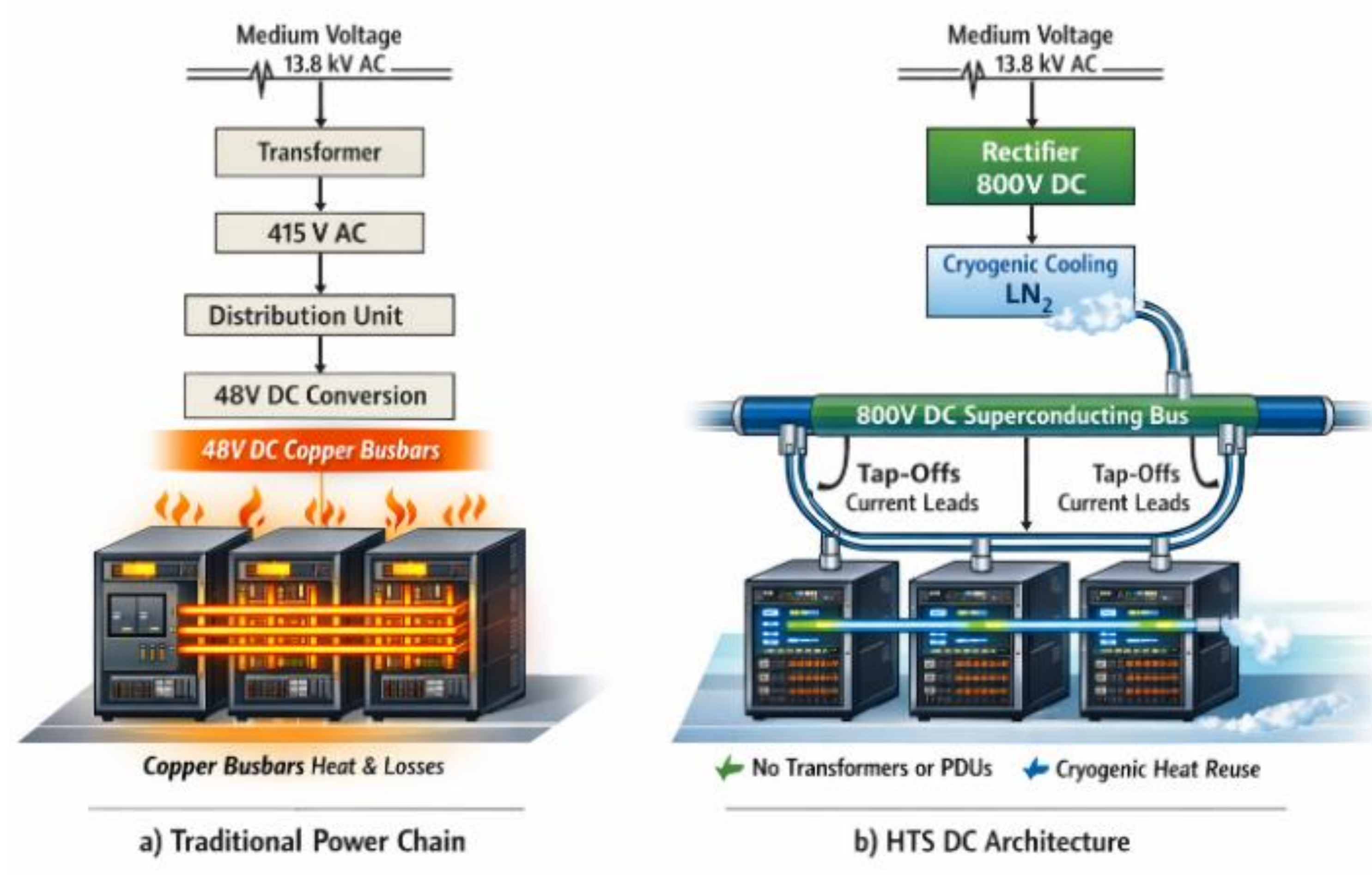
Meeting AI Power Density at Scale: Superconducting Distribution for Multi-MW Data Halls

Authors: Shrikanth Venkateshappa – Rittal GmbH & Co. KG, Herborn, Germany | venkateshappa.s@rittal.de
Peter Abrell – Vision Electric Super Conductors GmbH | abrell@vesc-superbar.de

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.



