Advancing Power Distribution in Data Centers Through Solid-State Transformer (SST) Technology

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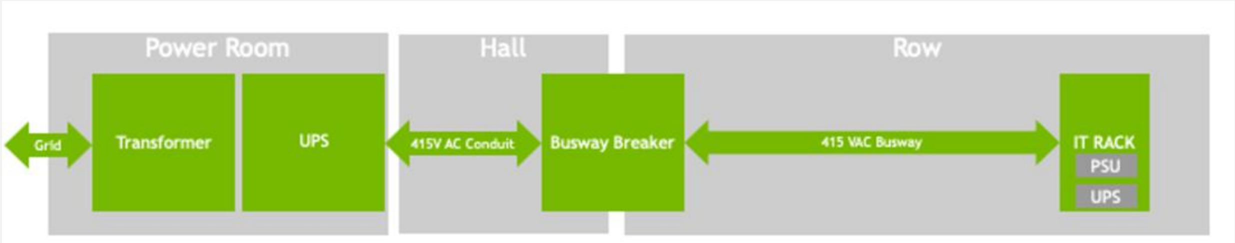
Motivation for 800V DC Distribution in Data Centers



Current datacenter architecture [1]

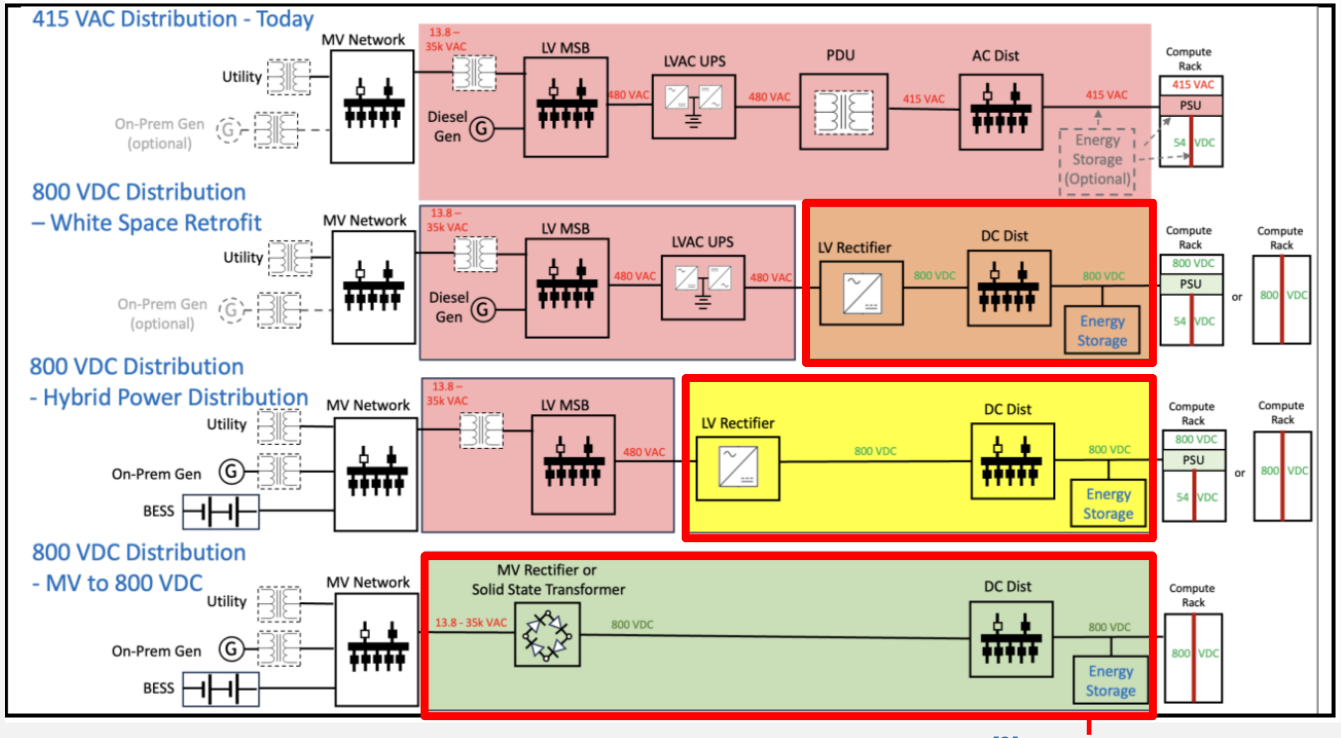
NVIDIA 800 VDC architecture minimizes energy conversions [1]

