AI服务器机柜电源架构
演进与挑战

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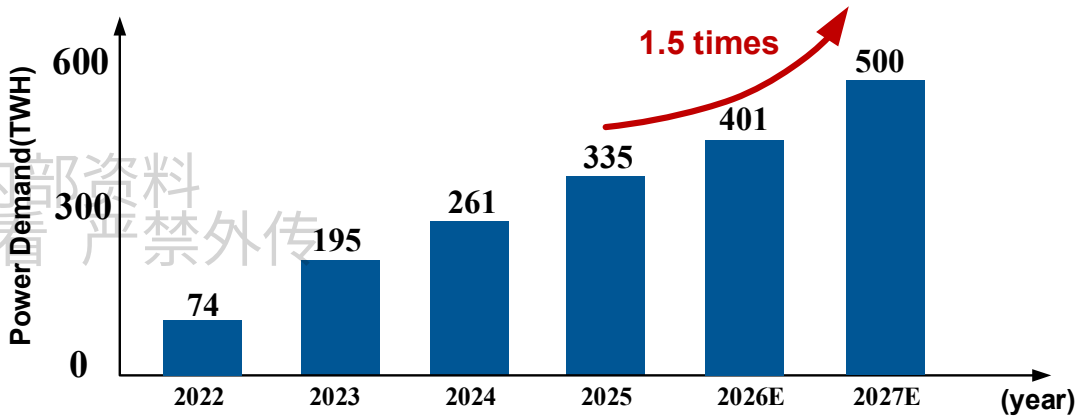
Power Demand of Data Center

AI Server Rack

- ☐ Higher Efficiency
- ☐ Higher Density

➢ **Predicted Power Demand of AI Data Center[2]**



➢ **By 2027, the electricity demand for AI servers will reach 500 TWh/year**

[1]中国信通院《中国算力发展指数白皮书（2022）》
[2]Gartner

Why High Efficiency Power Conversion?

PMIC Power Management Innovation Consortium

ByteDance 字节跳动　阿里云

Tencent 腾讯　Baidu 百度

美团　HUAWEI　JD.COM 京东

bilibili　科大讯飞 iFLYTEK

AI Datacenter

Price of Power Dissipation in AI Data Center

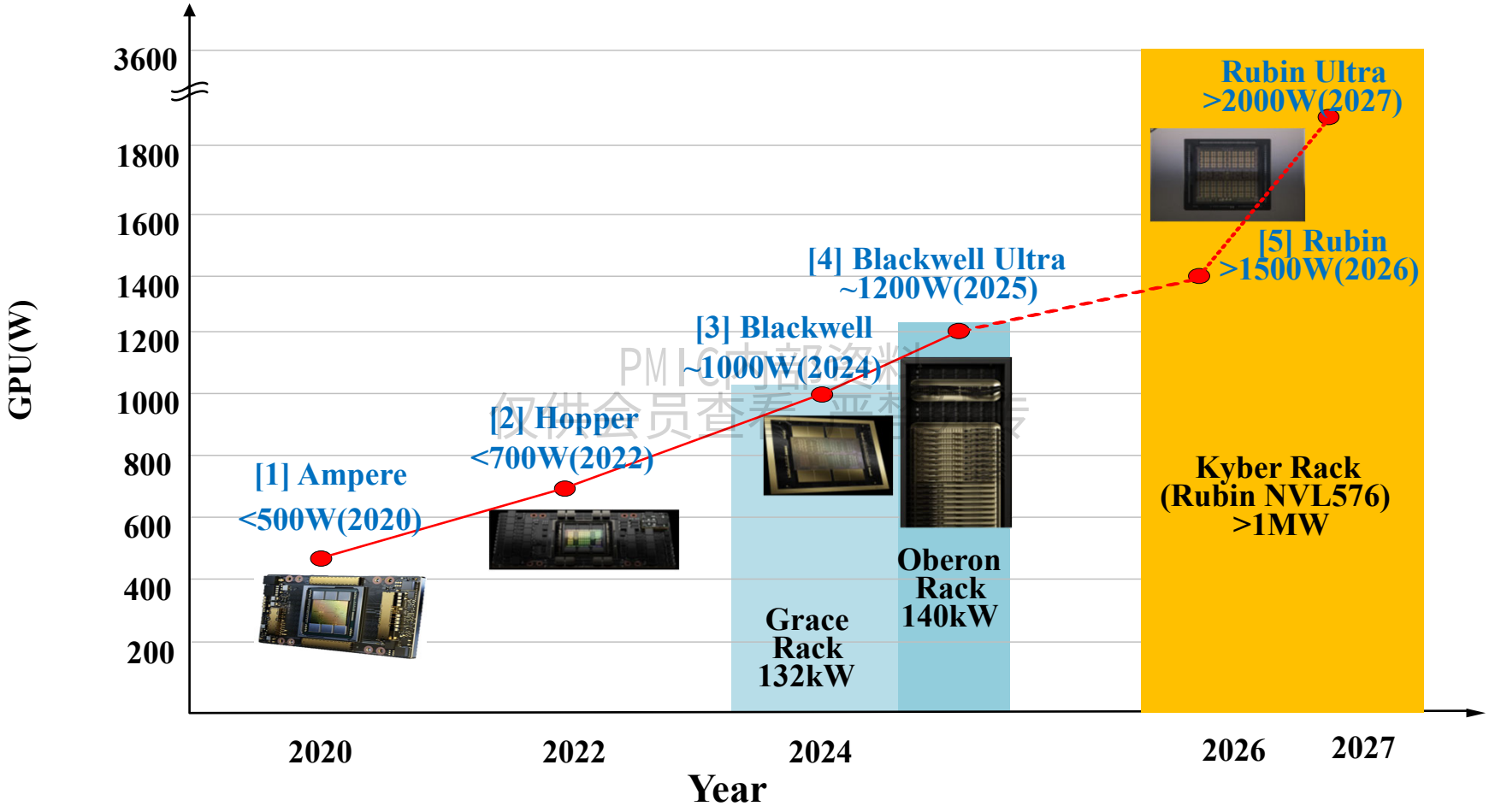
1W X 2000H X5 Year X 1.2 = 12¥

12¥X 4 = 48 ¥

Price
（for 5 years)

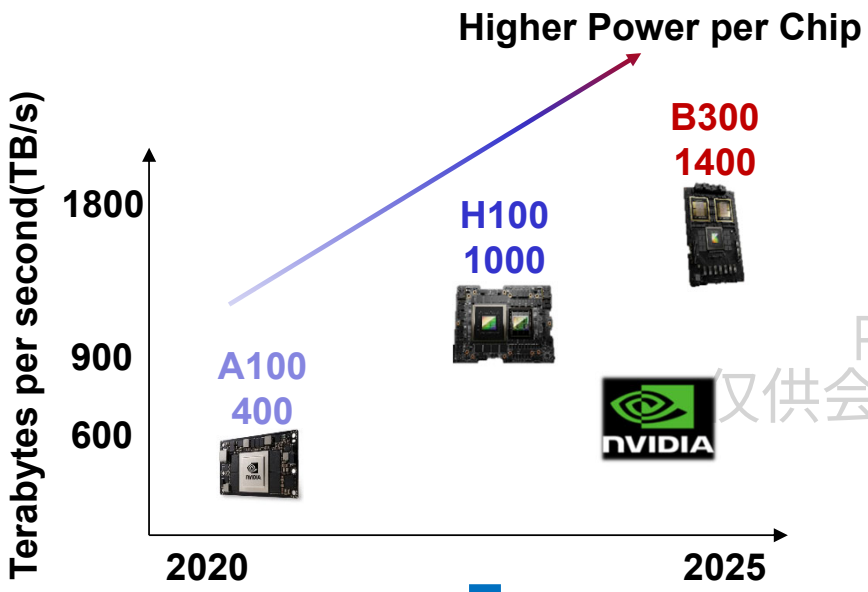
1W ≈ 48 ¥

Power Dissipation of XPUs

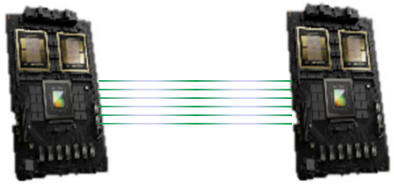


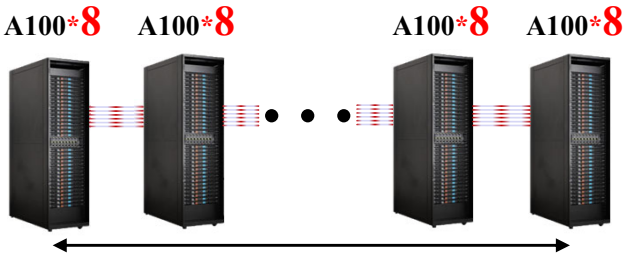
[1] https://www.nvidia.cn/data-center/ampere-architecture/
[2] https://blogs.nvidia.cn/blog/nvidia-announces-hopper-architecture-the-next-generation-of-accelerated-computing/
[3] https://www.nvidia.cn/data-center/technologies/blackwell-architecture/
[4] https://developer.nvidia.cn/blog/nvidia-blackwell-ultra-for-the-era-of-ai-reasoning/

Power Level Increasing of Server Racks due to Huge Data Communications



Lower Communication Latency





10-20 kW/Rack

Physical distance can > 10m

Low reliability
Low speed

2025
B300*72 ~120kW/Rack

More Chips in 1 Rack

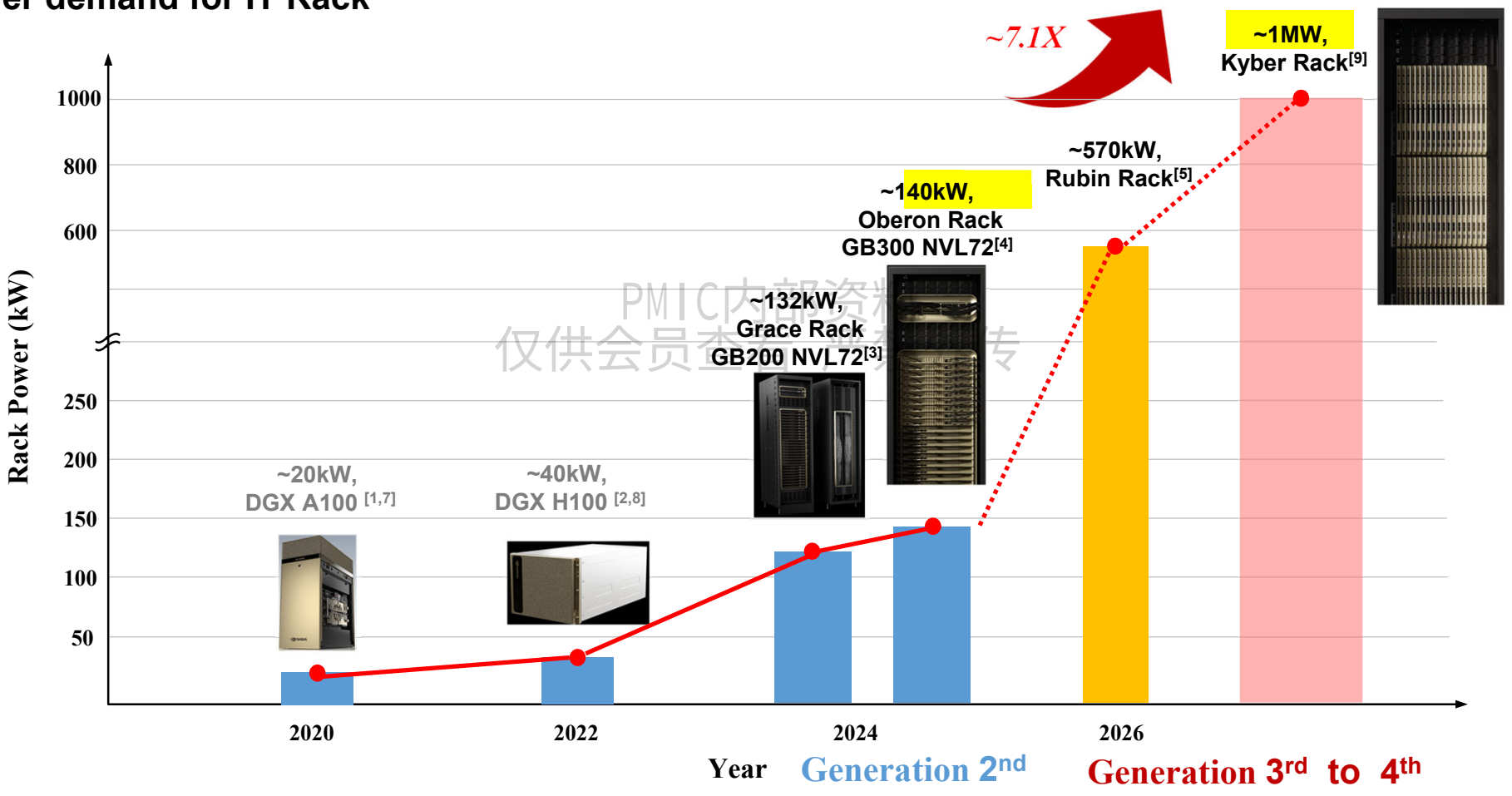
Rack Power Becoming Higher and Higher

[1] NVIDIA. https://www.nvidia.cn/data-center/nvlink/

Power Trends for IT Racks in AIDC

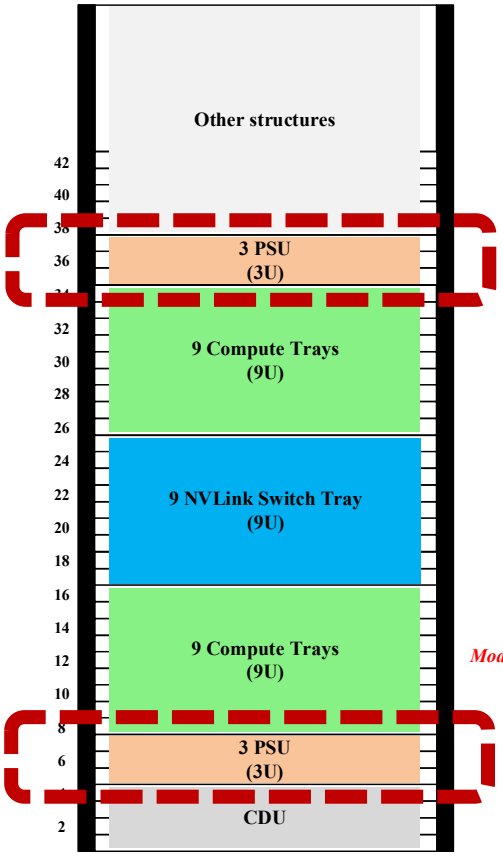
PMIC Power Management Innovation Consortium

➢ **Power demand for IT Rack**

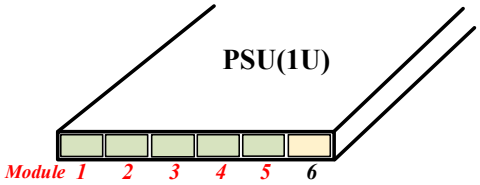


Grace & Oberon Rack of NVIDIA

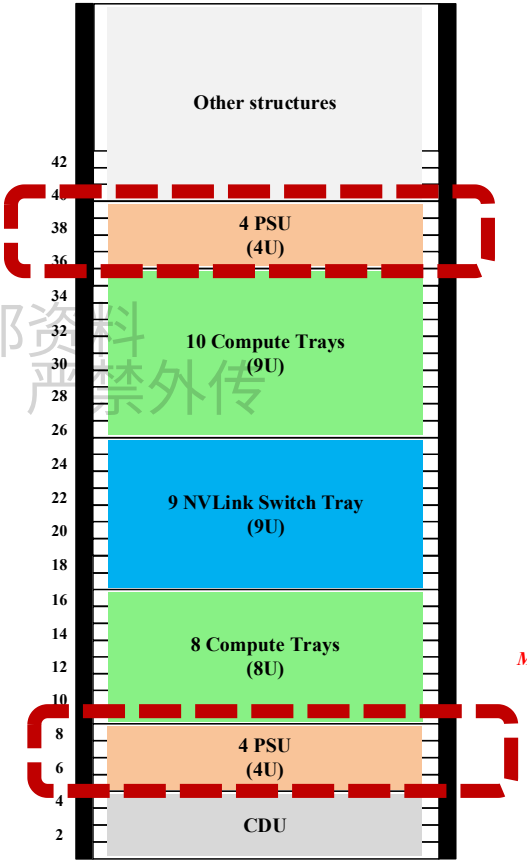
➢ Grace Rack(GB200 NVL72)[1-2]



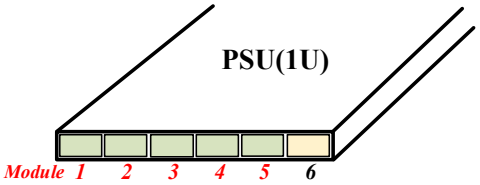
- **132kW**
- **72 × Blackwell GPU**
- **H × W × D: 2236*600*1068mm**
- **PSU(1U): 5.5kW × 6 @Red. 5+1**



➢ Oberon Rack(GB300 NVL72)[3-4]

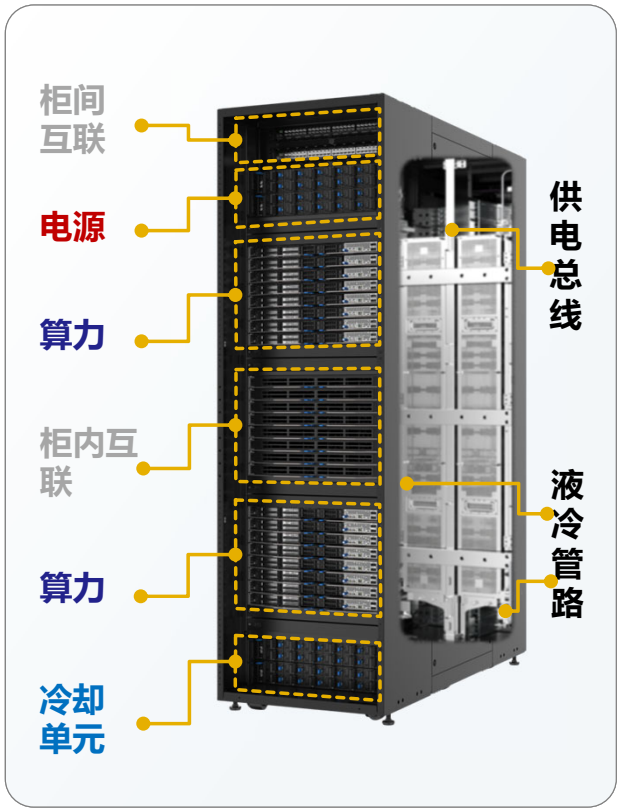


- **140kW**
- **72 × Blackwell Ultra GPU**
- **H × W × D: 2236*600*1068mm**
- **PSU(1U): 5.5kW × 6 @Red. 5+1**



