Meeting AI Power Density at Scale: Superconducting Distribution for Multi-MW Data Halls

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Abstract— **We propose a novel superconducting power distribution architecture designed to meet the extreme rack-scale demands of AI infrastructure. Using high-temperature superconducting (HTS) busbars, the system delivers multi-megawatt power at 800 V DC with near-zero losses—achieving over 10× the current density of copper in 1/5th the space. It eliminates medium-voltage layers, enabling direct, lossless power from utility AC to AI racks exceeding 1 MW. Fully compatible with OCP's 800 V standards, cryogenic tap-off modules provide seamless rack integration. Backed by proven HTS deployments in grid and industrial systems, this architecture transforms power delivery from a constraint into a scalable, open foundation for the AI era.**

I. MOTIVATION AND SCALING LIMITS

Modern AI-scale compute racks are now exceeding 1 MW, stressing copper-based power delivery systems. Even with the shift to 800 V DC, 1 MW per rack still demands ~1250 A, requiring bulky copper busways, parallel feeds, and incurring significant resistive losses and heat. This is approaching copper's physical and thermal limits at facility scale.

High-temperature superconductors (HTS), such as REBCO tapes, conduct DC with near-zero resistance below ~80 K and support >10× current density of copper. Proven in grid and industrial settings with current levels up to 200 kA, HTS enables compact, lossless transmission. This paper proposes an 800 V HTS busbar architecture to overcome copper's limitations and support scalable, high-efficiency power distribution for future data centers [1][2] [3][4],

II. HTS-BASED 800 V ARCHITECTURE OVERVIEW

Utility power is rectified from medium-voltage AC to 800 V DC at the facility level. Superconducting busbars then distribute power directly to racks, eliminating intermediate voltage stages and minimizing losses and footprint.

Superconducting Busbars: HTS conductors in vacuum-insulated cryostats (~20–30 cm) carry 5–50 MW per circuit without resistive loss. Commercial HTS cables (5–8 cm) handle tens of kiloamps at 800 V and can be routed overhead or underfloor in radial or loop topologies, with no voltage drop. Demonstrations show 3 MW delivery at 10× copper power density in 1/20th the space.

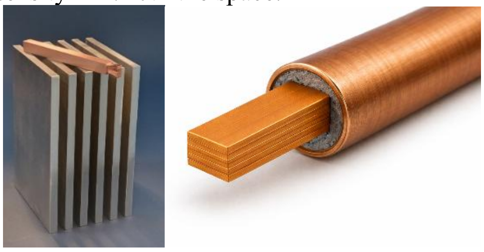

Fig. 1: HTS composite conductor atop a 20 kA aluminum busbar (left) and visualized cross-section (right).

Cryogenic Cooling: Liquid nitrogen cooling maintains operating temperature at 65–77 K. With no resistive heating, thermal load is limited to cryostat leakage (~few W/m). Cooling energy use is ~10% of equivalent copper I²R losses. The system is sealed, inert, and integrates cleanly with facility cooling design.

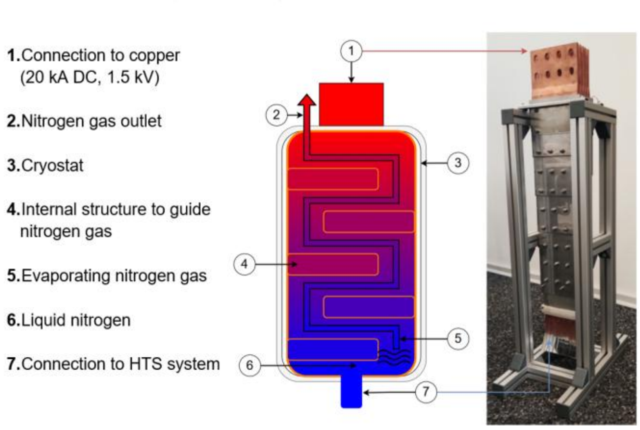

Fig. 2. The image shows a real-world 20 kA, 1.5 kV HTS current lead assembly, transferring power from copper to superconductors with liquid nitrogen cooling at 77 K.

Tap-Off Interfaces: Cryostat termination boxes use current leads to interface HTS conductors with 800 V DC power shelves, minimizing thermal ingress into the cryogenic system [6]. They support rack or sidecar termination and can be designed to match OCP form factors for modular integration, hot-swapping, and per-rack electrical isolation.