Metric	NVIDIA GB300 NVL72	NVL576 Rubin Ultra (Rubin Ultra NVL576)
Generation / Architecture	Blackwell Ultra (GB300)	Rubin Ultra (next-gen)
Number of GPUs per Rack	**72 Blackwell** Ultra GPUs	Up **to 576 Rubin Ultra** GPUs
CPU / Accompanying Processors	36 Grace CPUs (Arm)	Vera CPU (88-core custom Arm)
Power Consumption	~**120.8 kW**) per rack Supermicro spec: 132 kW (8 × 1U 33 kW PSUs)	~**600 kW** per rack (liquid-cooled “Kyber” rack)
Voltage / Power Delivery	- Supports **208V / 60 Hz**, **415V / 50–60 Hz**, **480V / 60 Hz**.	**800 VDC**
Performance (Speed Improvement)	“**1.5× more dense FP4 compute**” over prior architectures.	**~14× the performance** (FP4 inference) compared to GB300 NVL72.

[1] https://developer.nvidia.com/blog/nvidia-800-v-hvdc-architecture-will-power-the-next-generation-of-ai-factories/ [2] https://developer.nvidia.com/blog/building-the-800-vdc-ecosystem-for-efficient-scalable-ai-factories/

Progression of DC Distribution Development

- **Scalable:** 100 kW–1 MW+ racks on same backbone
- **Efficient:** Up to **5% better** than 54 V
- **Less Copper:** Lower current → less copper & heat
- **Reliable:** Centralized conversion reduces PSU failures
- **Cooler Racks:** Frees space, lowers thermal stress
- **Future-Proof:** Supports 1 MW+ next-gen racks

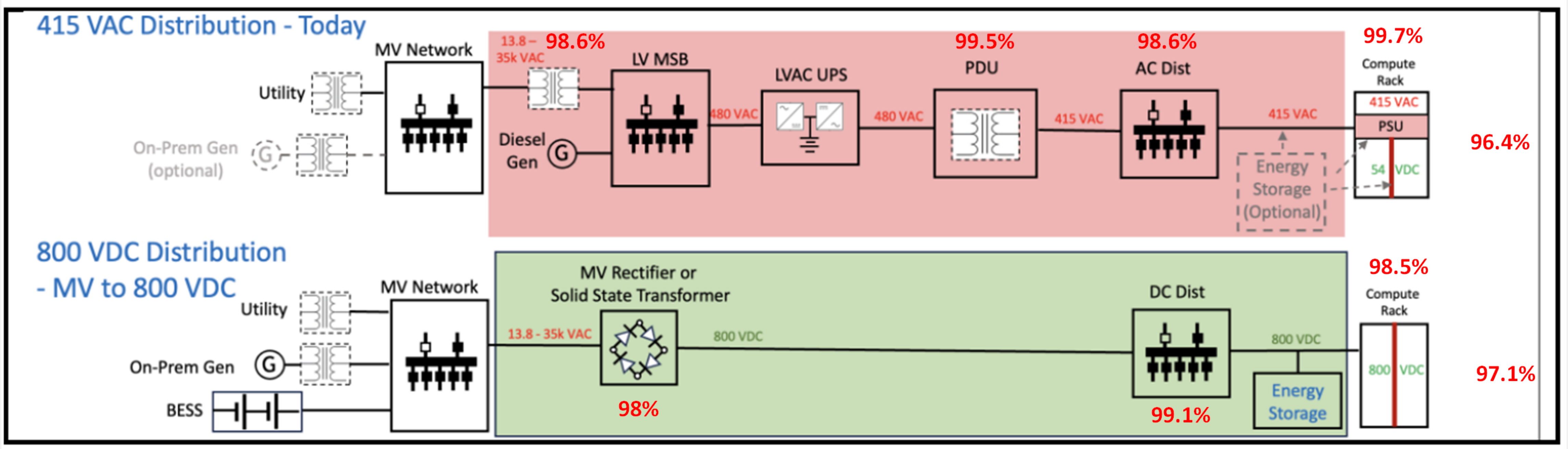


Proposed datacenter architecture evolution – NVIDIA[3]

Power electronics

[3] J. Huntington & M. Tu, "800 VDC Architecture for Next-Generation AI Infrastructure", https://nvdam.nvidia.com/assets/share/asset/zlg5snufeo