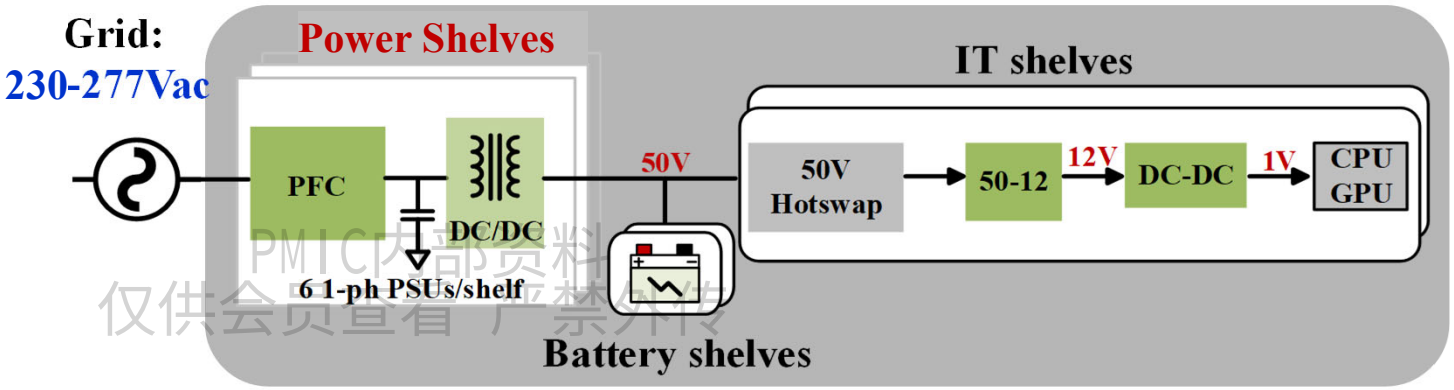
[1] https://www.supermicro.com/datasheet/datasheet_SuperCluster_GB200_NVL72.pdf?utm
[2] https://developer.nvidia.com/blog/nvidia-gb200-nvl72-delivers-trillion-parameter-llm-training-and-real-time-inference/?ncid=no-ncid
[3] https://www.supermicro.org.cn/datasheet/datasheet_SuperCluster_GB300_NVL72.pdf
[4] https://yzyz.substack.com/p/nvidia-nvda-us-gb300-power-system

Architecture of Current AI Server Racks

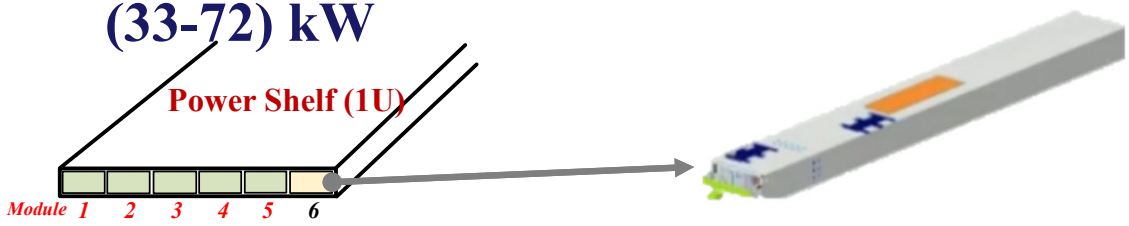


High Power Integrated Racks

Power Supply Architecture of Current AI Racks



(33-72) kW



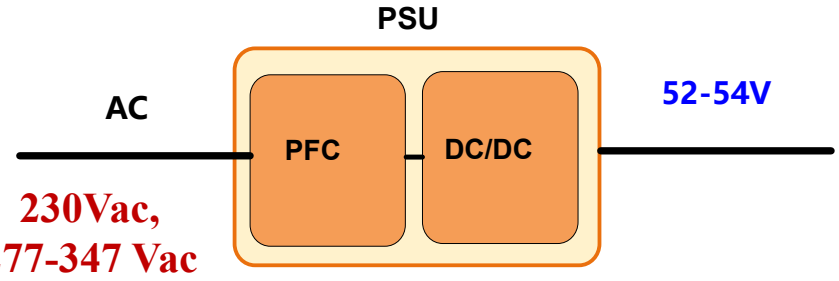
140kW = 4~8*Shelves
(4U-8U)

Module
(5.5kW，12kW)

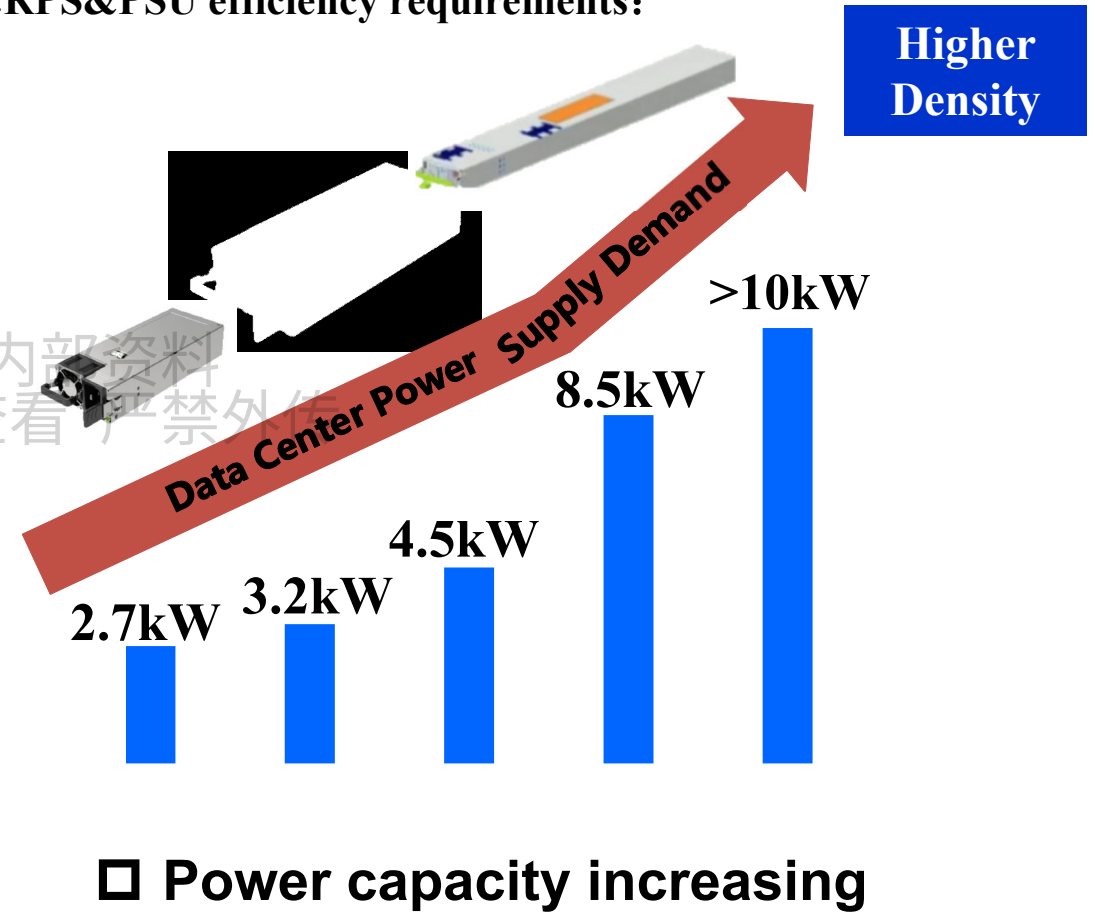
Increasing Rated Power of Single Phase PSU/Shelf

Data center

Single Phase PSU/CRPS module:



CRPS&PSU efficiency requirements:



☐ Power capacity increasing

[1] https://mp.weixin.qq.com/s/_vQpt4-j_wkuzDhx80Xaxw;

Efficiency Requirements of CRPS/PSU Isolated AC/DC 48V Power Supply

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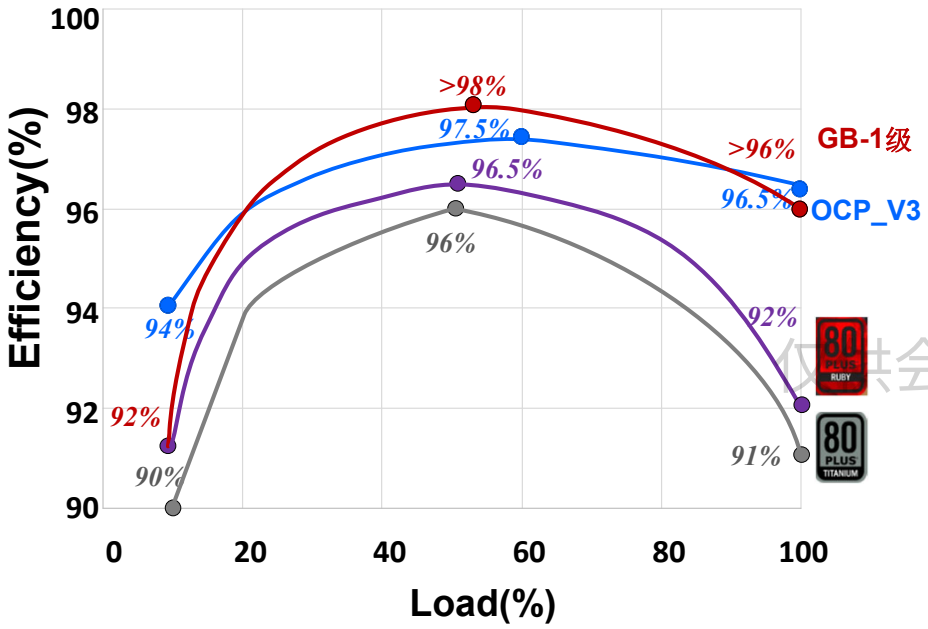
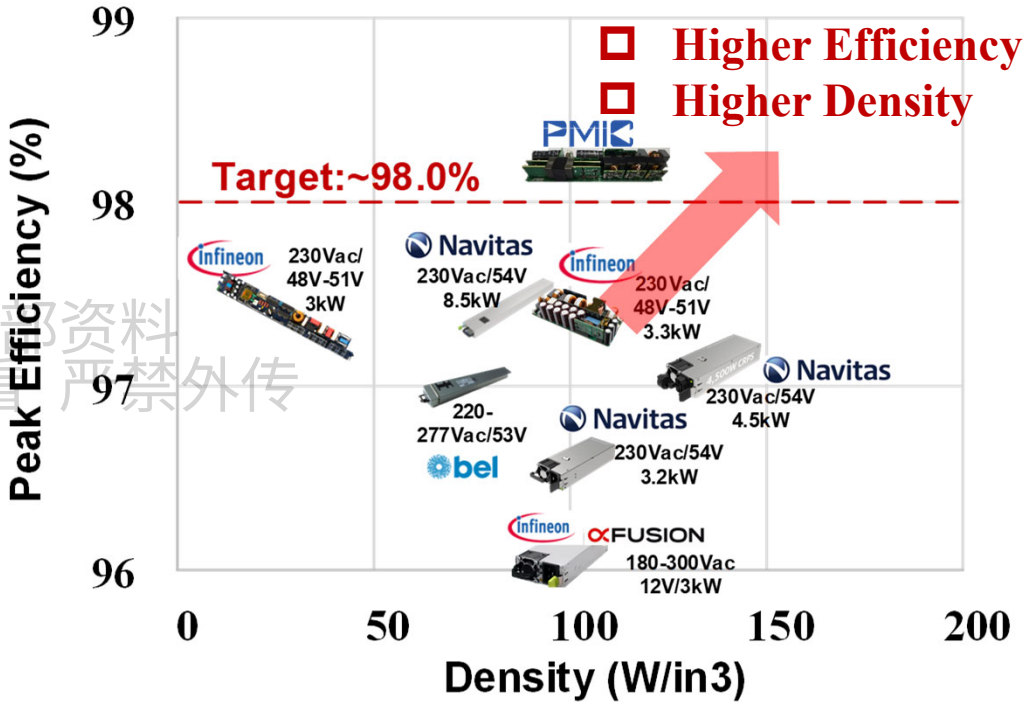
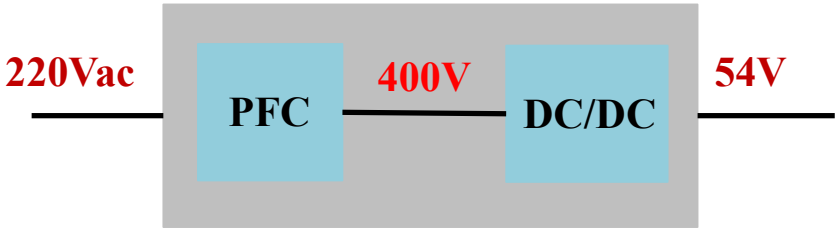
PSU efficiency requirements



State-of-the-Art:

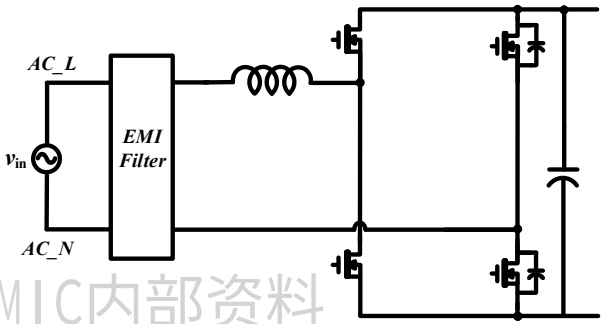


Typical Topologies for Single-Phase PSU Module

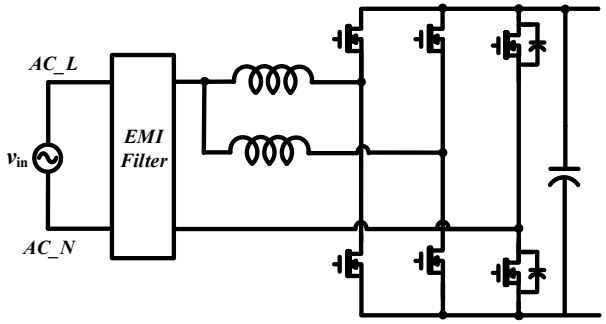


Single Phase AC/DC Architecture

Single-Phase PFC Topology

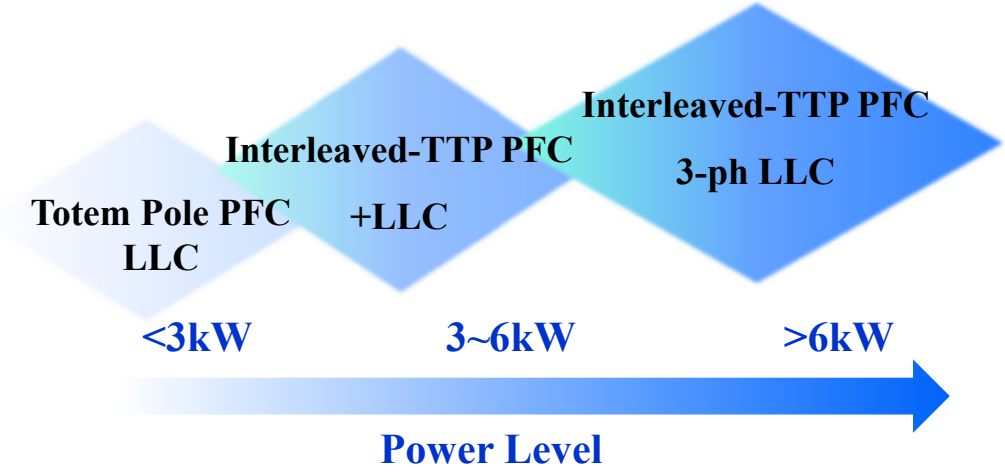


TTP PFC

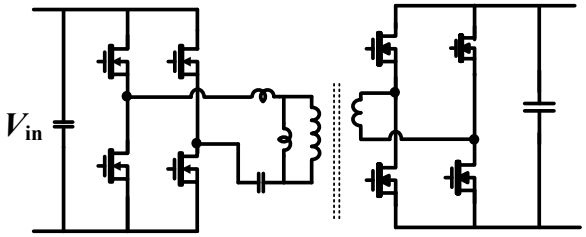


Interleaved Totem-Pole PFC

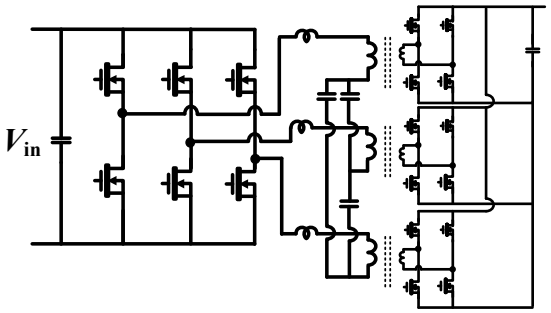
Power Stage Topology Evolution



Isolated DC/DC Topology



LLC Resonant



3-ph LLC

Millisecond-scale Load Dynamics Demand from AIDC

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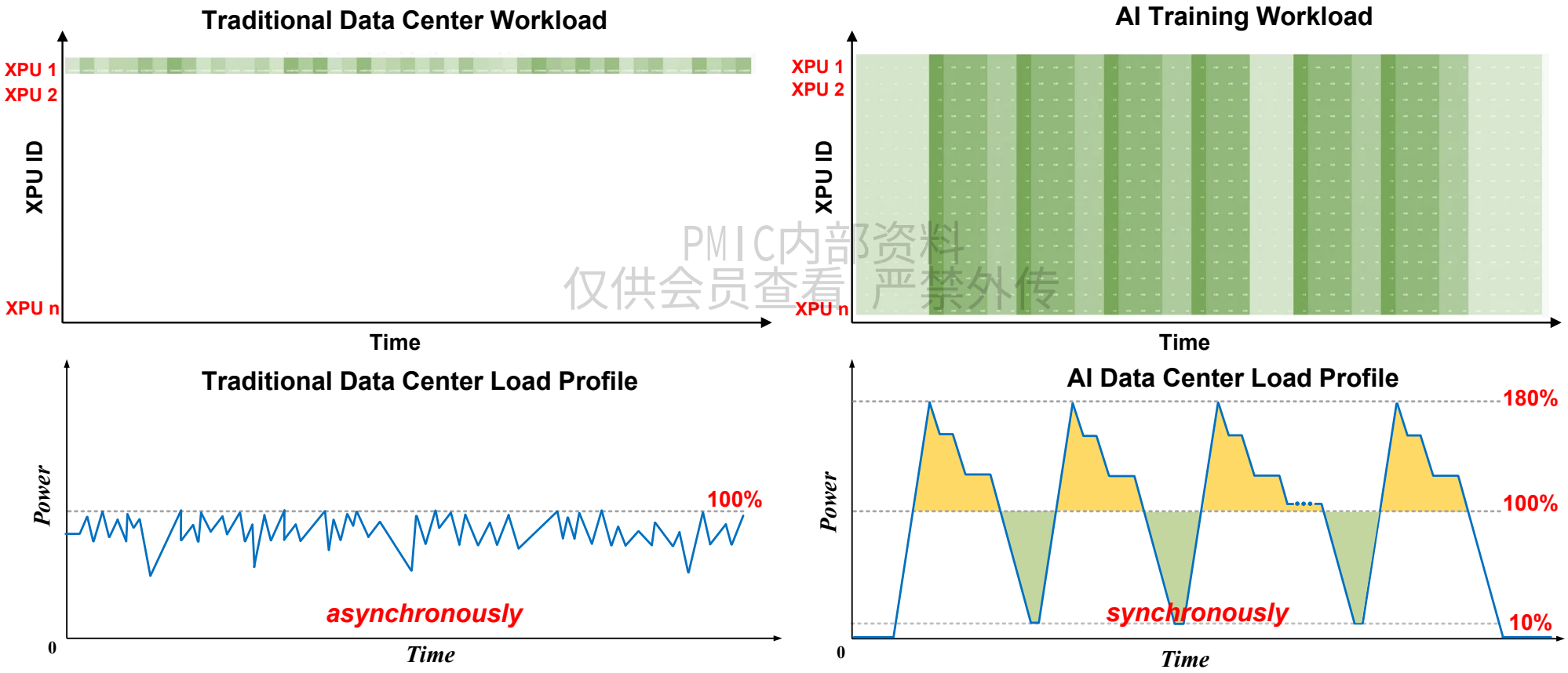
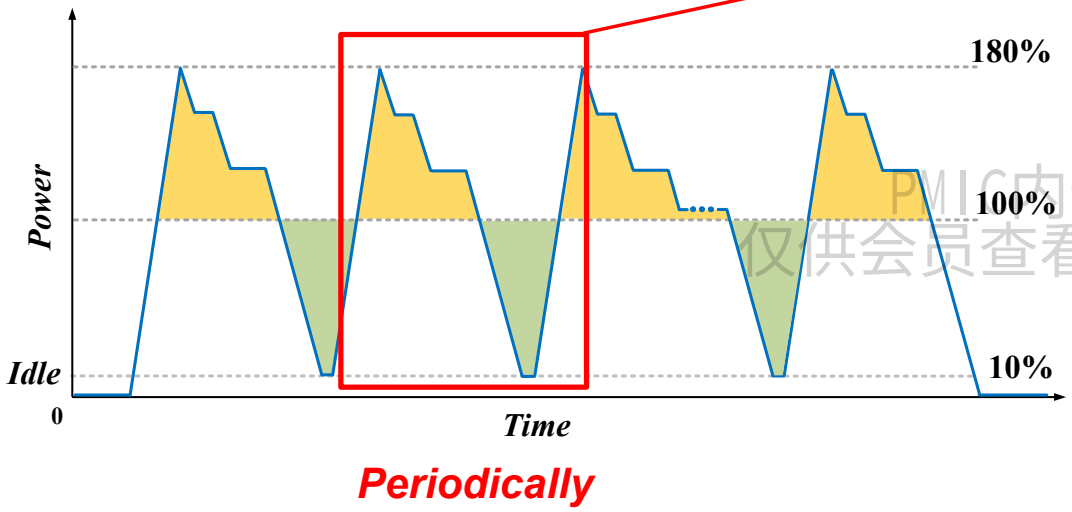
➢ **Power Consumption Heat Map of XPU** NVIDIA *Darker shade is more power