III. Performance Advantages Over Copper Systems:

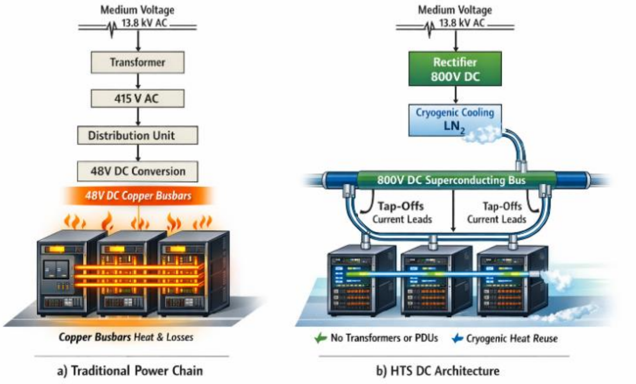

Fig. 3. Comparison of conventional multi-stage copper distribution (a) and proposed 800 V HTS-based architecture (b), highlighting elimination of intermediate conversions, reduced thermal losses, and direct rack-level delivery.

Efficiency and Thermal Performance:
HTS eliminates resistive losses in distribution, with cooling overhead <10% of copper I^2R losses. No in-room heat is generated; thermal load is shifted to external cryogenic systems, reducing HVAC demand. LN_2 absorbs transient thermal spikes, improving system response under fluctuating loads. Fewer conversion stages further increase end-to-end efficiency.

Current Density and Deployment Scalability: HTS cables deliver 5–10× higher current per cross-section than copper, enabling compact routing of multi-megawatt power. This supports high-density EDPP layouts and simplifies row or pod-level delivery at 800 V DC. Demonstrated systems show 3 MW+ delivery in 1/20th the copper footprint, easing physical integration and structural overhead.

Stability, Protection, and Safety: Low-impedance HTS links maintain voltage stability during load swings. Quench response provides intrinsic current limiting. Combined with superconducting fault current limiters, fast fault isolation is achievable. Cryostats offer shielding and touch-safe containment, while LN_2 reduces fire and arc risk. Standard tap-offs maintain compatibility with OCP 800 V rack inputs.

Parameter	Conventional Copper	HTS-Based System
Amperage Capacity	5–10 kA per conduit	≥100 kA per conduit
Distribution Losses	High (resistive+ conversion)	Near-zero (cooling overhead <10%)
Cable Footprint	Large (multi-duct systems)	Compact (cryostat pipes)
System Mass (50 MW)	1,200 kg/m (incl. supports)	125 kg/m (incl. supports)
EDPP Capability	Limited by conductor scaling	Direct, high-current delivery across long distances

Table I. Comparative summary of key performance parameters for a single line, highlighting the advantages of HTS-based 800 V distribution over conventional copper systems in capacity, efficiency, footprint, and EDPP scalability.

IV. Feasibility and Early Deployment

Superconducting power systems have been validated across grid, industrial, and scientific sectors. Urban medium voltage HTS cable deployments have achieved >99% uptime, while an industrial pilot in an aluminum smelter delivered 200 kA with LN_2-cooled busbars. Scientific facilities, such as CERN, routinely operate HTS, replacing LTS (low temperature superconductors) as a more technically viable and economical solution.

In data centers, prototypes have demonstrated 3 MW HTS delivery, with which full-scale 55 MW HTS-based designs have been developed. All key components are readily available, enabling incremental deployment starting with single-rack feeds as power needs exceed 500 kW.

V. Integration with OCP requirements & Open Architecture

The HTS architecture aligns with OCP's 800 V rack standards by delivering power through compliant busbar interfaces, enabling interoperability without modifying IT equipment. Tap-offs output 800 V DC via standard connectors, treating the HTS system as a high-capacity feeder behind the rack interface. Protection elements—overcurrent, grounding, and fault detection—match existing DC practices, with superconducting fault current limiters (SFCLs) improving isolation. HTS modules are scalable: each cable loop (e.g., 10 MW capacity) includes defined tap-off points and coolant ports, supporting modular deployment and multi-vendor compatibility. Maintenance is supported through redundant cryocoolers and integrated monitoring of temperature, pressure, and vacuum. Physical compliance with OCP rack power spacing (e.g., ORv3 rear interfaces) allows phased adoption alongside copper, with minimal impact on rack design. Standardizing dimensions and connectors for cryogenic tap-offs and feed modules would enable drop-in integration, ensuring the HTS system remains open and vendor-neutral.

VI. CONCLUSION

High-temperature superconducting (HTS) power distribution enables lossless, high-current delivery at 800 V DC—meeting the rising demands of AI-scale data centers while reducing weight, heat, and system complexity. Proven in grid and industrial use, HTS offers >10× the capacity of copper in a fraction of the footprint, eliminating the need for intermediate conversions. With all core technologies commercially available, the primary challenge is system integration, not feasibility. Aligning HTS with OCP's modular standards allows seamless rack-level interoperability and scalable deployment. As rack power densities exceed 500 kW, superconducting distribution offers a technically superior, future-ready solution to data center power delivery.

VII. Acknowledgment

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