SST Based Datacenter Architecture Efficiency comparisons

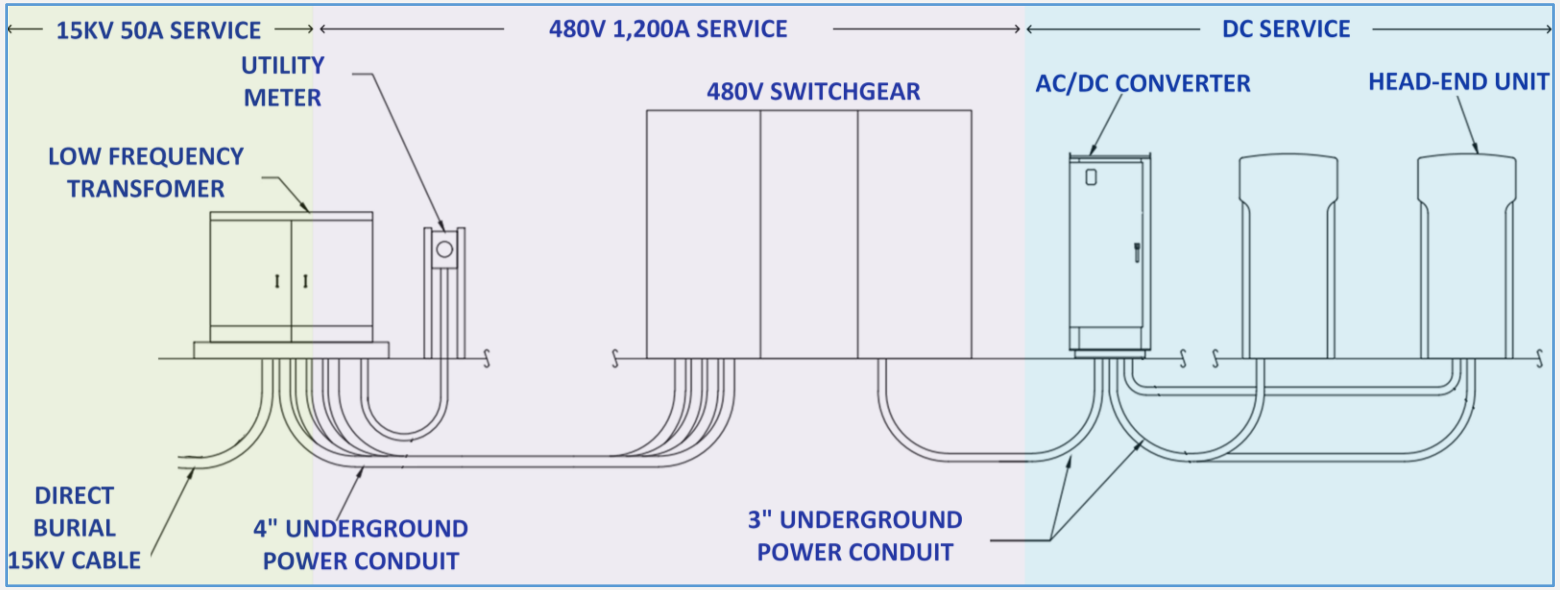


SST Parallel with EV charging Applications

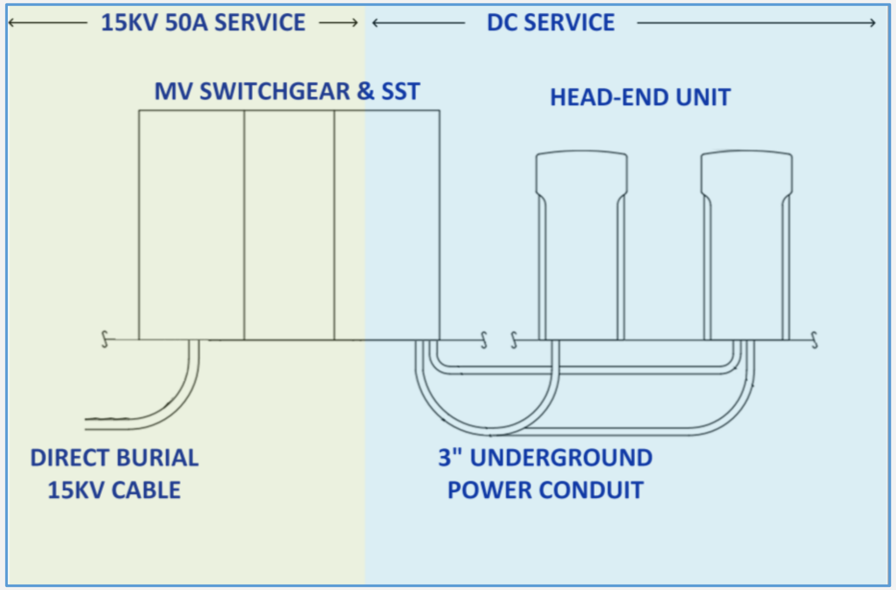
Smaller System Footprint and Higher Efficiency at Lower System-Level Cost

Power:	720 kW	40% more power	1,000 kW
Volume:	12,910 L	2x volume reduction	6,000 L
Mass:	13,000 lb.	3x mass reduction	4,000 lb.
Efficiency:	92%	2x loss reduction	96%
Concrete pad:	177 sq. ft.	2.5x footprint reduction	75 sq. ft.