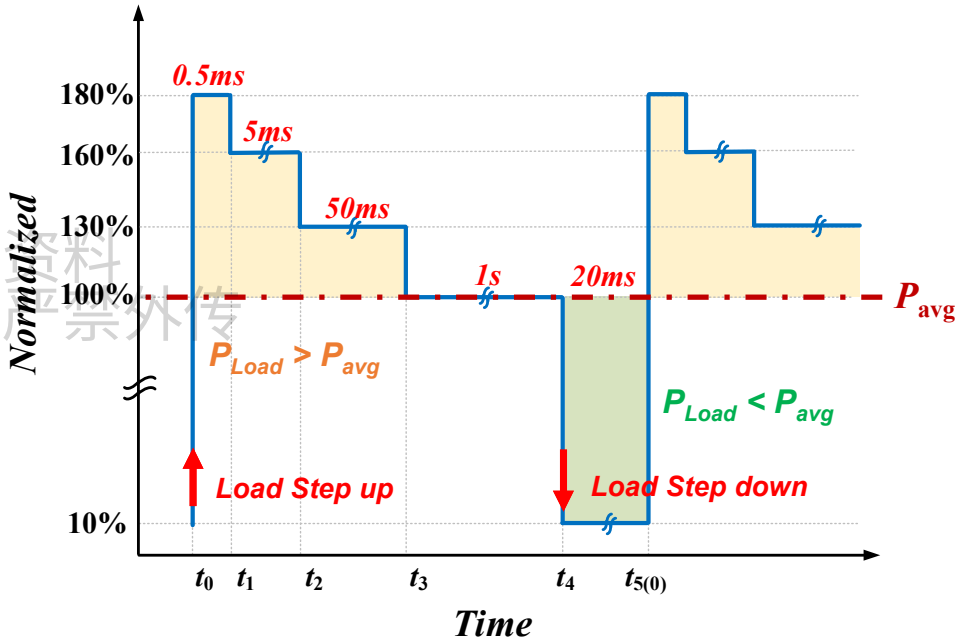
[1] https://developer.nvidia.cn/blog/how-new-gb300-nvl72-features-provide-steady-power-for-ai/
[2] https://www.opencompute.org/documents/open-rack-v3-bbu-module-spec-1-4-pdf

Typical EDPP Test Standard for AI Load Profile

➢ AI Load Profile for NVIDIA



➢ Typical EDPP Test Standard

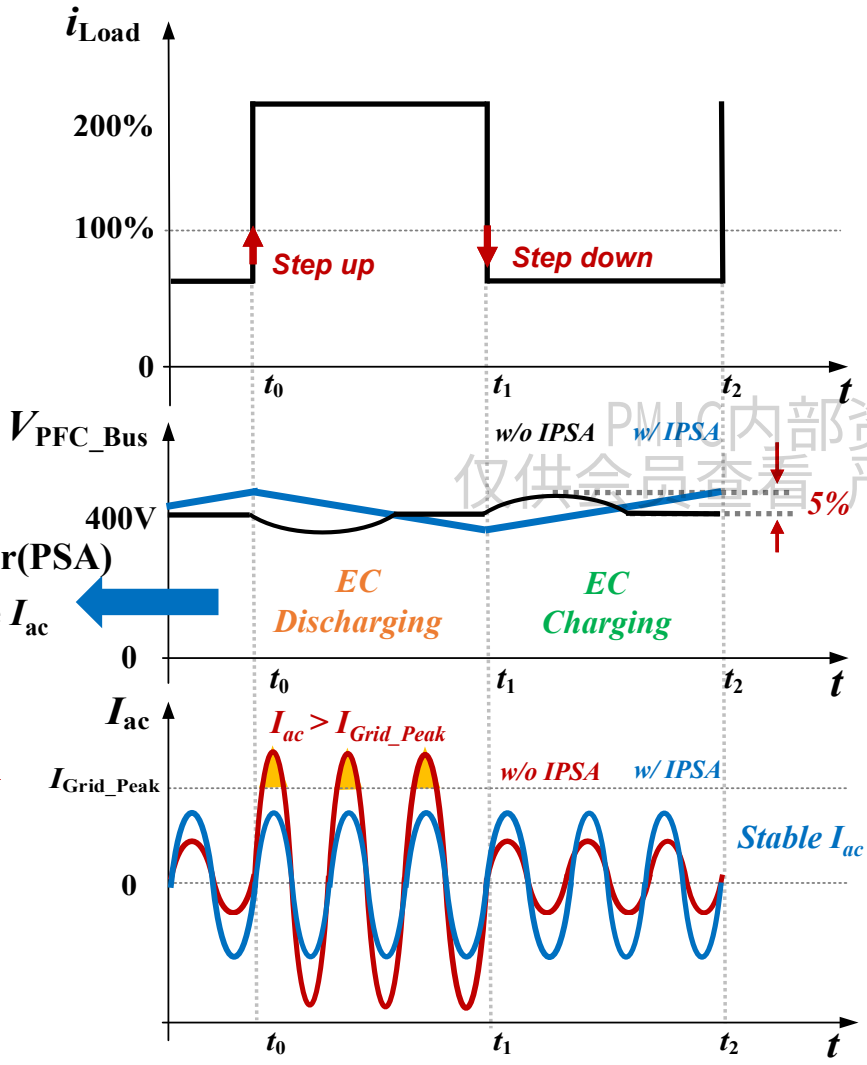


*EDPP：Electrical data peak processing

How will AI Load Transient affect Grid ?

[1] NVIDIA. 800VDC_Architecture_for_AIInfrastructure_Whitepaper

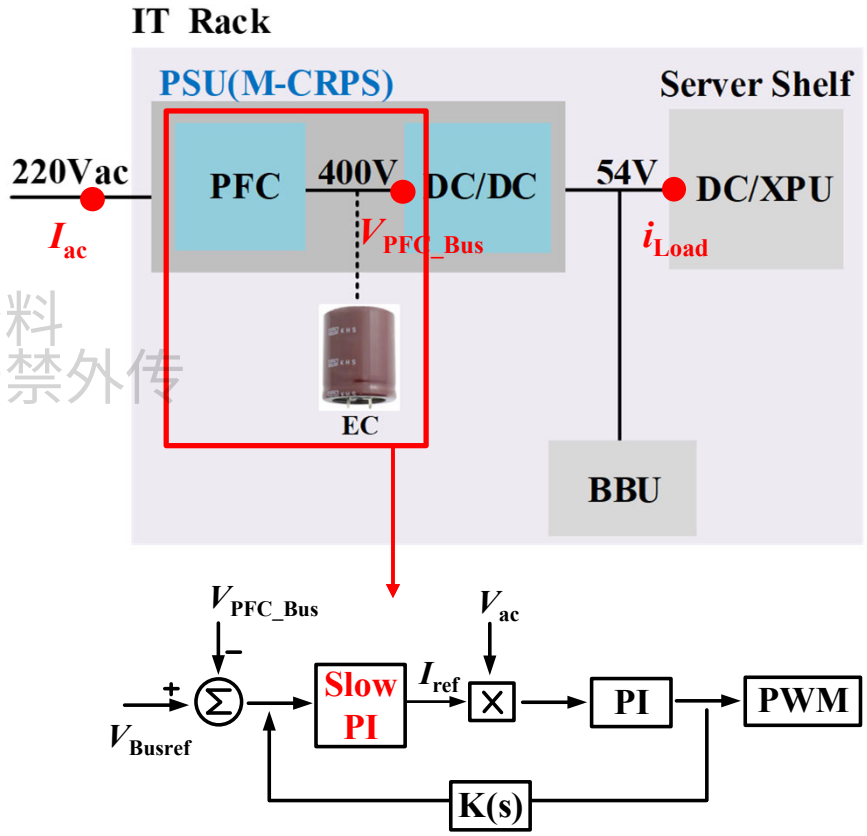
Role of IPSA in 2nd Architecture under AI Load Dynamics



Power Shock Absorber(PSA) to maintain stable I_{ac}

Integrated PSA (IPSA)