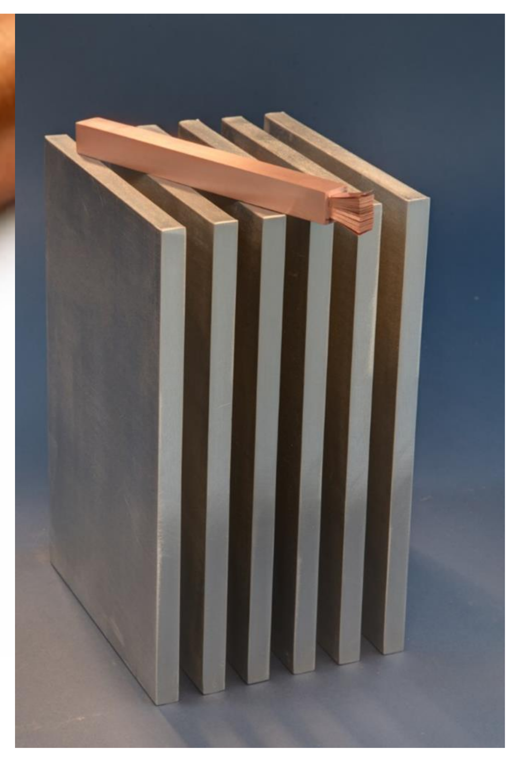
Motivation and Scaling Limits

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 ~1,250 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.

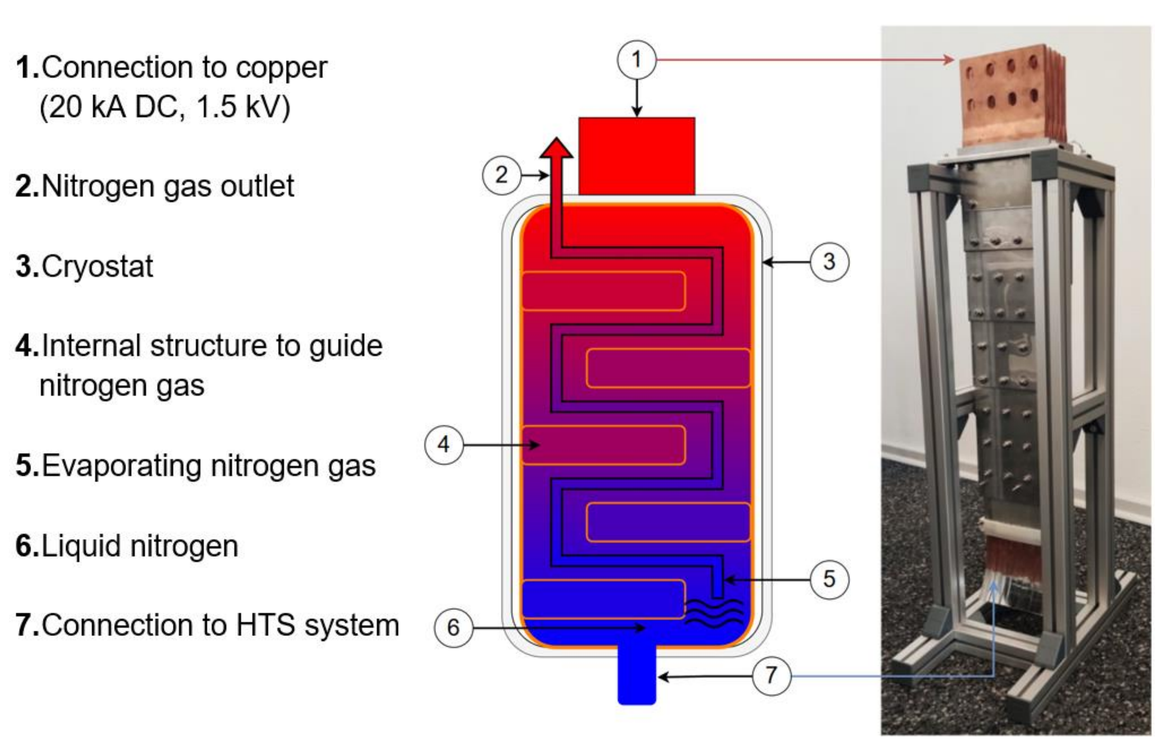
Possible solution: HTS-Based 800 V Architecture Overview