SST leads to Lower installation costs



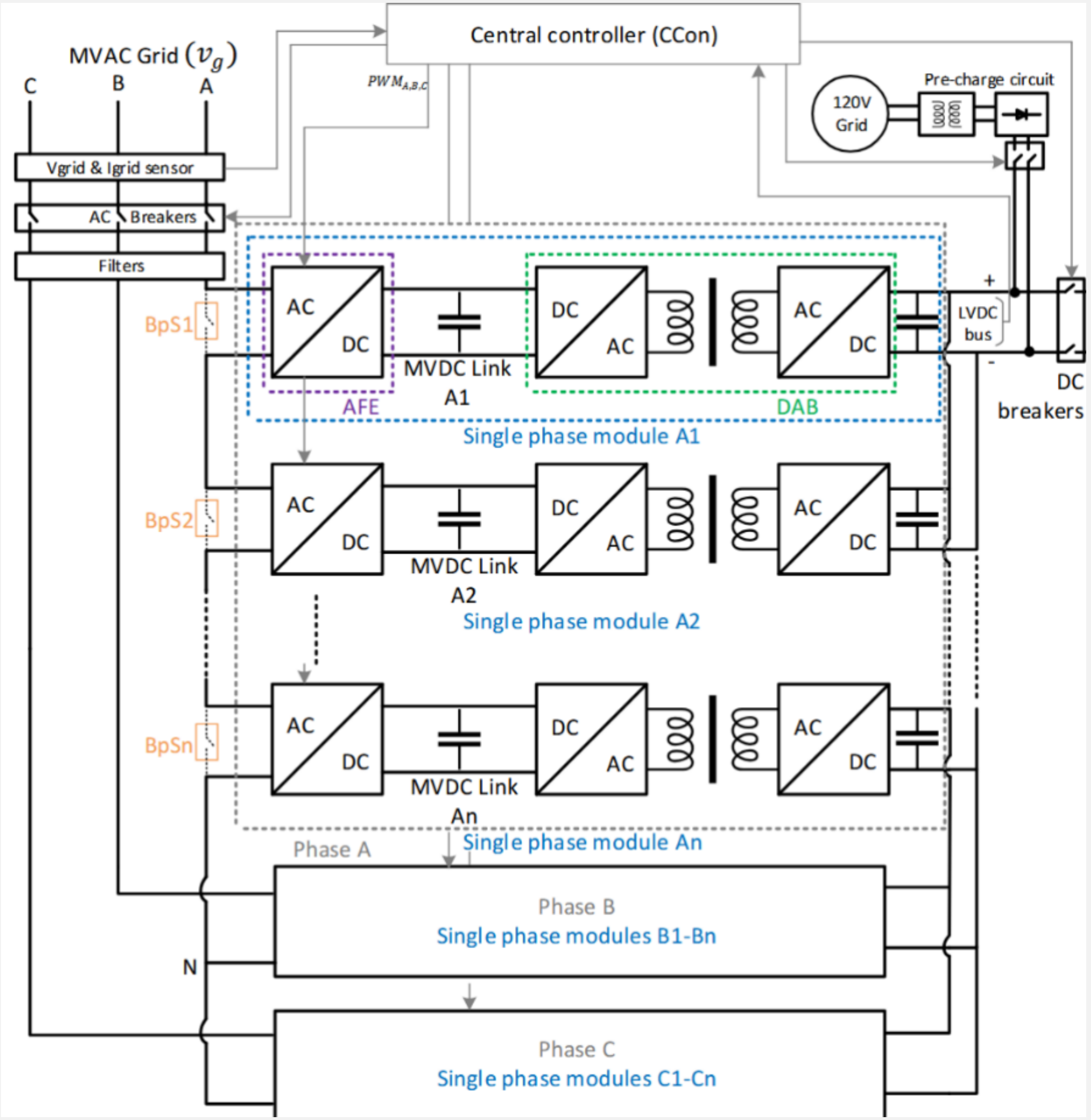
Conventional Installation



Medium Voltage Installation

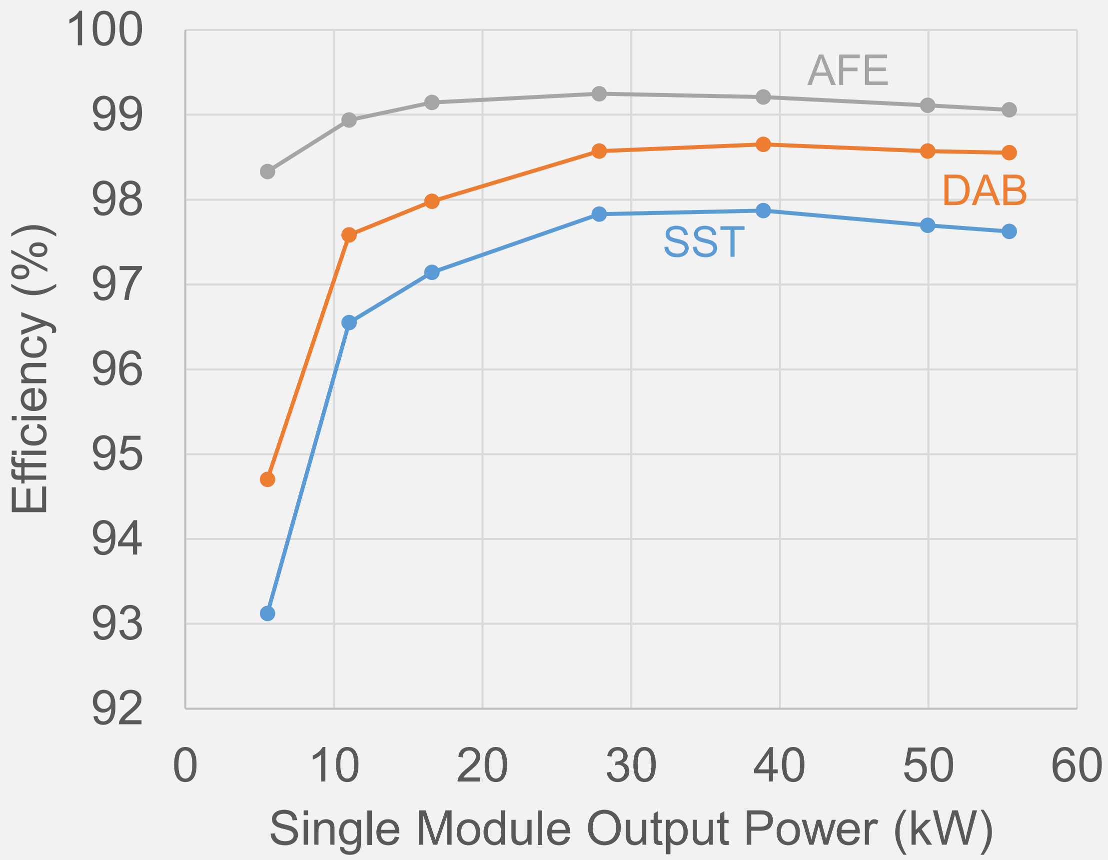
SST Architecture

- The SST connects to three-phase $13.2kV_{LL}$ input and delivers 750V DC
- A total of 18 modules are arranged in 6 levels using input-series output-parallel configuration
- Each module consists of an active front end (AFE) and dual-active-bridge (DAB) isolated DC-DC stage



SST Efficiency

- High efficiency in line with an active front end.
- Reported efficiency up to 98.6% by Delta; higher in academic publications
- Advantages at light load compared to LFT+AFE