➢ 2nd Cloud and AI Server Rack

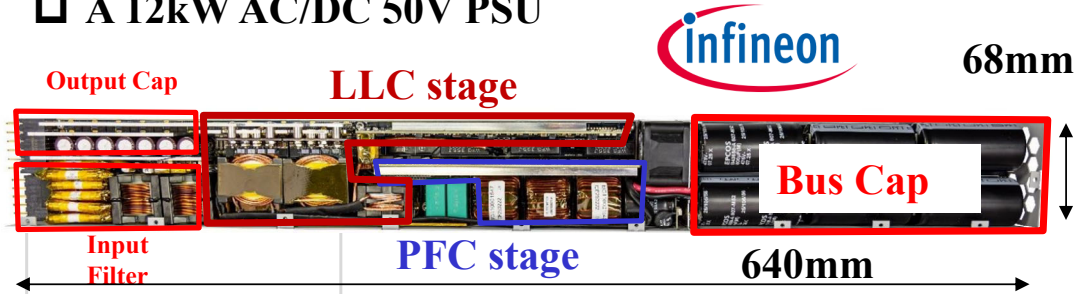


lower-bandwidth DC-link voltage loop to achieve IPSA

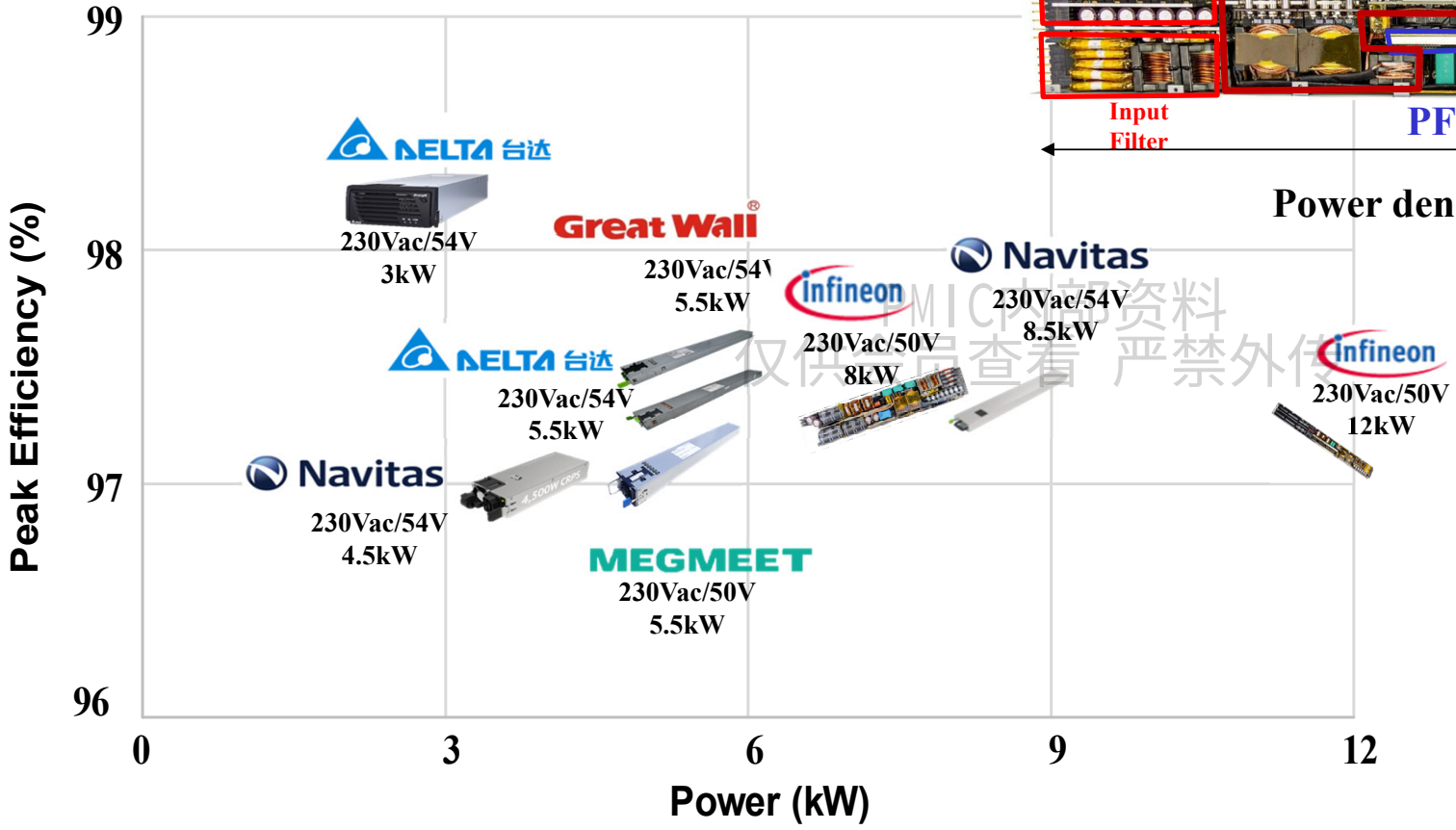
Single-Phase PSU Industry Status

Power Management Innovation Consortium

- A 12kW AC/DC 50V PSU



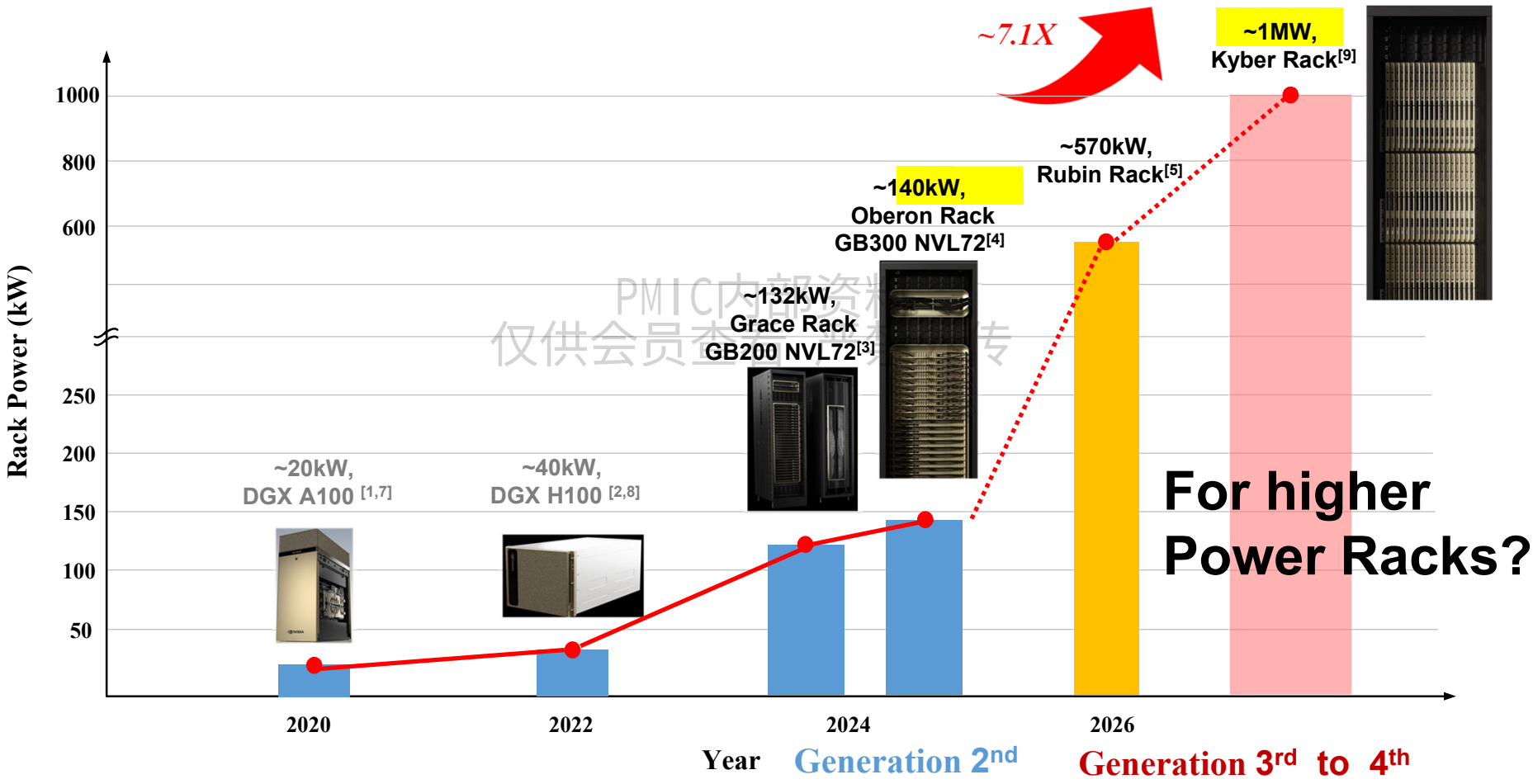
Power density 113W/in^3



E-Caps: 40-50% occupation

- Single-phase server PSUs are concentrated below 12kW range

Power Demand for IT Racks in AIDC

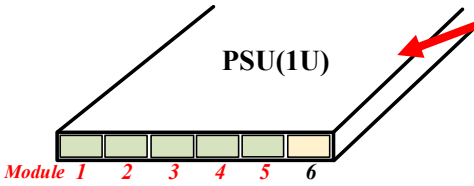


Side-car Power Rack for HVDC Server Racks

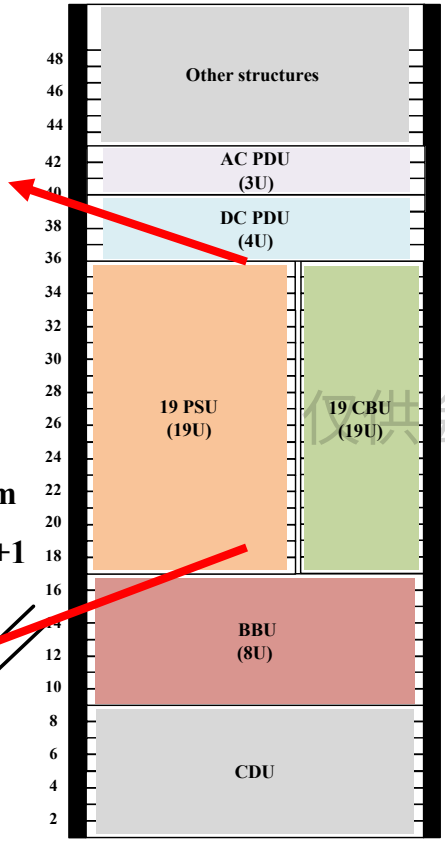
Power Rack

Power	600kW (19*33kW)
Input	384~528Vac
Output	**800Vdc (37.5A)**
Eff.	98.0%

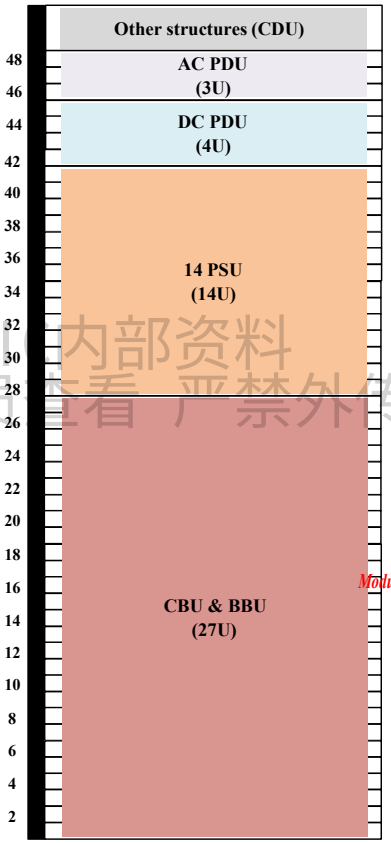
- H × W × D: 2236*600*1068mm
- PSU(1U): 5.5kW × 6 @Red. 5+1



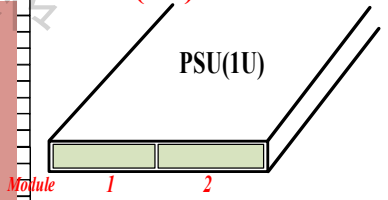
MEGMEET ~600kW



MEGMEET ~1MW



- **14 × 72kW**
- H × W × D: 2236*600*1068mm
- PSU(1U): 36kW × 2



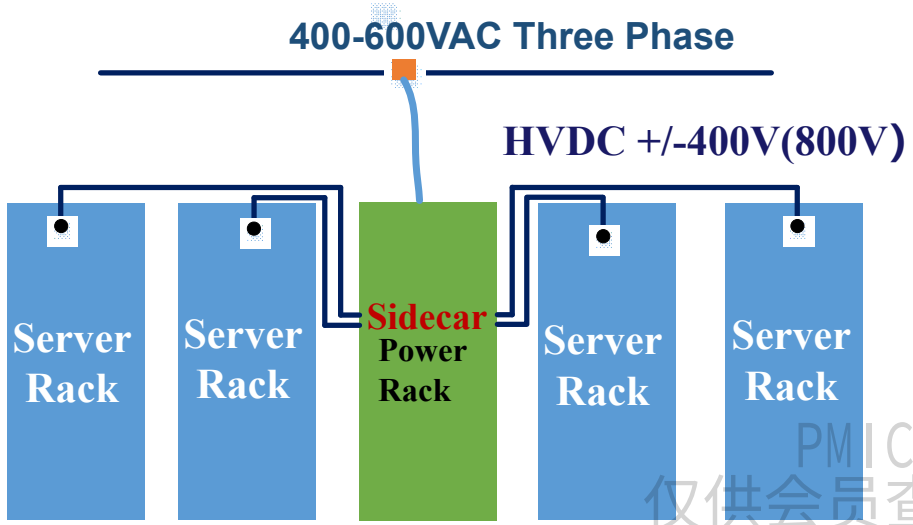
Server Rack

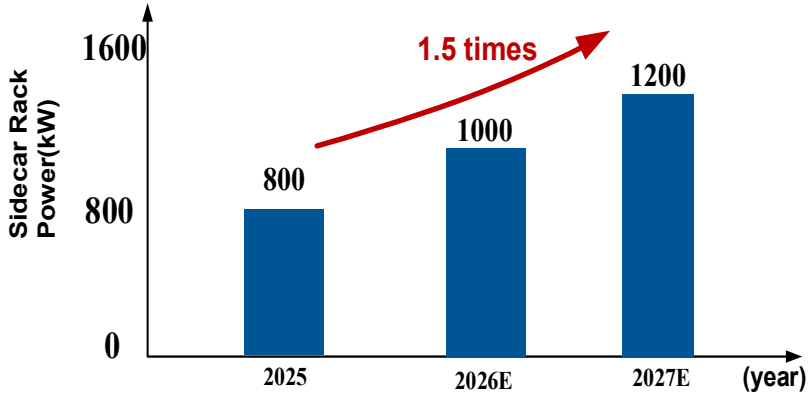
NVIDIA

- 288/576 × Rubin(Ultra) GPU

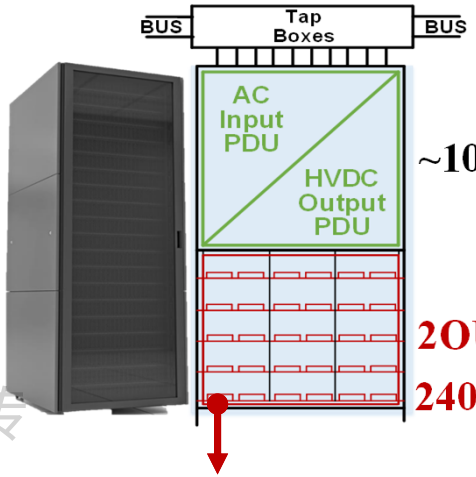
[1] https://en.megmeet.com/products/info.html?id=319&utm
[2] R. Movahedi, Y. Meng, and W. Zhang, "Megmeet 800V 1MW Sidecar Power System for AI Data Centers," presented at OCP Global Summit 2025, San Jose, CA, USA, Oct. 2025.
[3] https://www.opencompute.org/events/past-events/2025-ocp-global-summit?utm
[4] https://www.youtube.com/watch?v=FNwvDGZTf4g
[5] https://globaltechresearch.substack.com/p/2025-computex-review-an-introduction

Super Power Rack with Three Phase Input

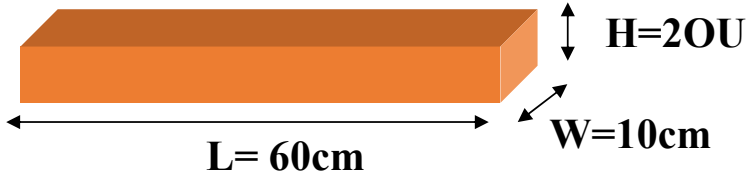




1.2 MW Sidecar Power Rack



Available space for 40kW PSU



Prototype：Volume×70%

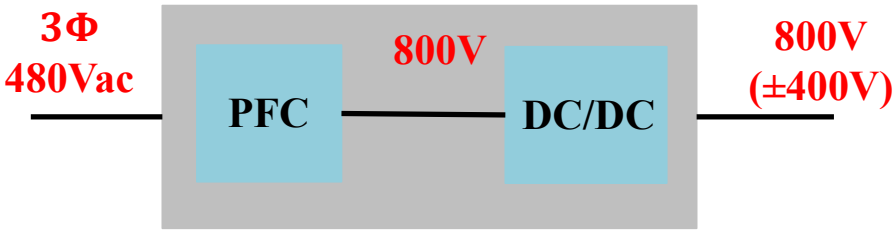
Power Density:~170W/in^3

[1] Open rack V3.0, 2021;

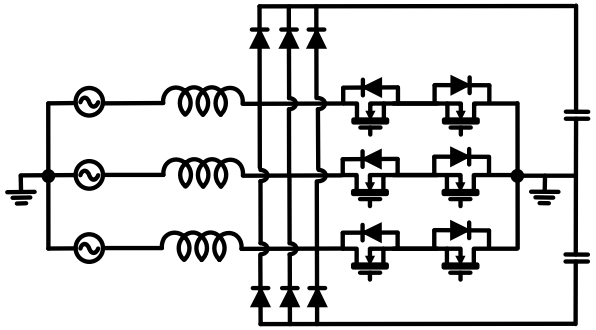
[2] 纳微半导体. 第三代半导体驱动超高功率密度CRPS185 3200W钛金Plus服务器电源设计 [EB/OL].(2024-04-03)[2025-02-10].https://navitassemi.com/wp-content/uploads/2024/04/3rd-Gen-Device-Drives-Ultra-Power-Density-CRPS185-3200-W-Titanium-Server-Design-Chinese.pdf

Commercial Three-Phase PSU Topologies

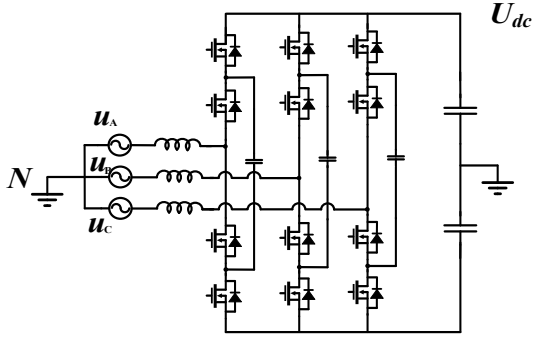
Two-stage Three Phase Architecture



Three Phase PFC Topology

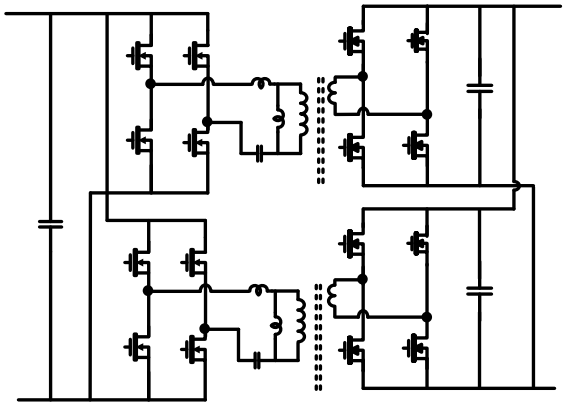


Vienna PFC

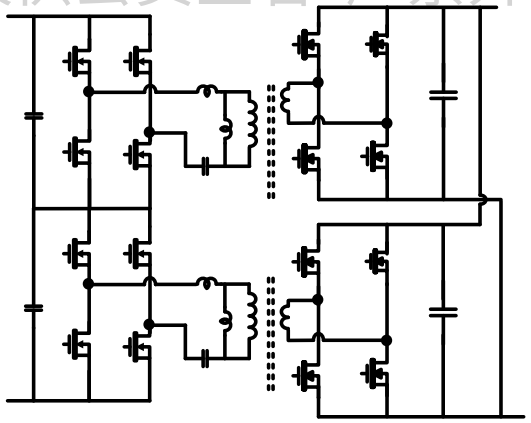


FC TL PFC

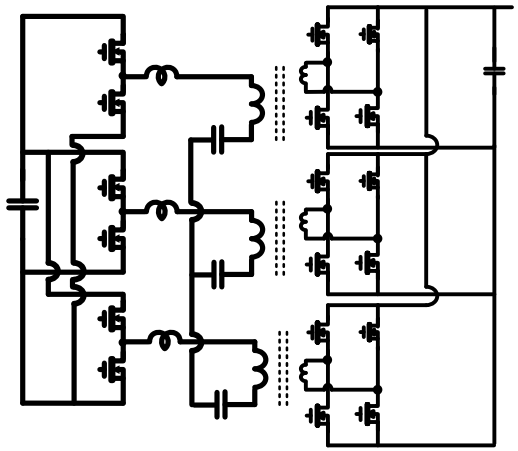
Isolated DC/DC Topology



Interleaved LLC with 1.2kV SiC Devices

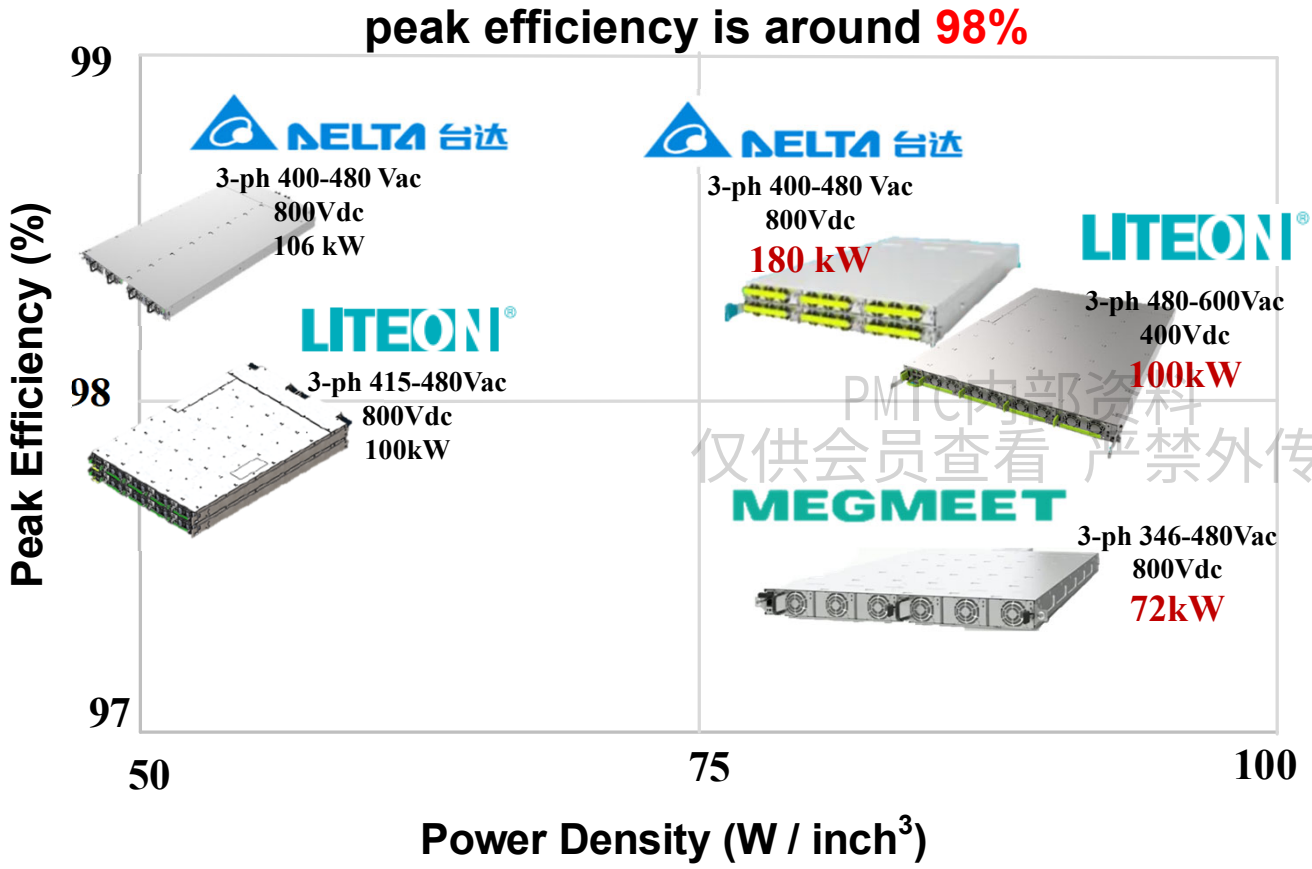


Stacked LLC



3-ph Half-Bridge LLC with 1.2kV Devices

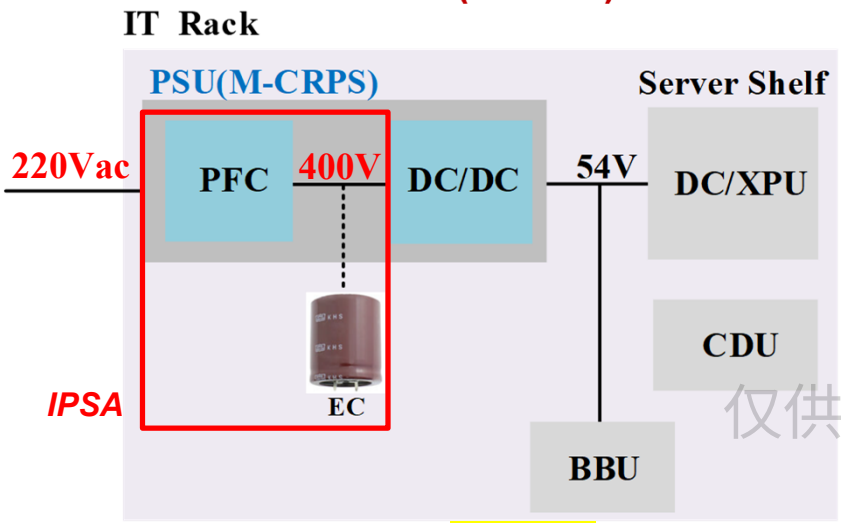
Commercial Three-Phase PSU for Power Rack from Industrial



