Scaled: Substation in a cable for adaptable low-cost electrical distribution

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September 12, 2025

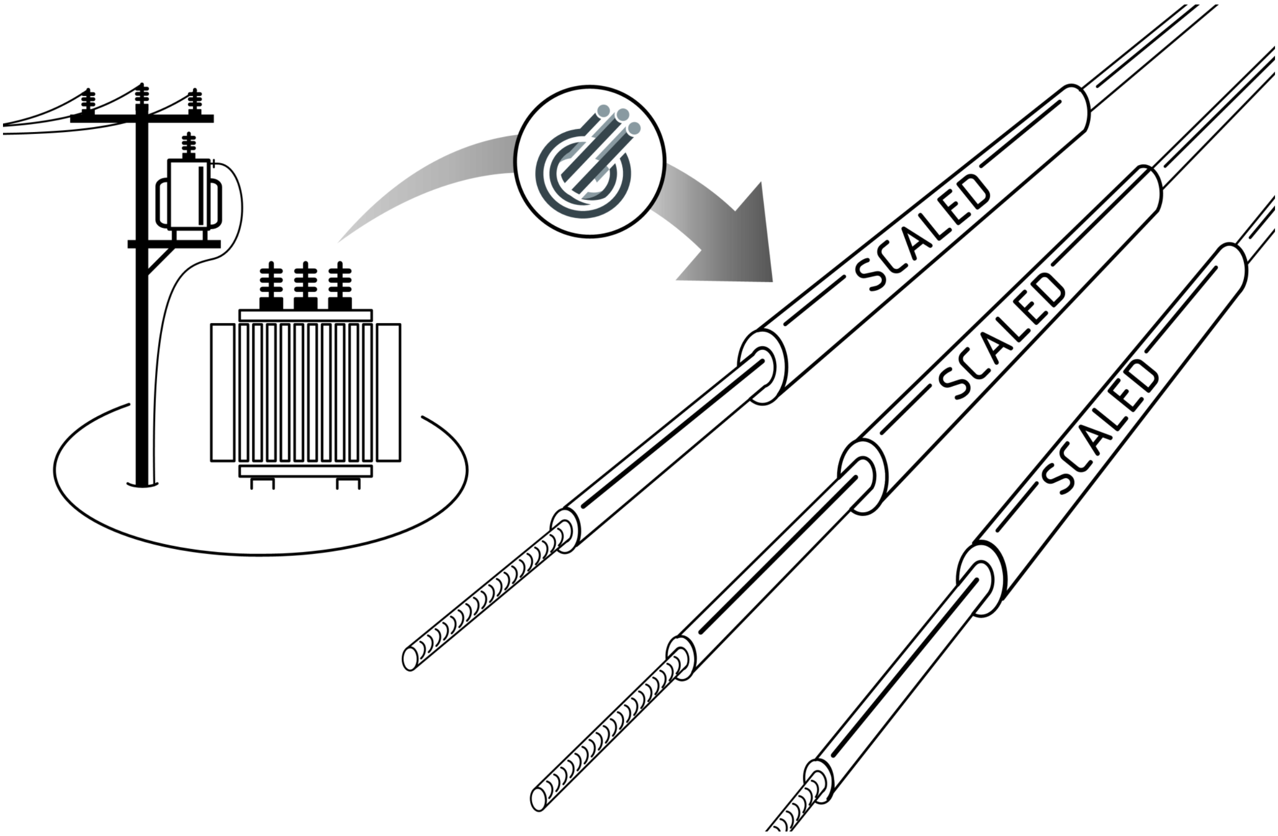


Figure 1: Cable-integrated, inline power electronics conversion cells as a replacement for bulky distribution infrastructure.

Modern power electronics meets medium voltage cables to create a high-density inline power conversion system for the grid of tomorrow

Global electricity networks face a mounting dual challenge: increased demand and higher risk. Rapid electrification, the accelerated rollout of renewables, and the surging energy appetite of data centers are all straining grid capacity. At the same time, climate change and geopolitical instability raise the stakes for security and resilience. Recent conflicts have highlighted the vulnerability of energy infrastructure during crises, while market volatility has underscored the urgency of building systems that can withstand disruptions. Together, these forces are driving unprecedented stress across transmission and distribution networks.

