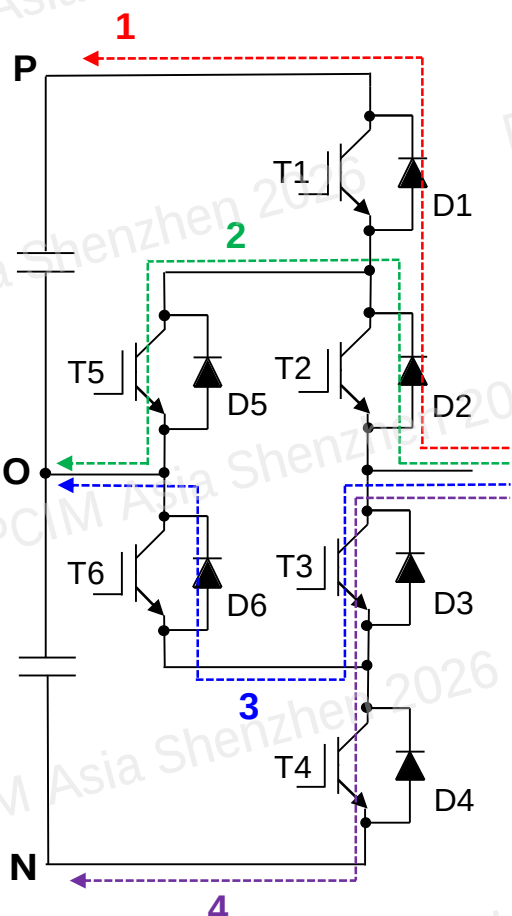
- When the polarity of output voltage changes (state between O+ and O-), the current conducts through paths 1-3 or 2-4 with the large inductance $L_{S,LCL}$ resulting in high spike voltage on T2 or T3.
➔ The ZSC is an effective method in suppressing spike voltage



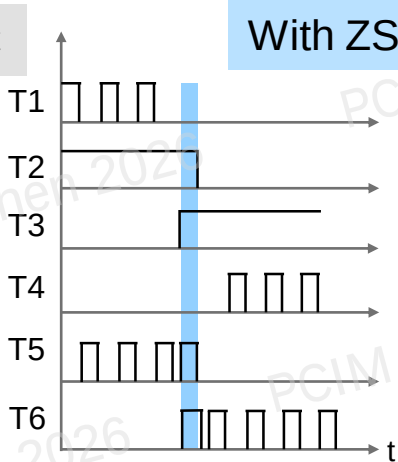
Output current >0 A



Without ZSC



Output current <0 A



With ZSC

ZSC: T2, T3, T5 and T6 tun-on, path 2 and 3 in parallel

① Reduce turn-off current ② Turn-off voltage raises from 0 V

State	T1	T2	T3	T4	T5	T6	Conduction path
P	1	1	0	0	0	0	1
O+	0	1	0	0	1	0	2
ZSC	0	1	1	0	1	1	2, 3
O-	0	0	1	0	0	1	3
N	0	0	1	1	0	0	4