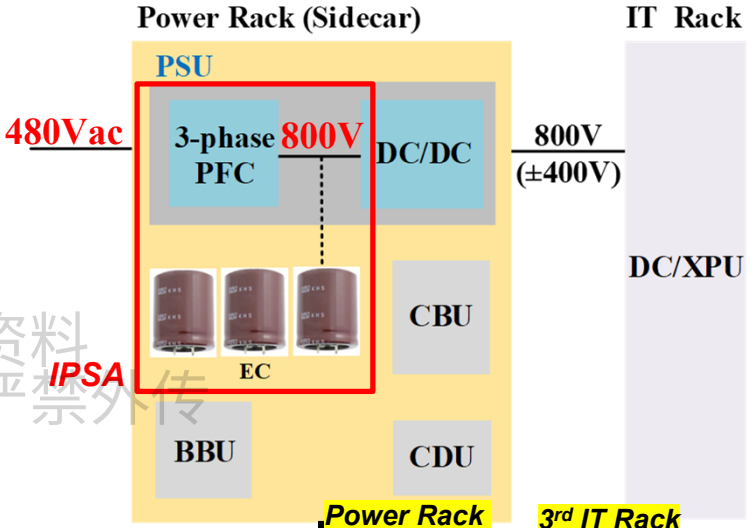
Higher Density Three Phase PSU are needed

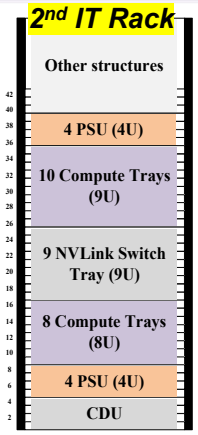
Comparison of Power Supply Architecture between 2nd and 3rd

➢ **IPSA in 2nd IT Rack (140kW)**

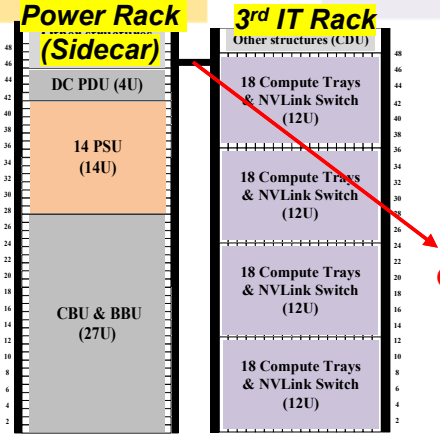


➢ **IPSA in 3rd Power Rack (600kW~1MW)**





- **Difference:**
  - (1) **Separate** the Power and IT Racks to improve power level with 800V HVDC power delivering
  - (2) PFC output: 400V —> 800V
  - (3) More PFC Bus Caps
- **Similarity:**
  - **IPSA** to cope with AI Load Dynamics



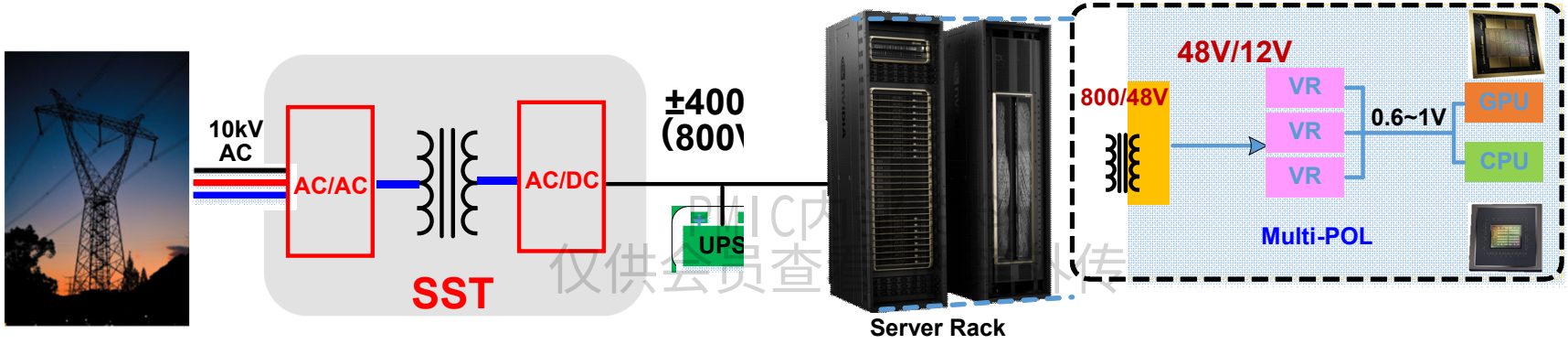
Cascaded by HVDC Bus

[1] https://www.ti.com/lit/ta/ssztdb4/ssztdb4.pdf?ts=1772740769563&ref_url=https%253A%252F%252Fwww.google.com%252F

HVDC 800V with SST Instead of Individual AC Super Power Racks

Power Management Innovation Consortium

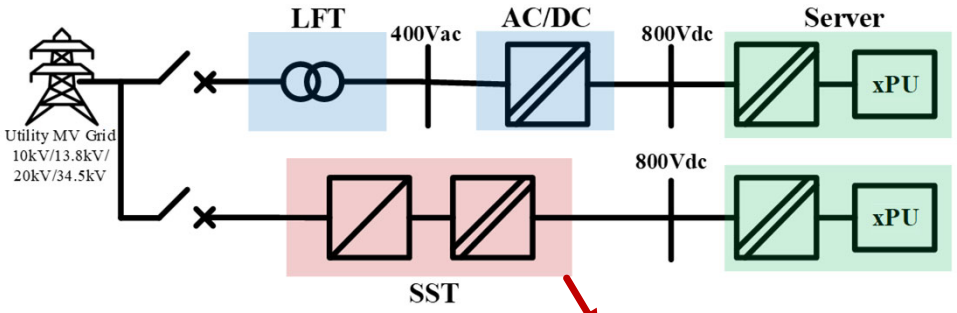
- **Solid State Transformer for HVDC**

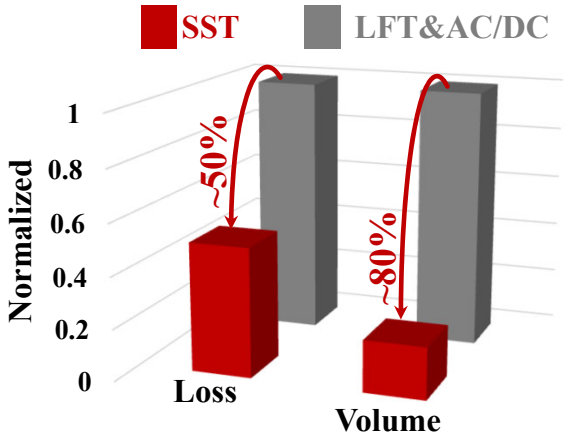


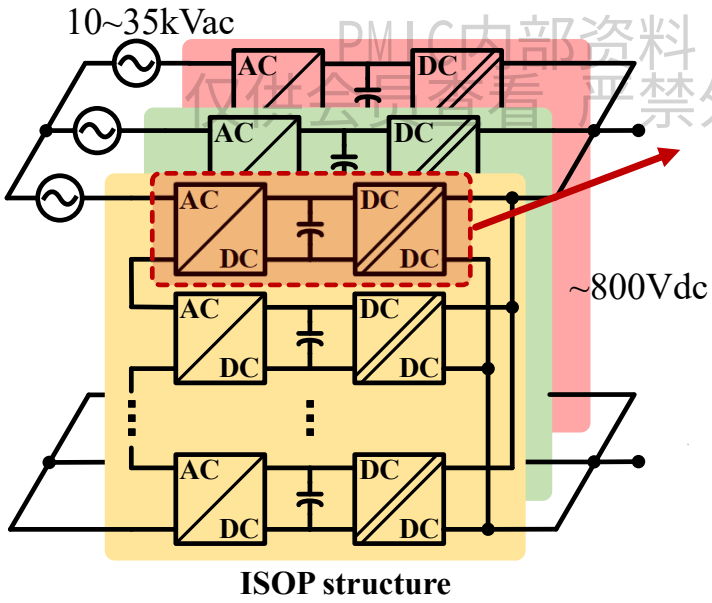
Topologies of Commercial SSTs

Power Management Innovation Consortium

➢ **SST in Data Center**

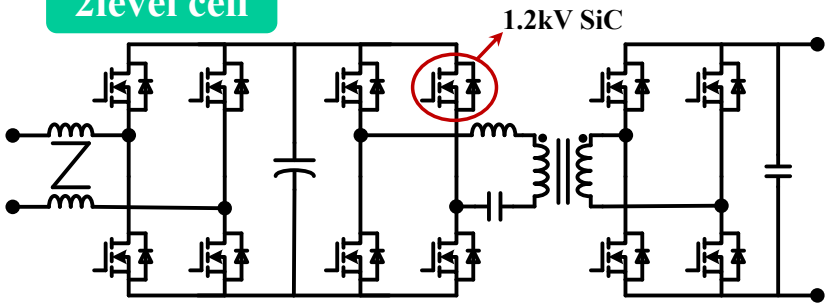






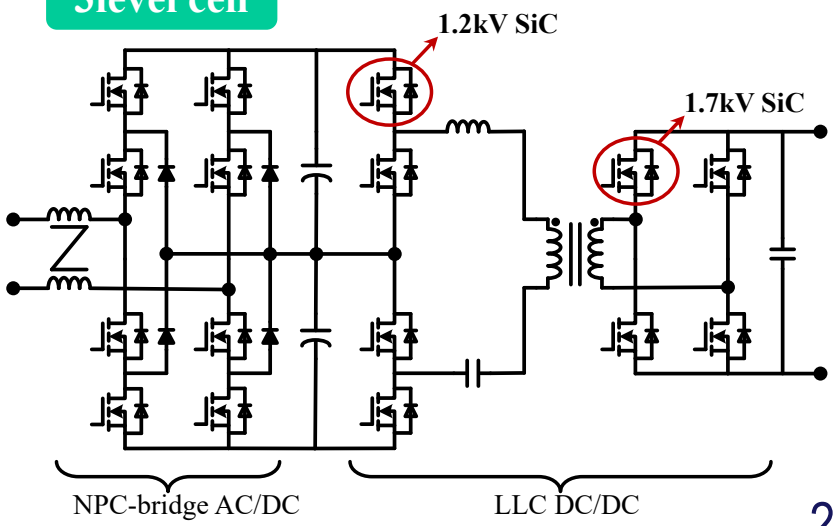
Key players: DELTA ABB EATON SUNGROW …

2level cell



Multilevel ⇩ **Smaller and less cells**

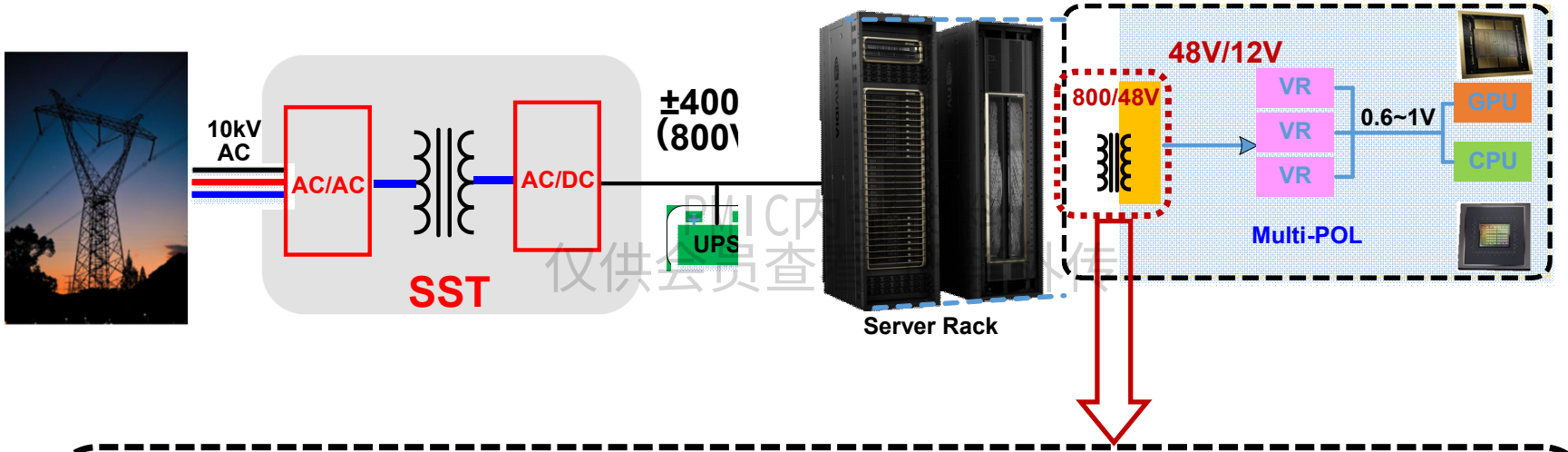
3level cell



HVDC 800V Resulting 800V DC/DC Conversion in Server Racks

Power Management Innovation Consortium

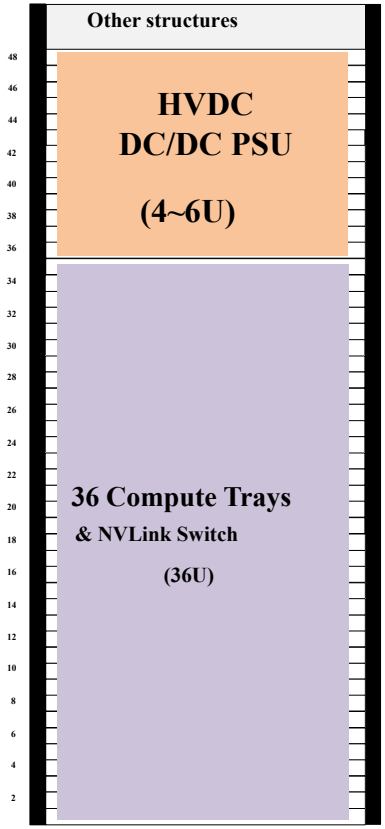
- Solid State Transformer for HVDC

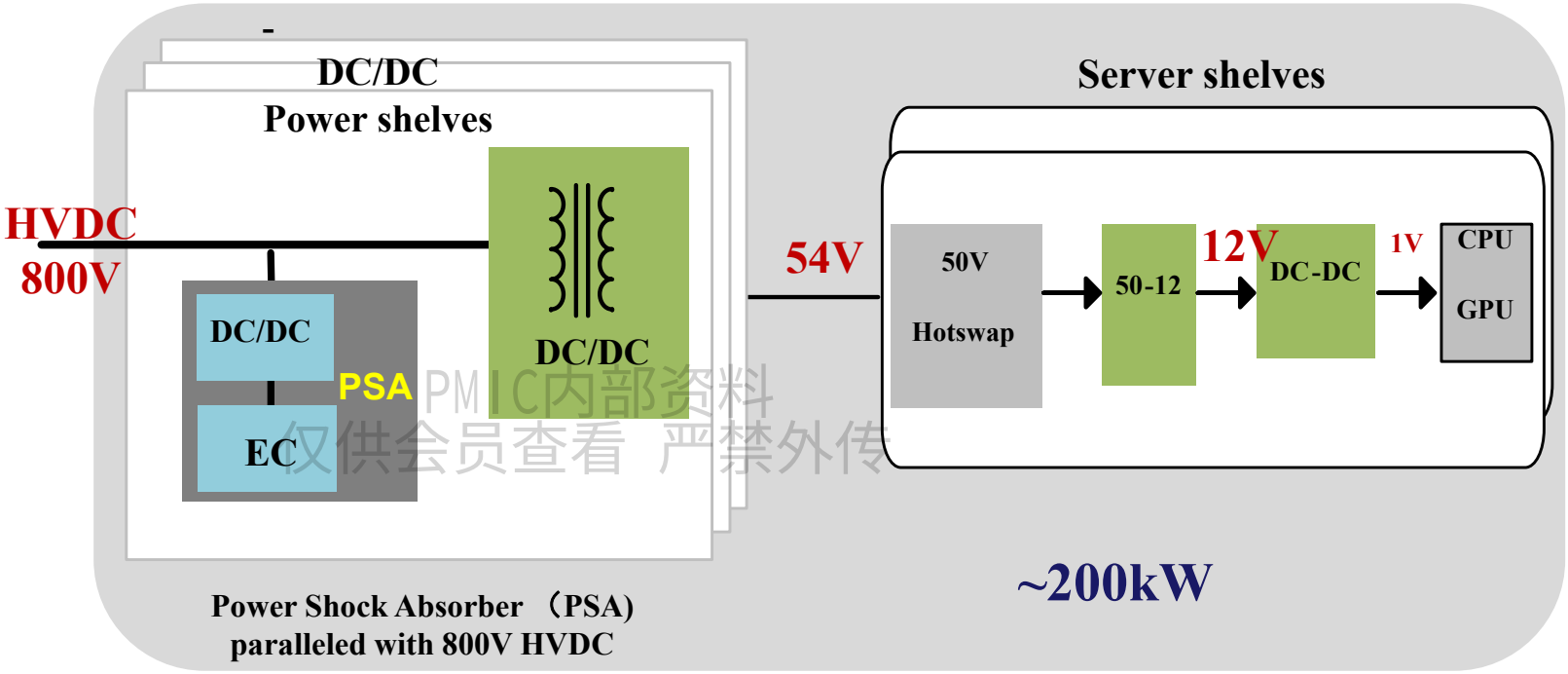


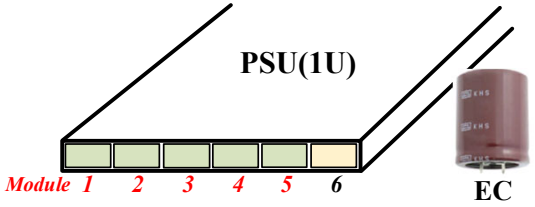
Challenges

- Electrical insulation
- EMI
- High Efficiency (99%peak)
- Ultra Density (>3kW/in^3)

Power Architecture in 800V HVDC Server Racks



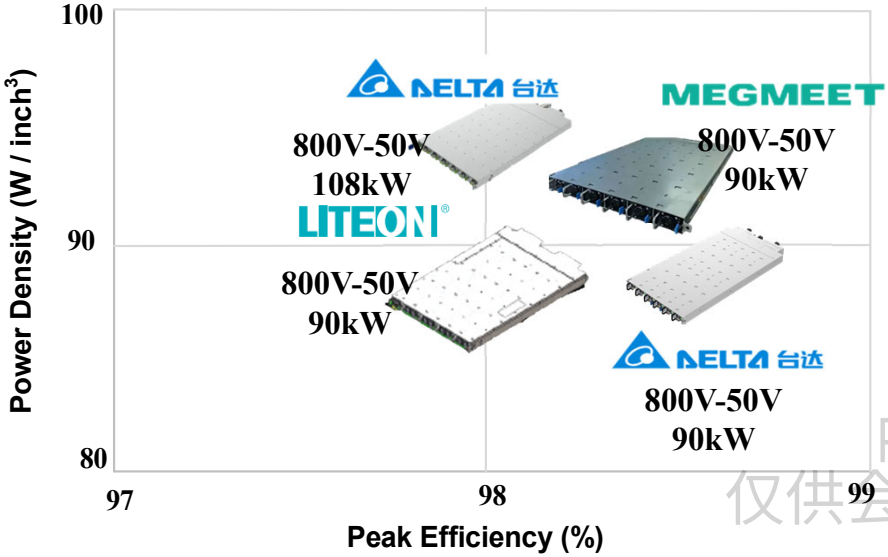


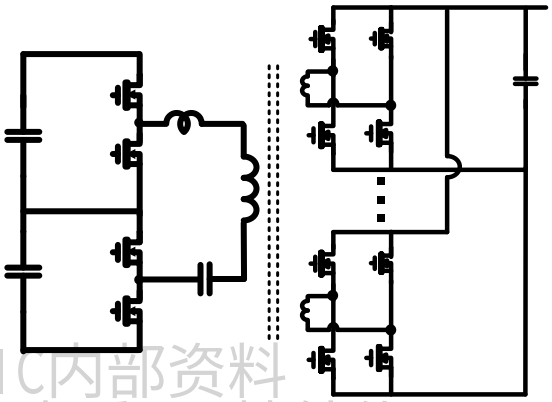


- H ×W × D: 2236*600*1068mm for Server Rack
- PSU(1U): 12-18 kW*6

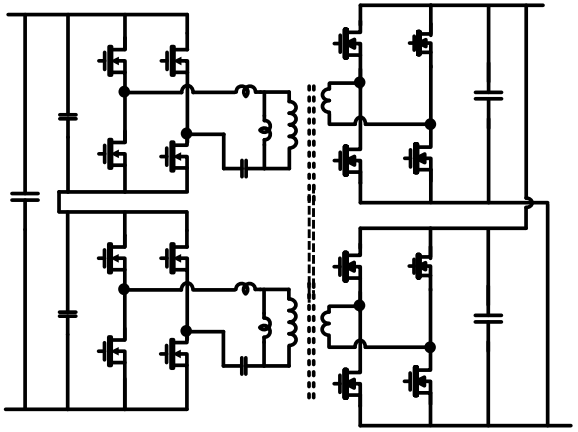
Huge ECs are still needed in HVDC Server Racks