Meeting this demand requires more than just expanding the grid. It requires rethinking how it is built and deployed. Conventional transformers and switch gear face long lead times from international supply chains, compounded by long installation times. In population-dense urban environments, the zoning, permitting, and right-of-way acquisition extend the installation time by years, throttling the rate of expansion. Greater distribution also increases susceptibility: more assets in the field mean more points of failure, higher exposure to extreme weather, and greater system complexity. Power electronics are helping to ease these pressures by enabling smaller footprints, bi-directional power flow, hybrid AC/DC operation, and high-speed sensing. Yet even advanced technologies like solid-state transformers cannot fully overcome the scale and speed challenges the grid now faces.

Innovation lies in medium voltage cables

When considering the future of distribution technology, one of the most overlooked models may already be all around us: cables. Europe’s grid contains millions of kilometers of medium voltage distribution cable, engineered to last for decades with minimal maintenance while enduring harsh environments. Their design achieves extremely high-power density through solid insulation and coaxial geometry, and they are produced using continuous formative manufacturing processes, where raw materials enter one side of a factory and a finished, ready-to-install product exits the other. This streamlined process stands in sharp contrast to the bespoke, batch-oriented manufacturing of today’s high-power converters.

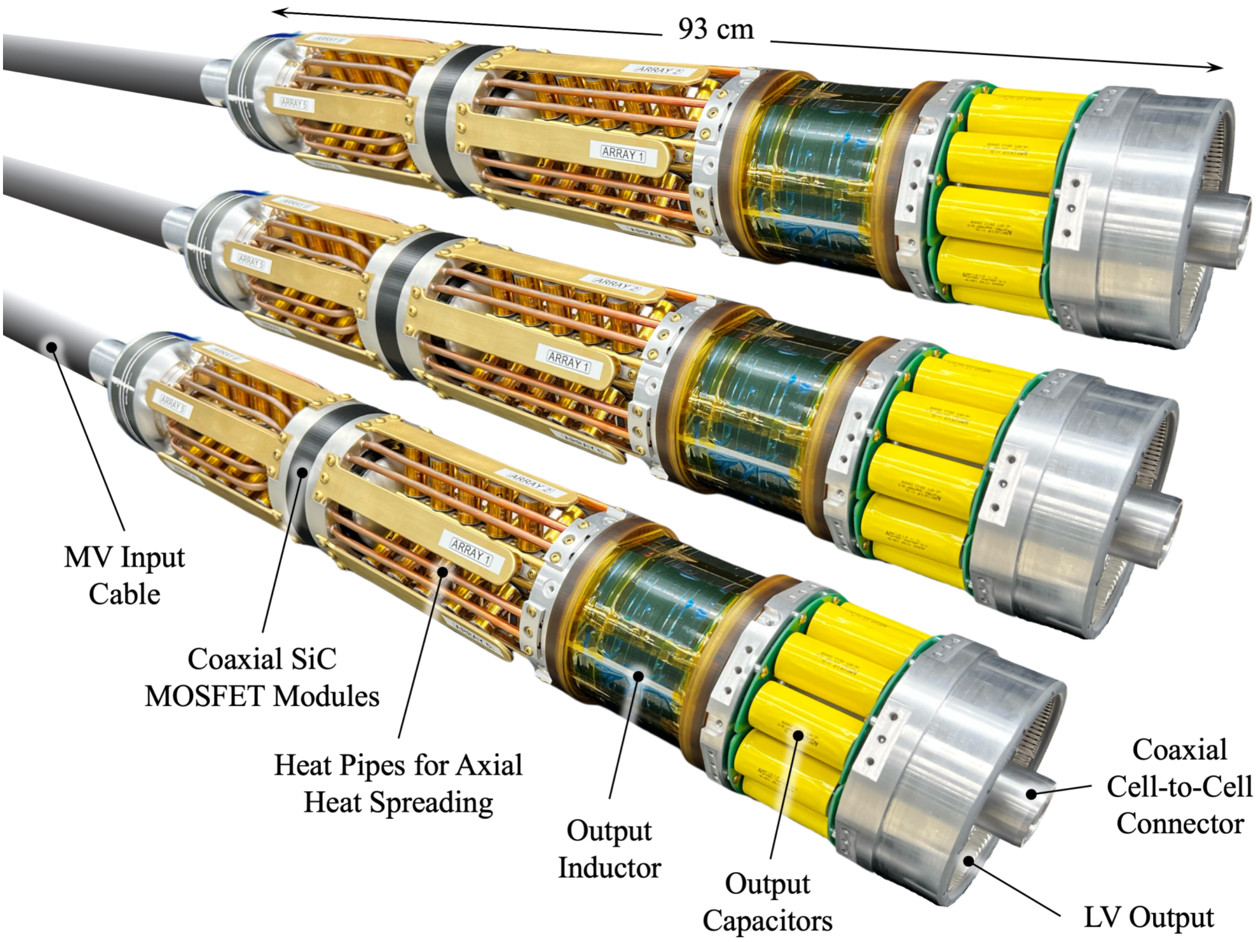
What if we could bring cable-like principles into grid equipment? Imagine power electronics built with the durability, density, and manufacturability of cables, produced at scale using continuous processes. Such an approach could significantly reduce costs while accelerating deployment by allowing utilities to further exploit existing cable rights-of-way for distribution equipment. Beyond density improvements, it opens the door to transformative concepts: inline power conversion for stepping voltage up or down inside the cable itself, inline power factor correction, and new opportunities for undergrounding distribution equipment. Rethinking power electronics through the lens of cable engineering may unlock the density and timelines needed for Europe’s future grid.