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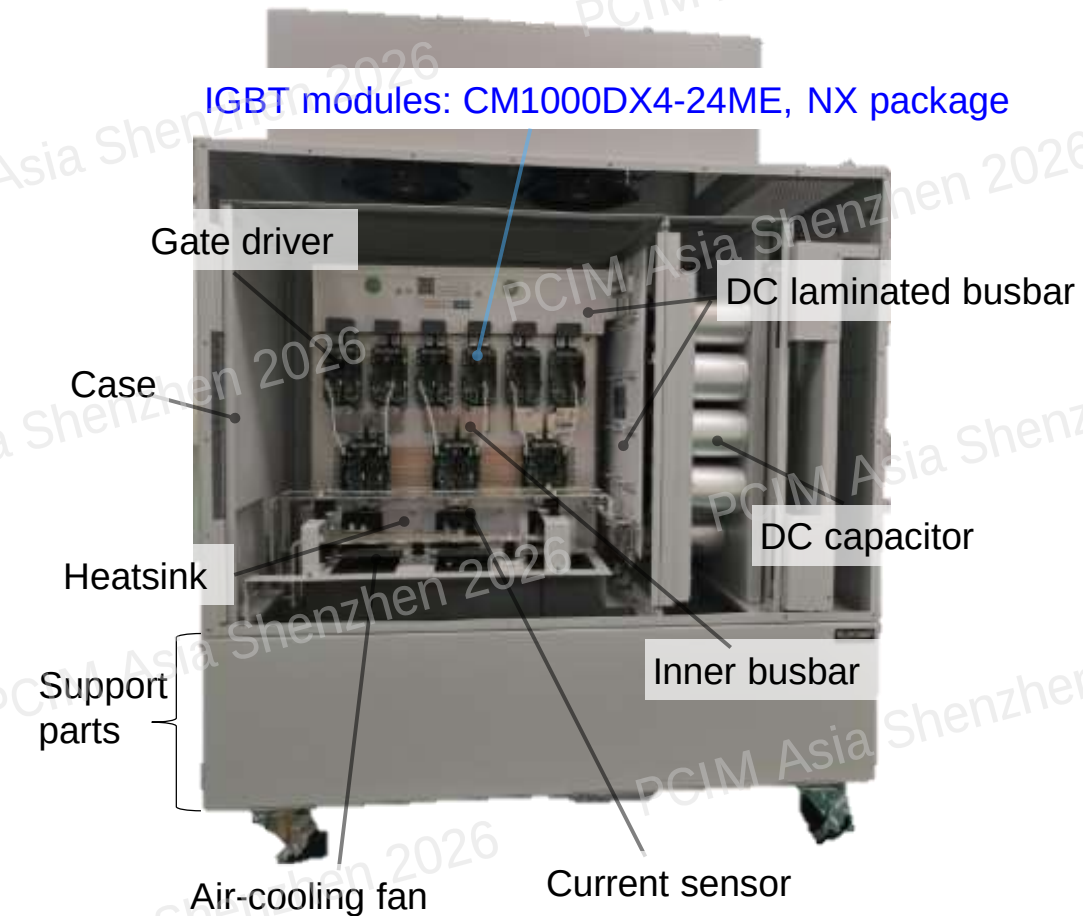
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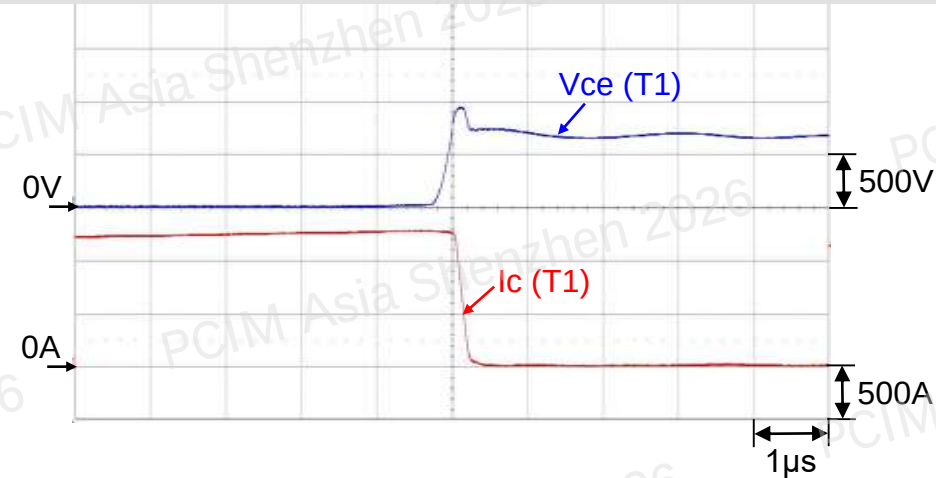
Control Methodology

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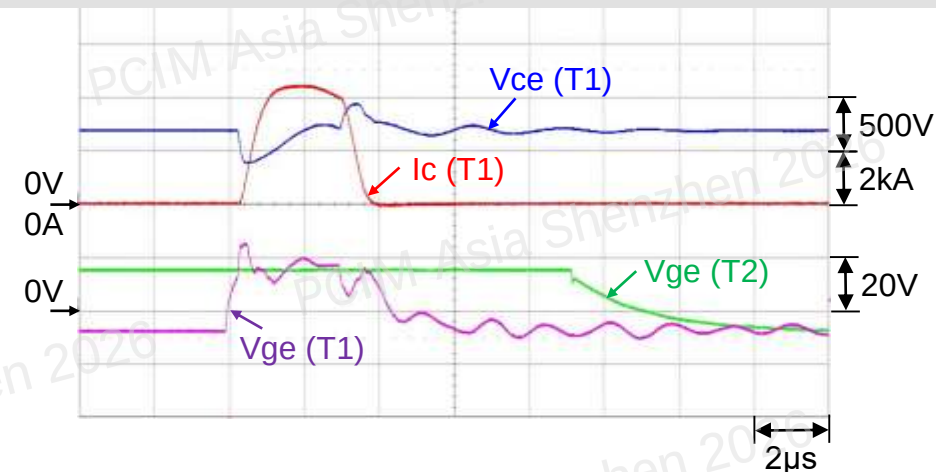
- Double pulse test (DPT): Spike voltage having **255 V margin** from 1200 V IGBT.
- Short circuit (SC) test: Sequence turn-off working to prevent inner IGBTs.