Topologies for 800V-54V DC/DC Shelves

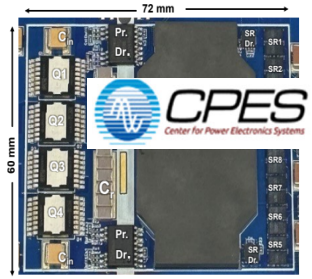




3-L LLC with 650V Devices



Cellular LLC with 650V Devices

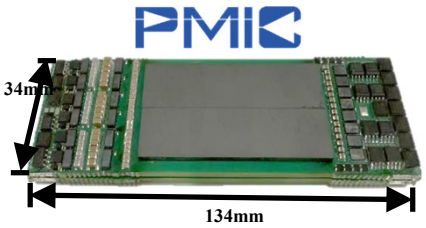


6kW

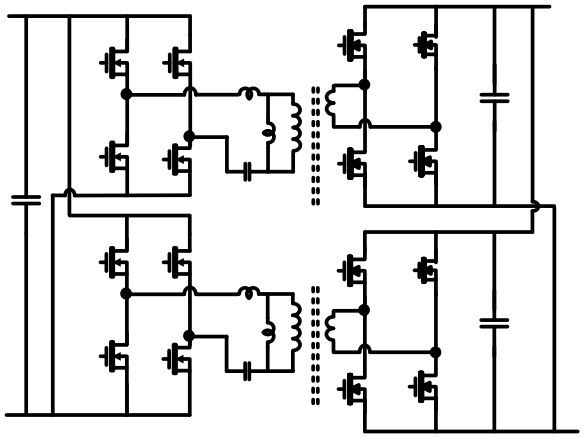
All GaN, 615 kHz
- 98.7% Peak-efficiency
- 2070 W/in3

Navitas

All GaN , 1 MHz
- 98.5% Peak-efficiency
- 2100 W/in3

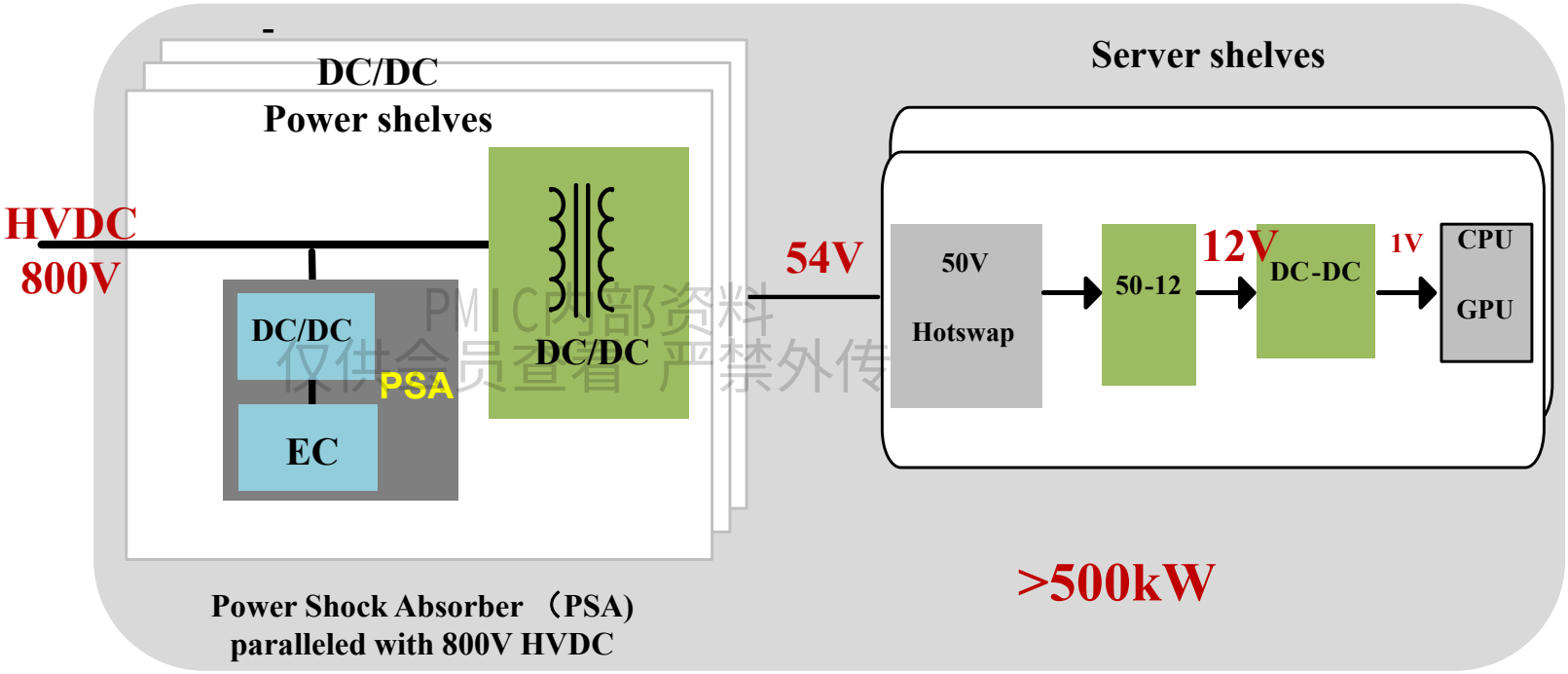


All GaN, 1MHz
- ~98.9%
- >3000kW/in³



IPOP LLC with 1.2kV Devices

Power Architecture of 800V HVDC Server Rack



- 288/576 × Rubin(Ultra) GPU

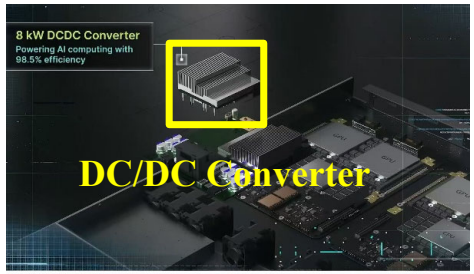
Higher Power Density and Efficiency are Required for 800V Power Module

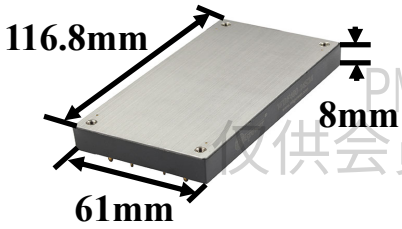
Power Management Innovation Consortium

➢ Compute Tray

NVIDIA DELTA 台达

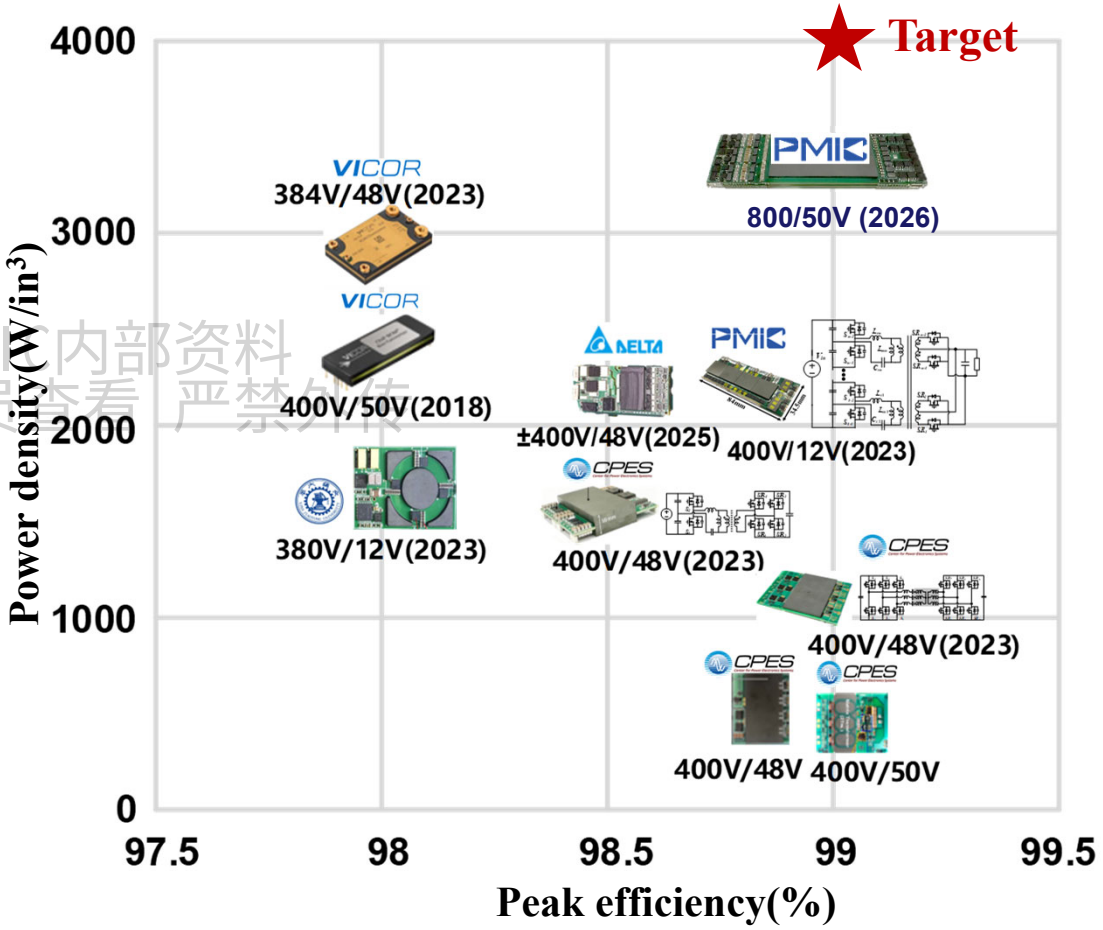
Rubin Ultra:≥12kW





Requirement:

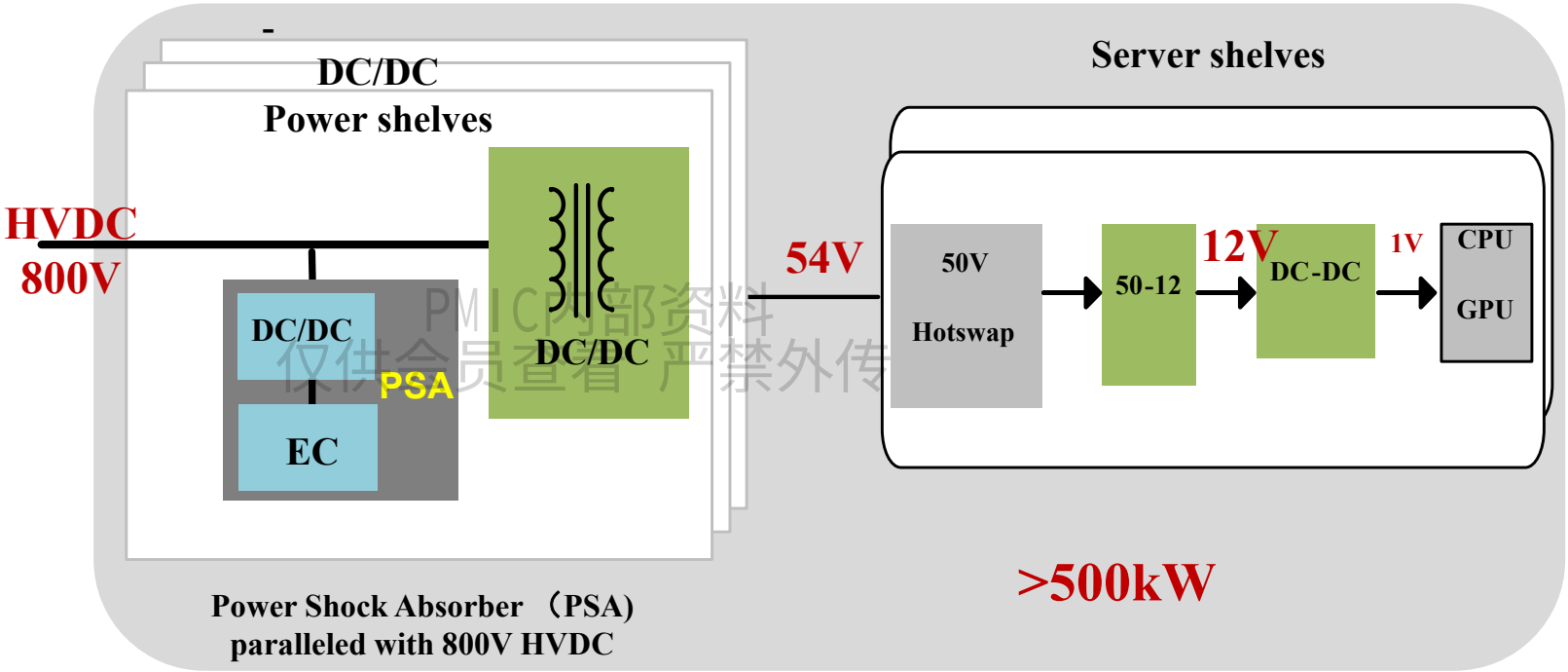
- Power density ≥5 kW/in³
- Peak eff. ≥ 99%
- Isolated



[1] Jared Huntington, Mike Tu. Nvidia. 800 VDC Architecture for Next-Generation AI Infrastructure.

Future Challenges of Power Supply for 800V HVDC Ultra-high Power Racks

- 288/576 × Rubin(Ultra) GPU



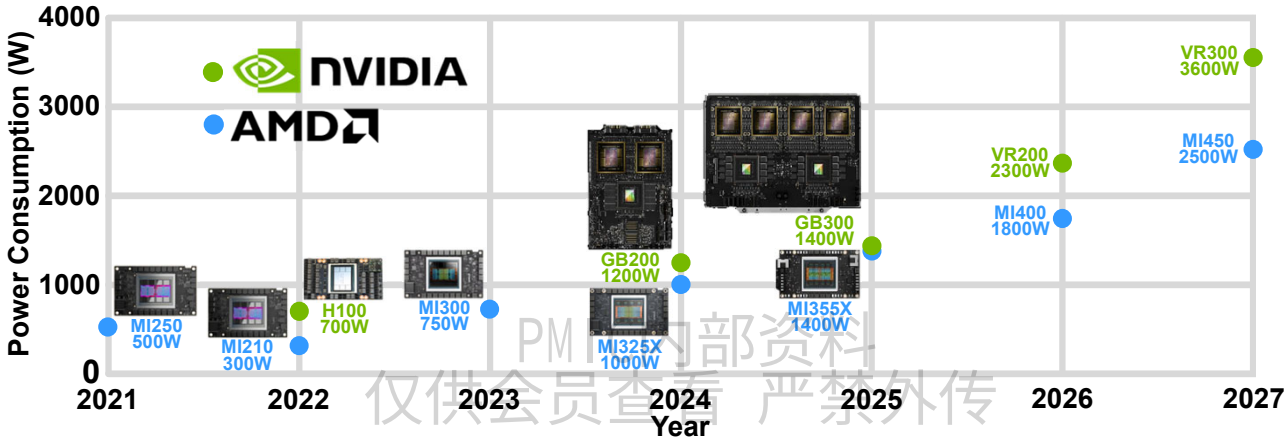
Challenges:

- ☐ Where can be PSA put?
- ☐ Huge current delivering for XPUs

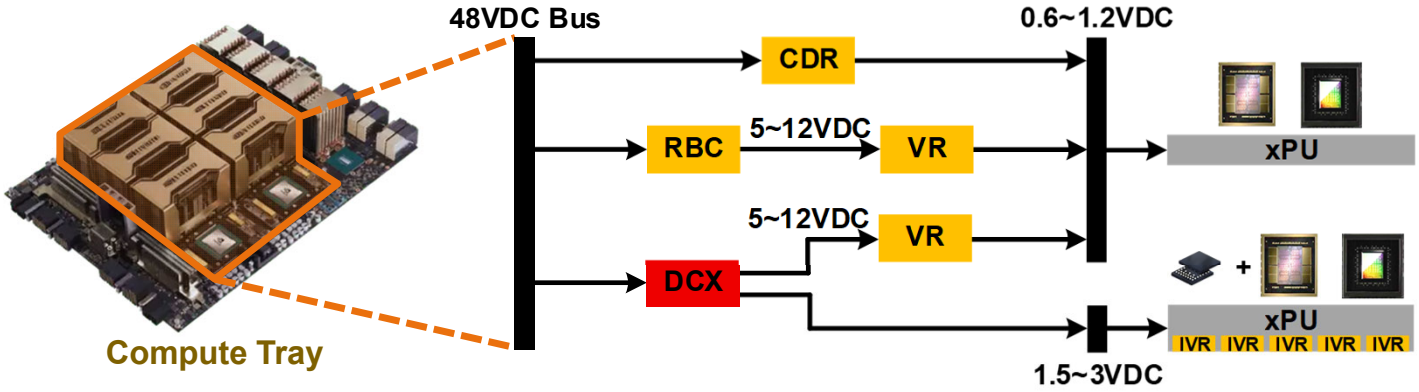
Higher Power Consumption is Required for GPUs

Power Management Innovation Consortium

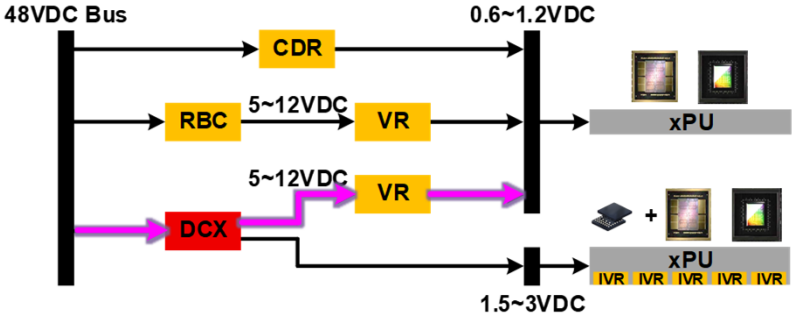
➢ **Power consumption of the single GPU**