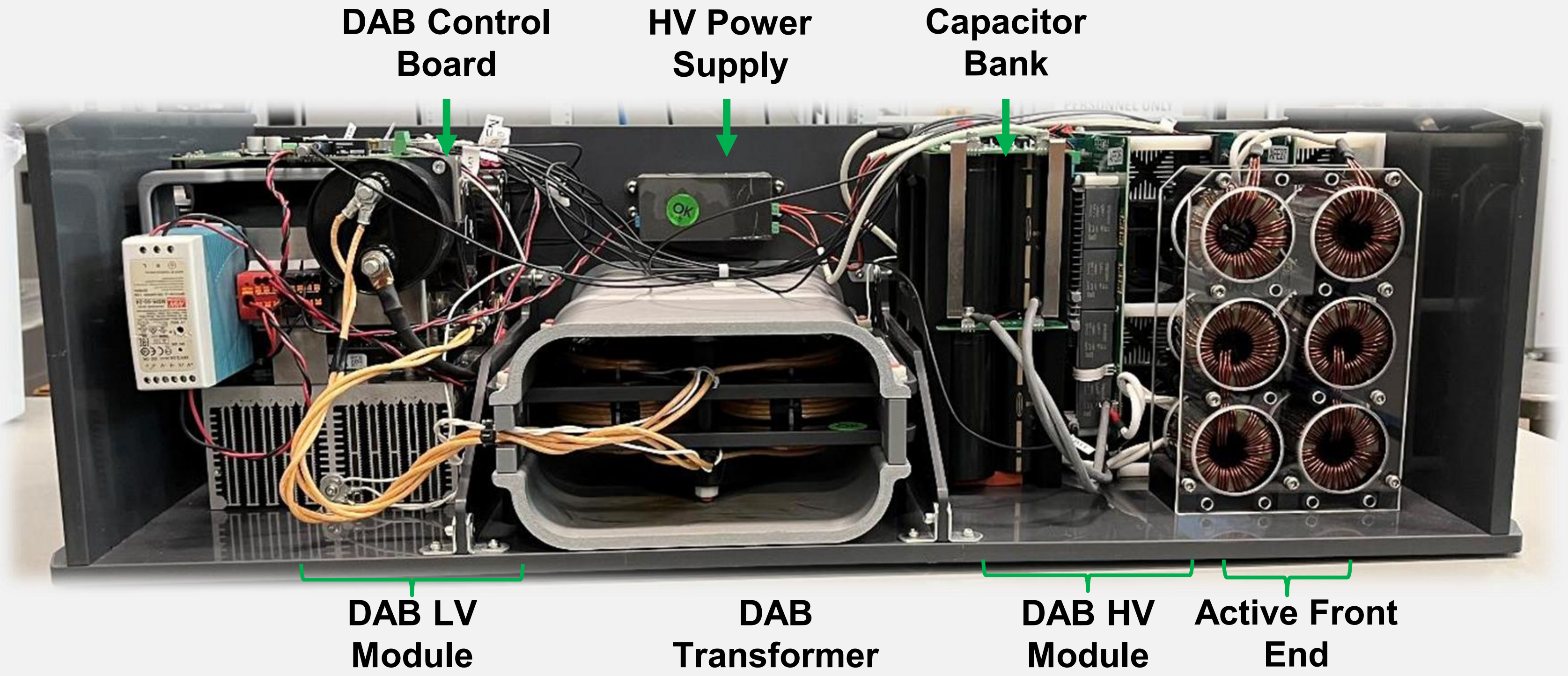


AFE - Active Front End

DAB - Dual Active Bridge isolated DC/DC converter

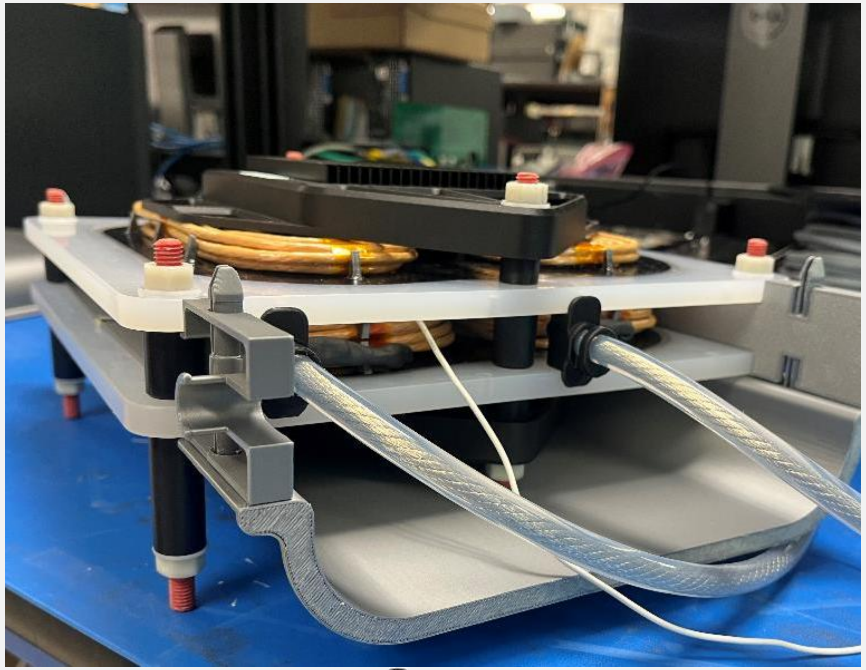
SST – Solid State Transformer (DAB+AFE)