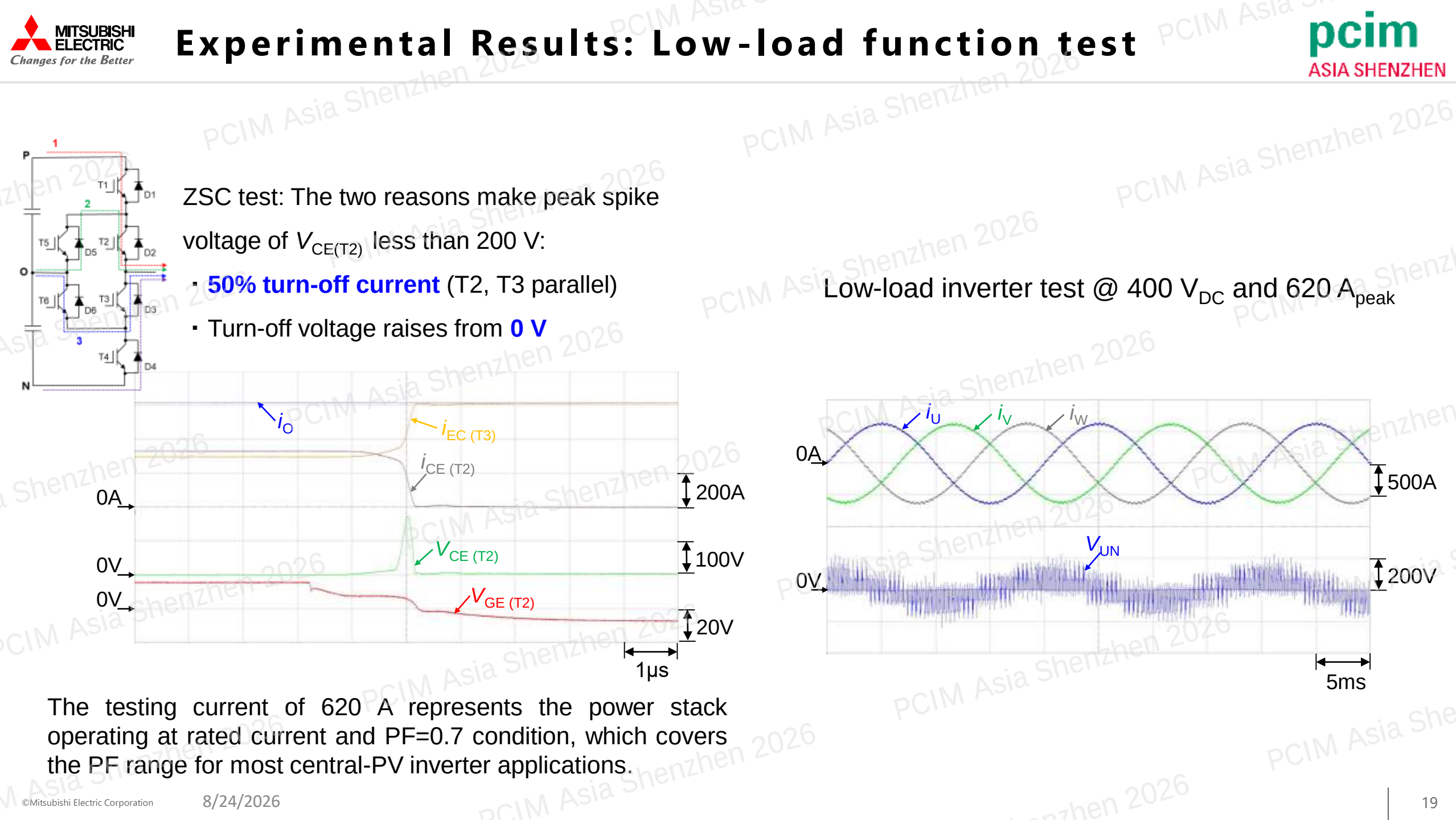


DPT: Peak voltage 945 V @ 1287 A (127% rated current)



SC: Outer IGBT turns off earlier than Inner IGBT → No over-voltage on M2





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- This paper proposed a design approach for **3L-ANPC 800 kW** power stack based on NX-package IGBT module by electrical and thermal FEA-assisted, which indicates that **NX-package IGBT could be a suitable solution for 800 kW-class modular inverters for both of central PV and ESS applications.**
- Two power stacks with different design concepts (Type A: layout flexibility; Type B: high power density) were compared from several perspectives including **mechanical layout**, **stray inductance** and **temperature rise**.
- For reducing the spike voltage, the suitable design of **DC laminated busbar provides low $L_{S,LCL}$** , and the proposed **ZSC methodology for ANPC-PWM1** could mitigate the effect caused by large $L_{S,LCL}$ **within 200 V**.
- The Type A power stack was manufactured for verification. The experimental result of DPT indicates a sufficient voltage margin of **255 V** from the rated voltage under **127%** rated peak current. The gate driver with the function of turn-off sequence to provide the **SC protection within 5 μ s**. The aforementioned results show the effectiveness of proposed design approach for power stack.

Thank you for attention