The future of distribution takes shape

At Virginia Tech’s Center for Power Electronics Systems (CPES) in Blacksburg, Virginia, US, researchers translated the ‘cable-like power electronics’ concept into reality. Supported by the US Department of Energy’s Advanced Research Projects Agency–Energy (ARPA-E), the team set out to design a cable-integrated power electronics converter that leverages the coaxial geometry and solid insulation inspired by medium voltage cables. The goal was to fundamentally reimagine how power electronics could be designed, manufactured, and deployed within distribution systems.

Traditional design begins with a converter topology, followed by component selection and then system integration. CPES flipped this sequence. By starting with the integration challenge and working within the tight radial constraints of a coaxial cable, the team identified both new opportunities and unique challenges. The resulting system is composed of cascaded coaxial conversion cells, enabling modular scaling: more cells allow higher power throughput and higher step-down ratios. Each element, including capacitors, inductors, and silicon carbide (SiC) MOSFET switch modules, was designed in a coaxial form to preserve the radial electric field of the cable from the medium voltage cable through the converter, and into the low-voltage output cable.

The CPES team has already demonstrated the concept with a full-scale laboratory prototype (Fig. 2). The coaxial conversion cells each process 2kV DC, stepping it down at a 5:1 ratio to 400 V DC, delivering 50kW per cell. Up to five cells can be cascaded to achieve an input voltage up to 10kV. Built with the latest 3.3kV SiC MOSFETs and operating with soft-switching at 100kHz, the system achieves over 98% efficiency. Heat is managed through an internal thermal bus network comprised of interconnected heat pipes, which distribute losses axially.



Electrical distribution reimagined

To accelerate real-world adoption, the team has spun out Scaled Power Solutions, a company dedicated to advancing commercialization. Current efforts are focused on identifying near-term market entry points and applications where power electronics functionality, combined with the density of the cable-integrated form factor, can deliver immediate value in building more flexible, resilient, and compact distribution infrastructure. Combining power transport and power conversion in a single structure marks a fundamental shift in the electrical distribution paradigm – the impact is limited only by our imagination.

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