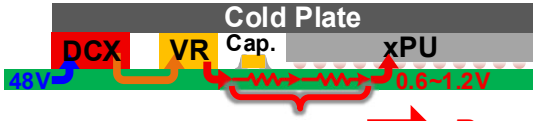
➢ **Current 48V-bus system architecture**



PDN Loss Rises as XPU's Power Increases

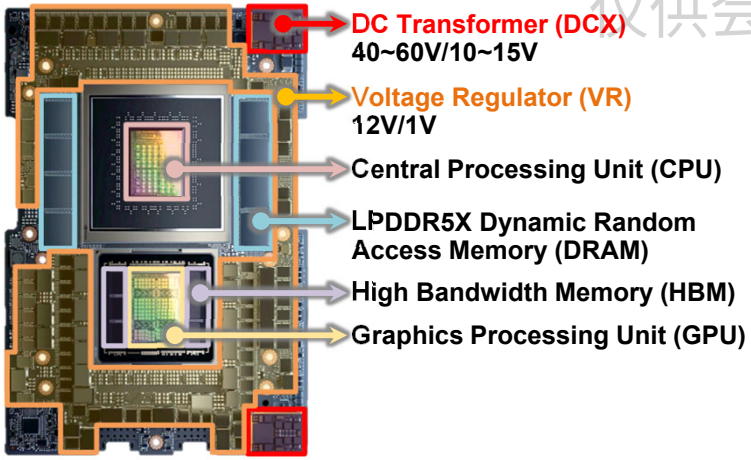


➢ **Power flow of the compute card**

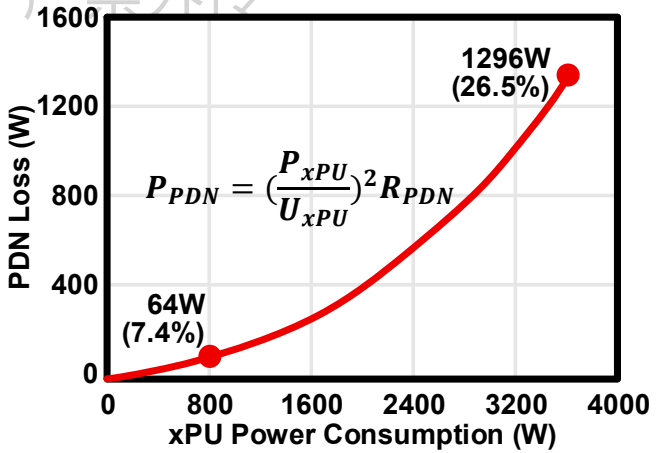


≈15mm ➡ R_{PDNVR}≈90~140μΩ [1]

➢ **Compute card**



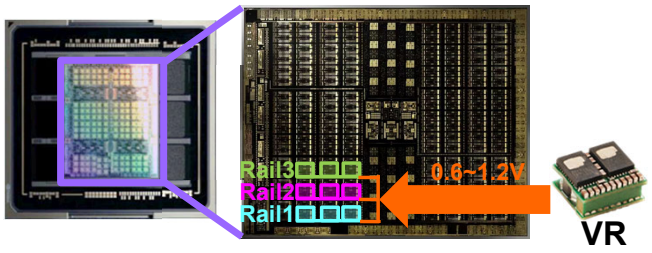
➢ **PDN loss vs xPU power @ R_{PDNVR}=100μΩ**



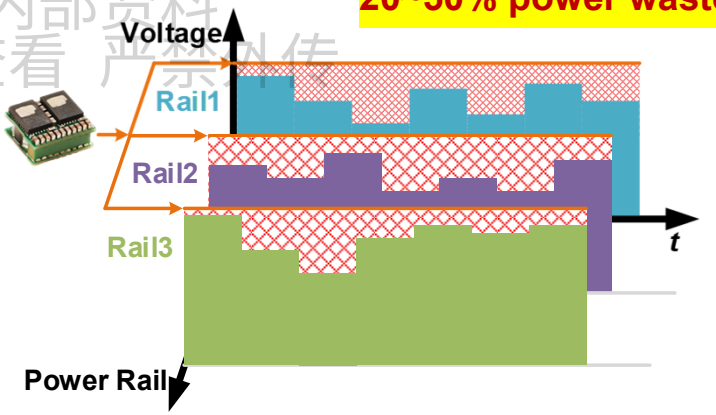
[1] https://www.infineon.cn/row/public/documents/corporate/investors/presentations/2025/2025-11-26-power-roadshow-v01-00-en.pdf.

Extra Power Losses Caused by one VR Powering Multiple Cores

➢ **One VR powers multiple rails**

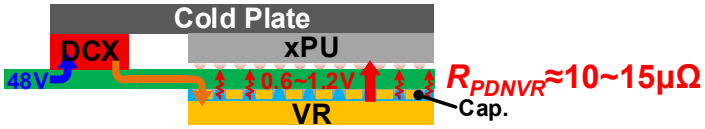


20~50% power waste [2]

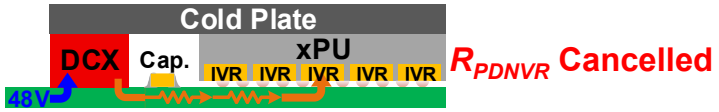


[1] https://www.infineon.cn/row/public/documents/corporate/investors/presentations/2025/2025-11-26-power-roadshow-v01-00-en.pdf.
[2] Ferric Technology, "Thin Film Inductors for Integrated Power Conversion," APEC, 2017, Industry Session - Component, Reliability and Manufacturing Innovations for 3D Power Packaging.

Redundant Power Saved by IVR

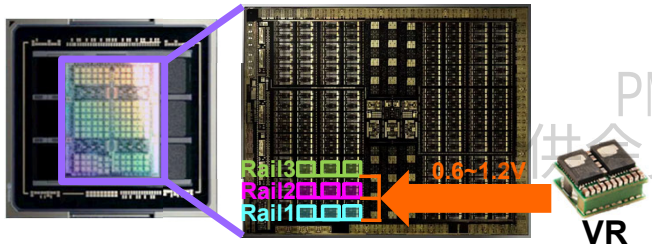


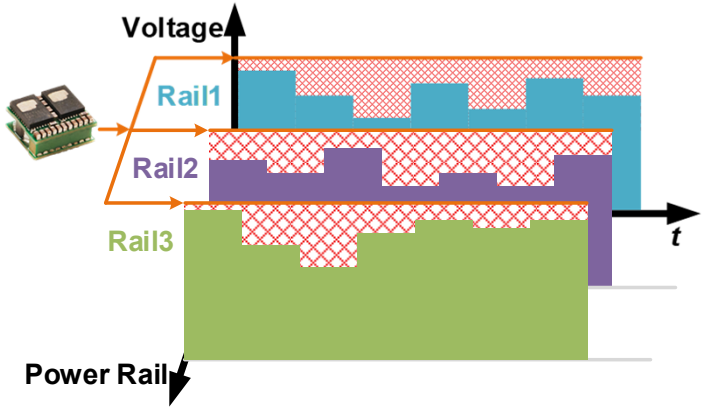
VR-Vertical



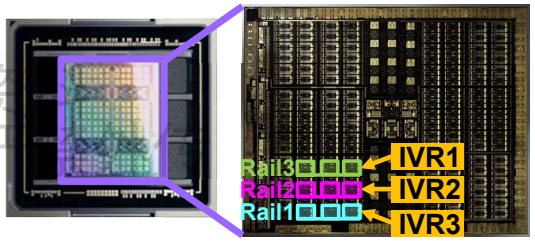
IVR-Vertical

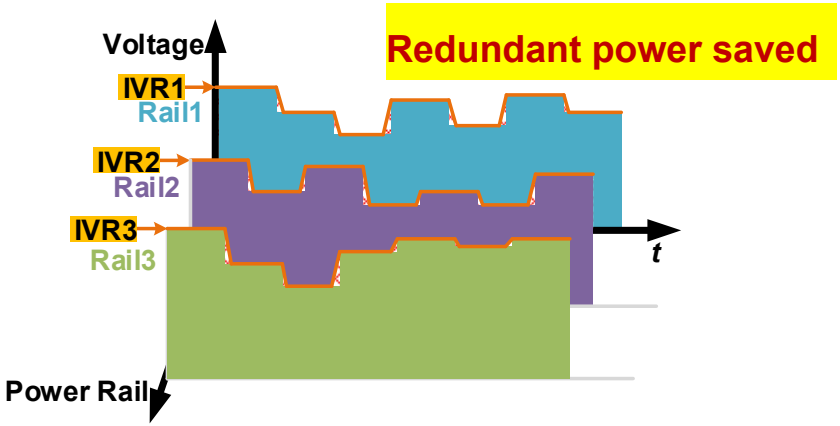
➢ One VR powers multiple rails



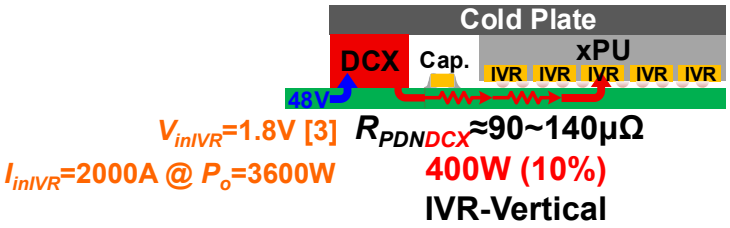


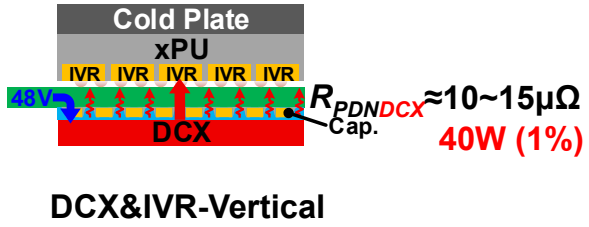
➢ One IVR powers one rail



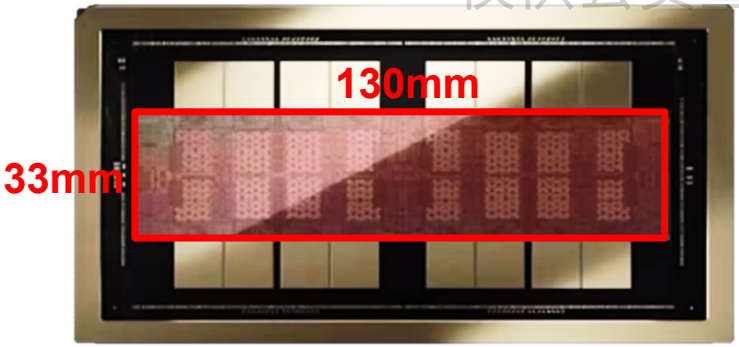


Higher Power Density DCX is Needed for Vertical Power Delivery with IVR





- Requested power density of DCXs

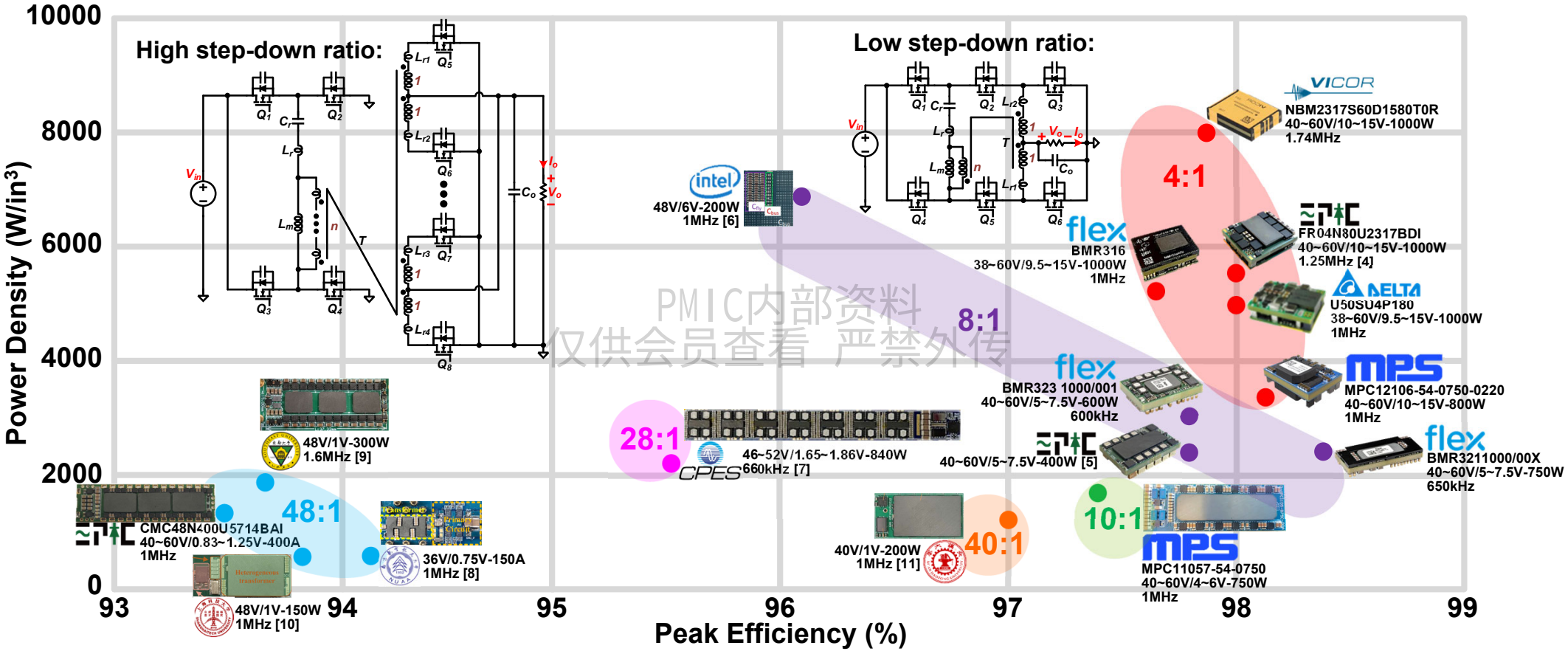


Rubin ultra @ 3600W

3000W/in^3 power density is needed for 48V/xV DCXs!

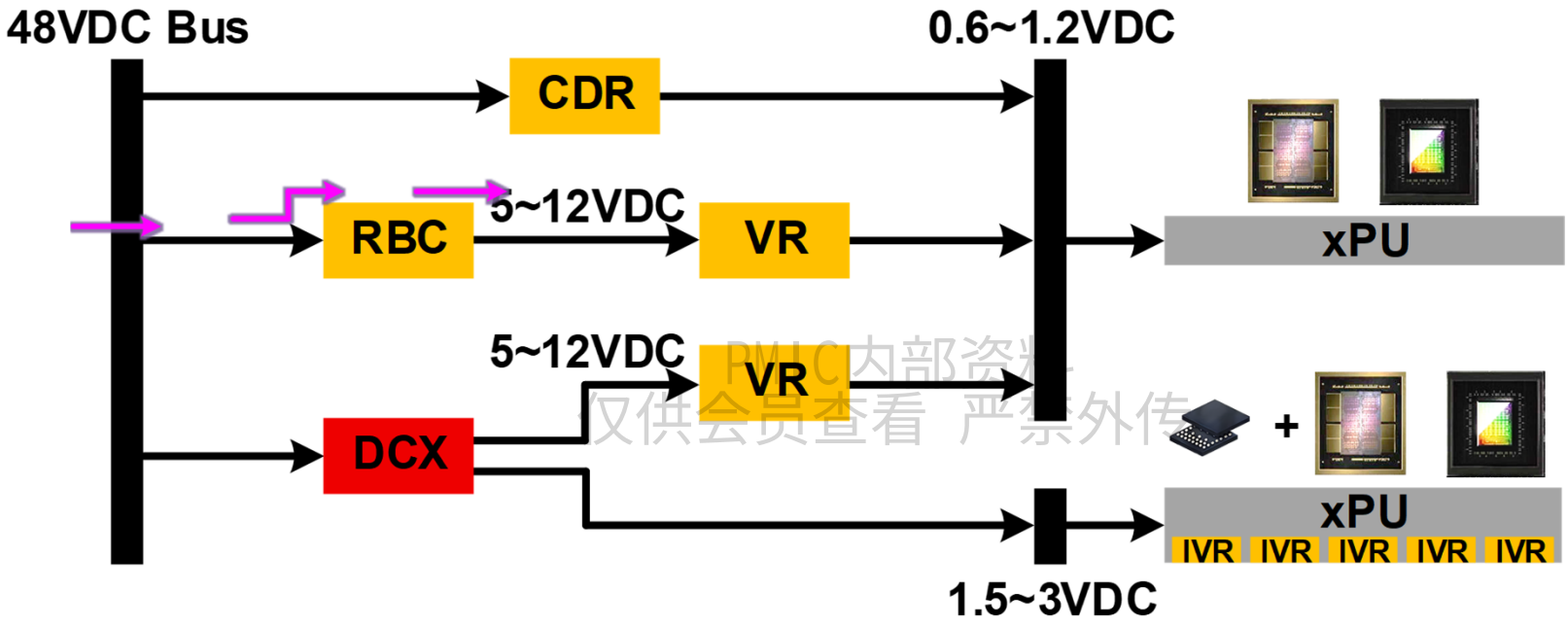
[3] Frede Blaabjerg, "An Overview of Fully Integrated Switching Power Converters Based on Switched-Capacitor versus Inductive Approach and Their Advanced Control Aspects," Energies, 2021.

48V DCX State-of-the-arts



[4] T. Long, "A Non-isolated Fixed-ratio DC-DC Converter Using Switched Auto-transformer (SATx) for Data Center Applications," ECCE, 2023, pp. 3321-3324.
[5] T. Long, "Design and Testing of an 8: 1 Non-isolated Bus Converter for 48V Data Centers," ECCE, 2024, pp. 2610-2614.
[6] Intel, "A 96.1% Peak Efficiency, 6.8 kW/in3, 48V-to-6V On-package Intermediate Bus Converter with LV-GaN Power Transistors," APEC, 2025, pp. 1681-1686.
[7] Q. Li, "High Current, High Power-Density Intermediate Bus Converters for Vertical Power Delivery to Next-Generation Processors," TPEL, 2025, pp. 14771-14784.
[8] H. Wu, "Current-Cancellation-Based Heterogeneous Integration of LLC-DCX With Ultralow-Voltage High-Current Output for Data Centers," TPEL, 2024, pp. 9144-9149.
[9] H. Wang, "Topology and Magnetics Integrated Design for Switched-Capacitor LLC Hybrid 48 V–1 V DCX in Data Center Applications," TPEL, 2026, pp. 781-790.
[10] Q. Qian, "Optimized Design of 48-1V LLC-DCX Transformer Structure Based on Finite Element Analysis Achieving 1900W/in³ Power Density," ICEPT, 2025.
[11] H. Li, "Integrated Planar Transformer for High-Voltage-Ratio LLC DCX With High Current and Ultra-Low Voltage Output," OJPE, 2024.