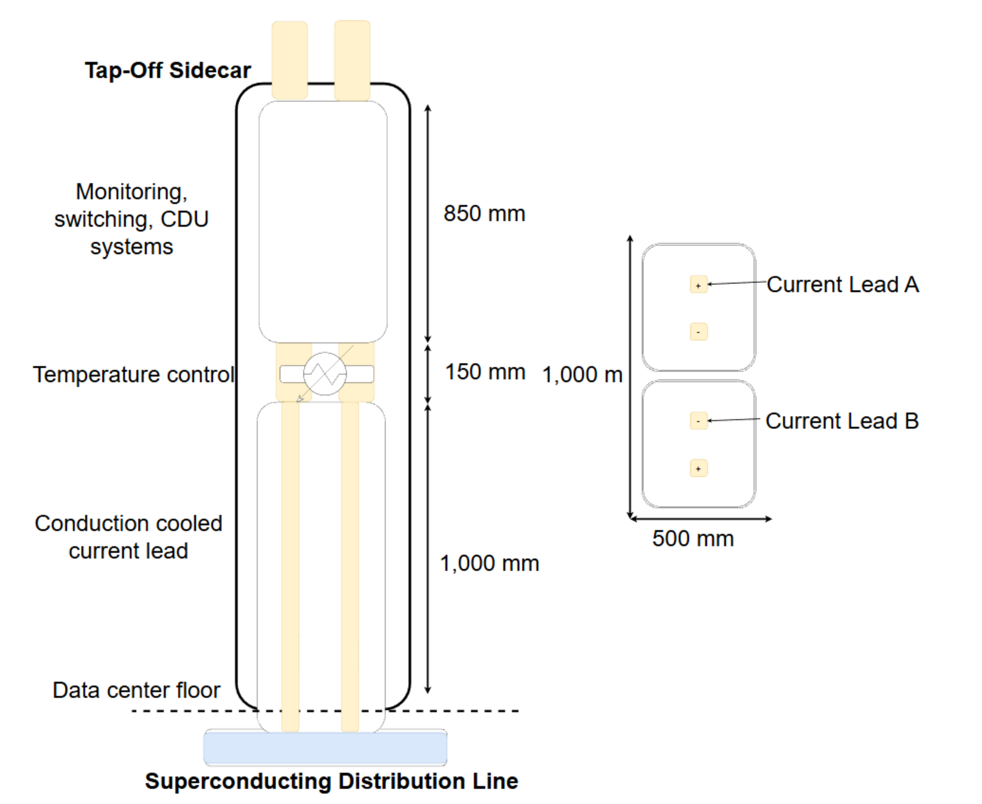
High-temperature superconductors (HTS), such as REBCO tapes, conduct DC with near-zero resistance below ~80 K and support >10× current density of copper. Proven in grid and industrial settings with current levels up to 200 kA, **HTS enables compact, lossless transmission**. The paper proposes an 800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

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.



Innovative, Efficient, Gas-Cooled Current Lead





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.

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.

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. 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.

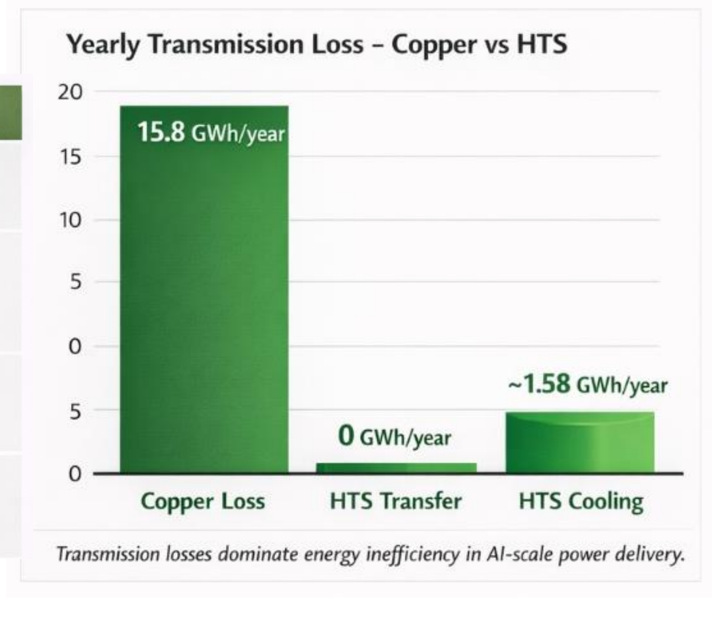
Efficiency and Thermal Performance

HTS eliminates resistive losses in distribution, with cooling overhead **<10% of copper I²R losses** for transmission lengths above 200 m. 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.

	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)



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.

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