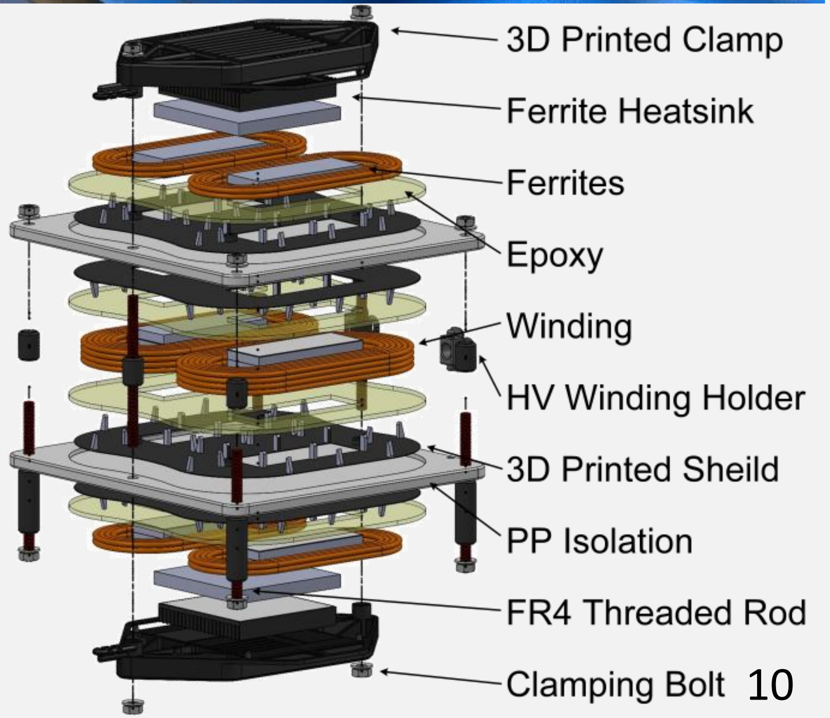
NCSU Design


DAB Control Board
HV Power Supply
Capacitor Bank
DAB LV Module
DAB Transformer
DAB HV Module
Active Front End