Other Power Supply Architectures of Computing Board

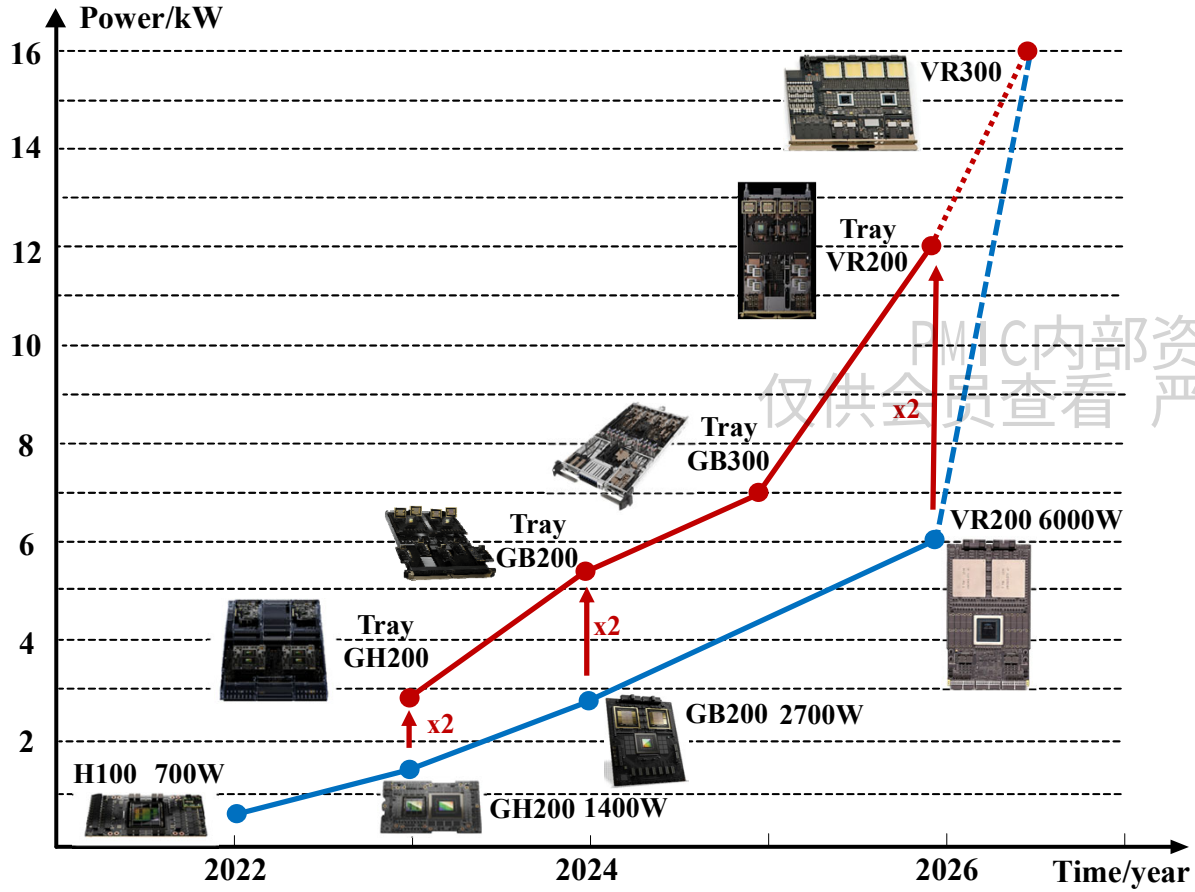


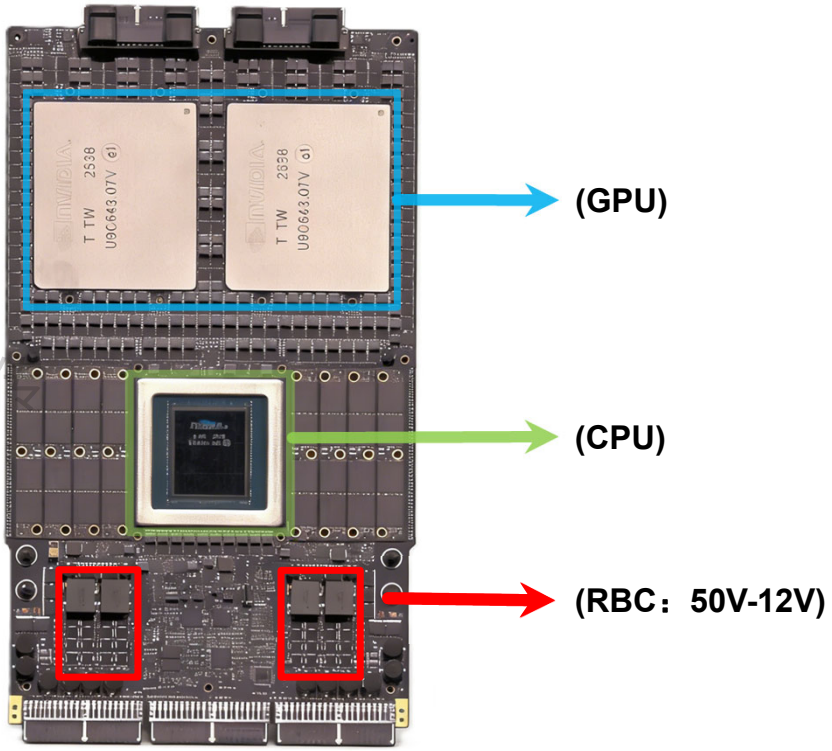
Regulated Bus Converter (RBC) is also a commercial architecture

[1] https://www.infineon.cn/row/public/documents/corporate/investors/presentations/2025/2025-11-26-power-roadshow-v01-00-en.pdf.

Regulated Bus Converter of On-board Power Supply Architectures

■ **Board-Level Power Consumption Trends**





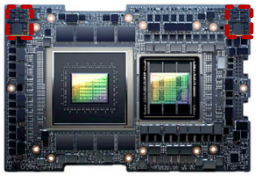
How about the board power supply?

Evolution of On-board Power Supply Architectures

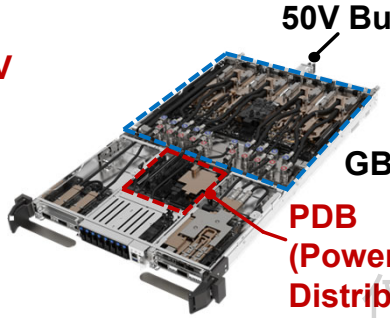
Power Management Innovation Consortium

■ Limitations on power module dimensions

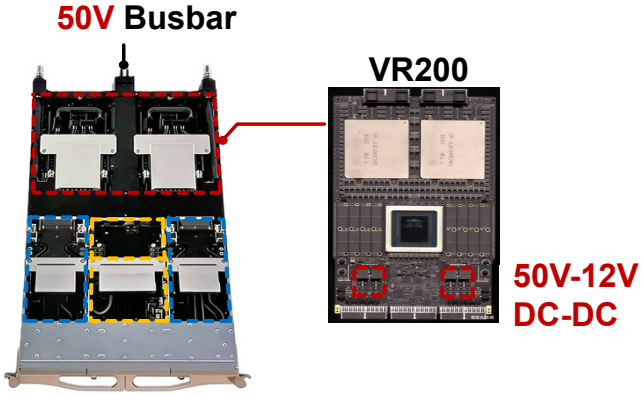
➢ Hopper



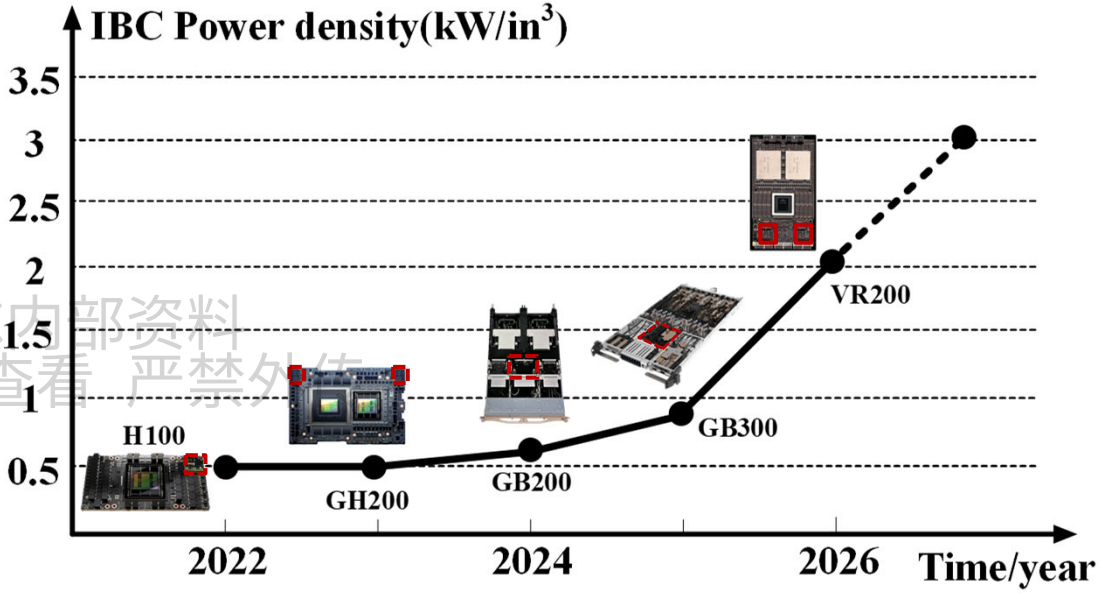
➢ Blackwell

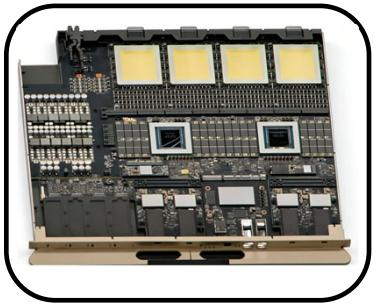


➢ Vera Rubin



■ A real density Requirements of Power Module





VR300

Power:16kW

Size:2*57.9mm*36.8mm*10.8mm

Power Density:3kW/in³

State-of-the-art 48-12V Regulated Buck

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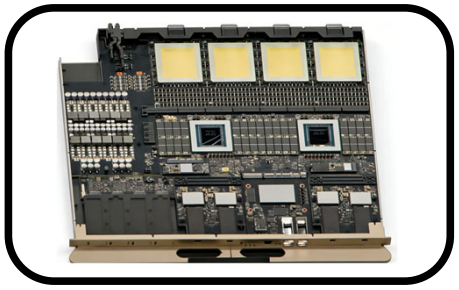
■ **Next-Generation Power Density Needs**

➢ **VR300**

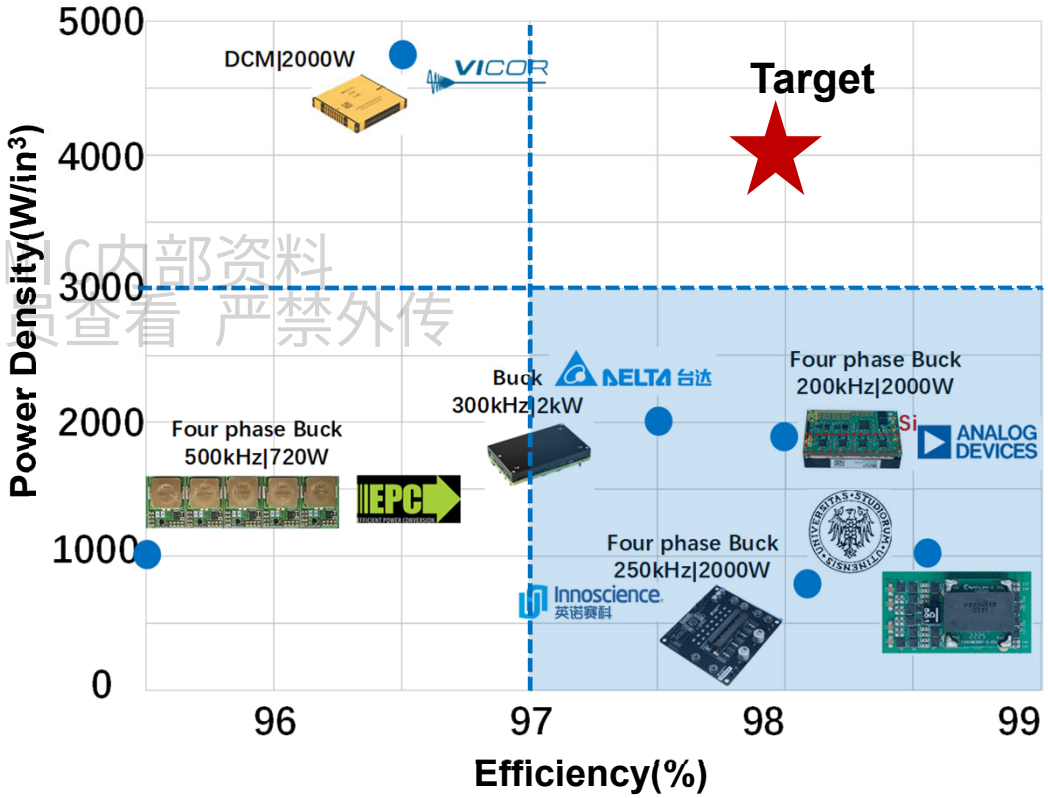


Power:16kW

Size:4*57.9mm*36.8mm*10.8mm

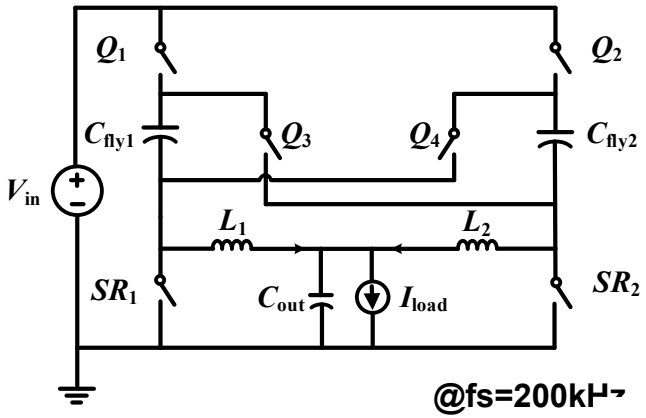
Power Density:3kW/in³

■ **The State of the Art**

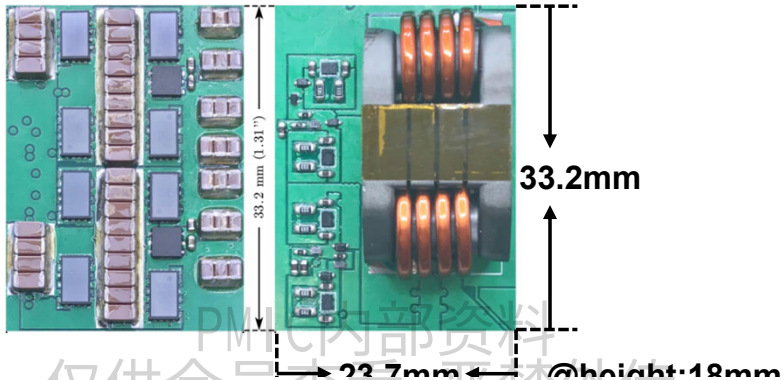


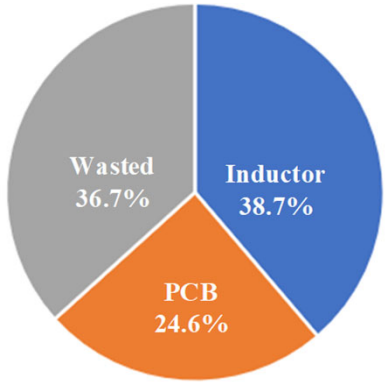
Why Power Density Requirements are Not Met

■ **Case1:Symmetric Series-Capacitor Buck**



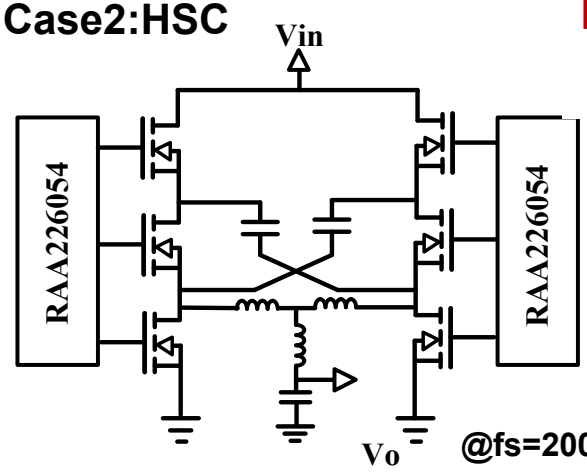
@fs=200kH





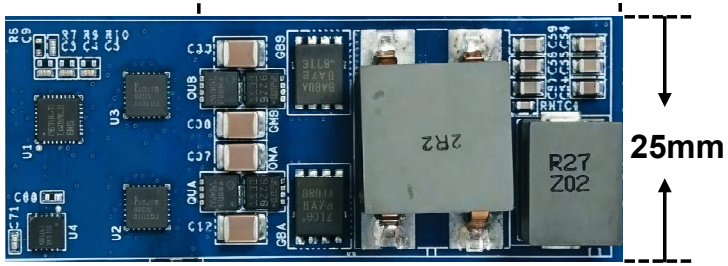
@Power density:1.11kW/in³

■ **Case2:HSC**

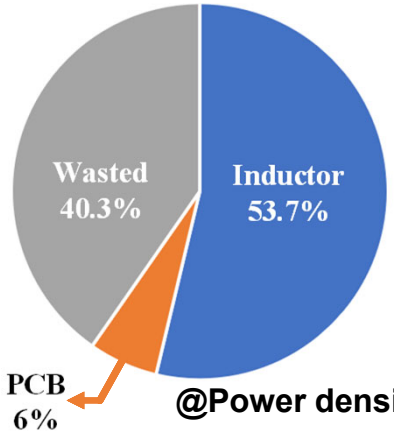


@fs=200kHz

Low switching Frequency for Buck Converters!



@height:about 14mm



@Power density:780W/in³

X. Xu and Q. Li, "Symmetric Series-Capacitor Buck in 48V-to-12V Regulated Conversion for High-Performance Server Boards," 2024 IEEE Energy Conversion Congress and Exposition (ECCE), Phoenix, AZ, USA, 2024

Conclusions

- Higher Power Rack needed higher density AC/DC power shelves and modules.
- Sidecar HVDC can integrate PSA, while SST derived HVDC needs additional PSA for AL loads.
- For Mega-watt Server Rack, the HVDC power conversion needs Ultra-high density DC/DC power modules.
- For low voltage onboard DC/DC, higher power XPU needs IVR and vertical power modules.

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AOHAI 奥海科技 | 爱科赛博 ACTIONPOWER | FOX ESS 麦田能源 | 航嘉 Huntkey | ZTE中兴
Great Wall 长城电源 | HAWUN 皓文电子 | Anker Innovations | Salcomp | flex
金升阳 MORNSUN | 军陶电源 | LITEON | EVTECH 富特科技 | CukTech
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高斯宝电气 Gospower | ATMOCE | 升宇科技 | 航域卓越 PROTIONIC | APLUSPOWER

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