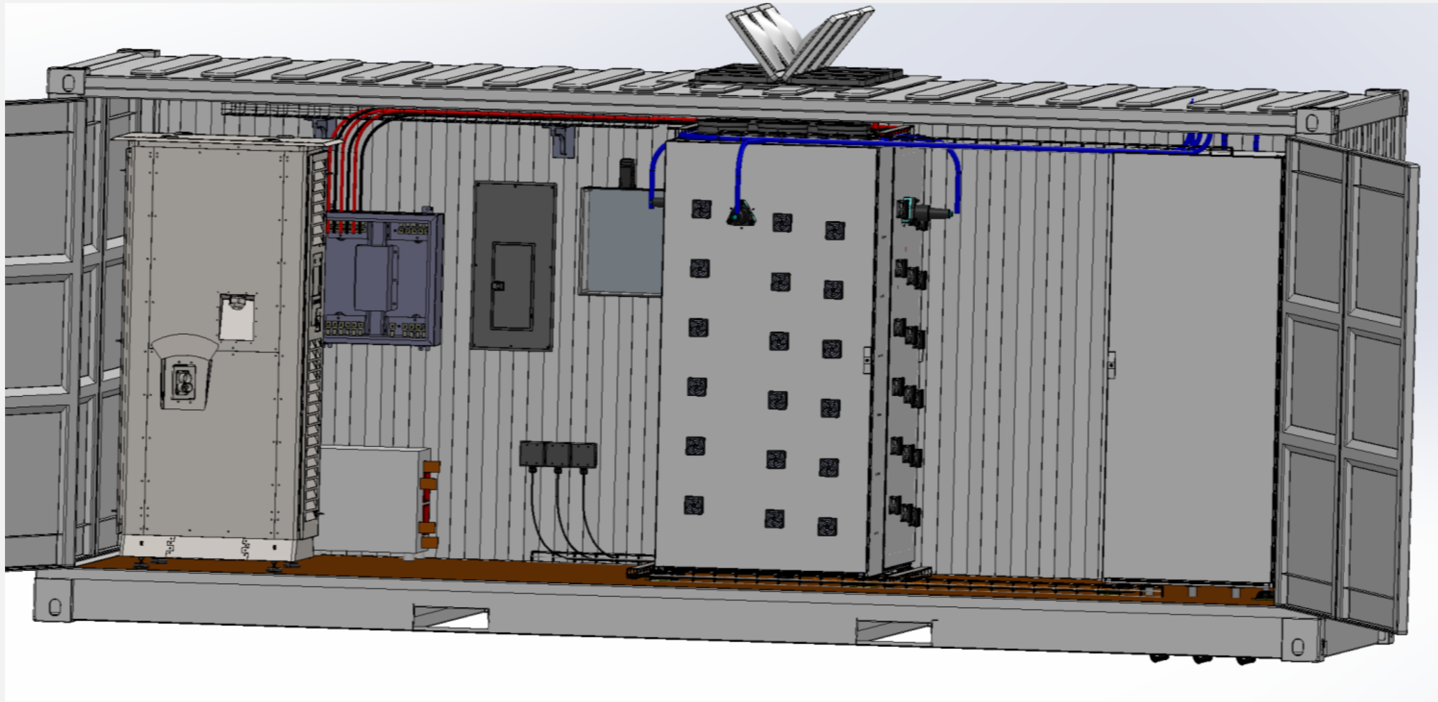
Transformer Design Challenges

- **Dual insulation stress:** HF switching dv/dt + LF high voltage increases insulation and PD stress. HF repetitive stress accelerates insulation aging.
- **High parasitic capacitance:** Leads to large common-mode currents and EMI challenges.
- **Thermal hotspots:** HF operation increases winding/core losses; difficult to cool in compact designs.
- **Core material limits:** HF-capable materials (ferrite, nanocrystalline) have lower flux density and higher cost.
- **Leakage inductance vs. capacitance trade-off:** Hard to optimize isolation, leakage, capacitance, and thermal paths simultaneously.
- **Manufacturing complexity:** Requires precision winding, shielding, and advanced insulation systems.

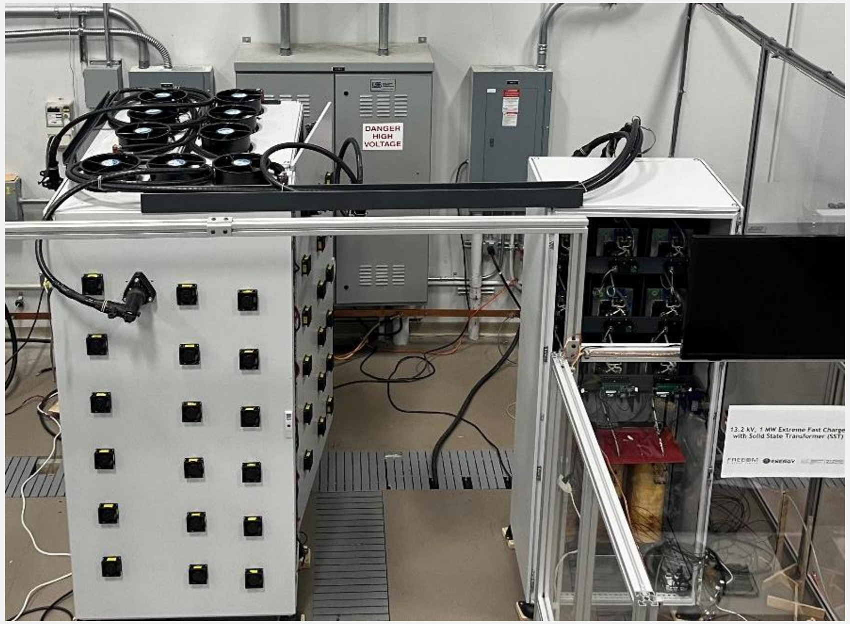




System Design



- Lightning protection
- MV breaker: solid state or fast mechanical
- Chokes; CM and Differential
- Liquid Cooling
- DC side protection: solid state or mechanical



Opportunities and Challenges

- Higher Efficiency & Improved Power Density
  - High efficiency even at partial load operating points.
  - Lightweight, compact, containerized.
- Modular & Scalable Infrastructure
  - Supports easy parallelization and N+1 redundancy.
  - Enables incremental and flexible capacity expansion.
- Seamless DER/BESS Integration
  - Native DC coupling for solar PV, BESS, and fuel cells.
  - Bidirectional converters enable grid services.
  - Simplifies DC microgrid integration.

- Technology Maturity & Reliability Concerns
  - SSTs still a new technology
  - Limited long-term field data in large MW-scale deployments
  - Large part count leads to complexity lower reliability
- High Initial Capital Expenditures
  - High BOM cost; potential supply chain issues
  - Retrofit projects may face economic barriers
- Interoperability & Standardization Gaps
  - Limited compatibility with legacy AC infrastructure
  - Standards are still in development
  - Limited experience from power systems experts
  - Requires power-electronics expertise, not transformer technicians for maintenance