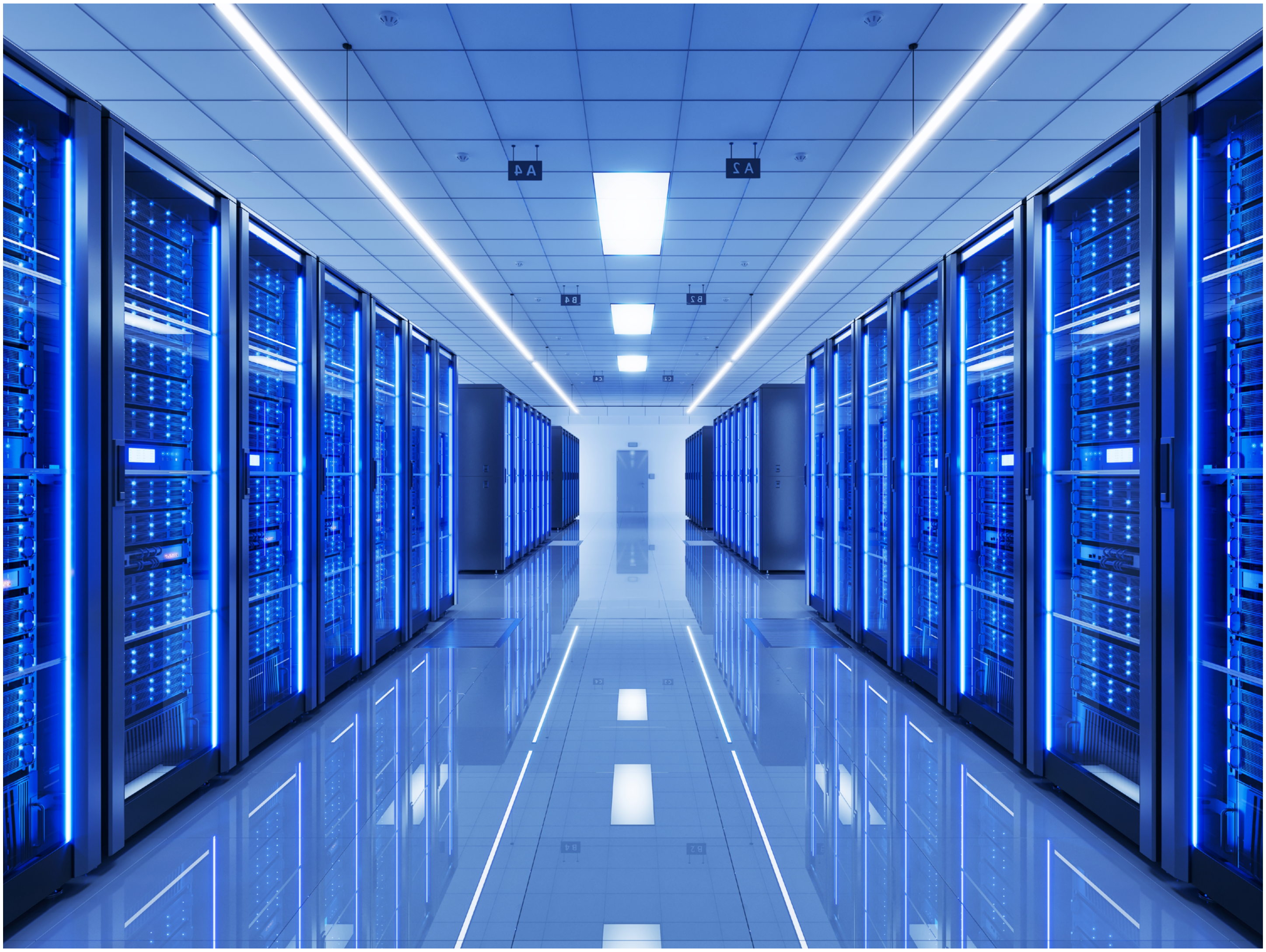
EVERY CONNECTION COUNTS

WHITE PAPER

HVDC: REDEFINING DATA CENTER PERFORMANCE AND SUSTAINABILITY

Explore the escalating data center power requirements, the advent of HVDC, and how TE is paving the way for some of next-gen designs



ABSTRACT

In an era of exponential data growth, data centers stand as the backbone of our digital infrastructure. However, their escalating power demands pose significant challenges to sustainability and environmental stewardship. This white paper delves into a groundbreaking solution: High Voltage Direct Current (HVDC) technology, which has the potential to revolutionize data center efficiency and reduce carbon footprints.

We begin by exploring the evolution of data centers and current market trends, setting the stage for understanding the pressing need for innovation in power management. The paper then introduces HVDC architecture, demystifying its complexities and presenting it in an a more accessible manner. This transformative technology offers superior efficiency compared to traditional AC-based systems, resulting in reduced strain on power grids and decreased environmental impact.

Beyond its eco-friendly benefits, HVDC systems boast enhanced reliability through simplified power conversion processes and improved heat management. As we navigate through the intricacies of this technology, we showcase a specific HVDC solution developed by TE Connectivity, highlighting its unique value proposition and potential to reshape the data center landscape.

This comprehensive exploration aims to equip industry professionals, decision-makers, and technology enthusiasts with the knowledge to embrace and implement HVDC solutions, paving the way for a more sustainable and efficient digital future.

Dual Rack Data Center
Separate power and server racks

Data Center Metrics

Projected Market Size: Synergy Research Group estimates that the total capacity of all operational hyperscale data centers will grow almost threefold by 2030.

Data Center Energy Consumption: According to the US Department of Energy, "data centers consumed about 4.4% of total U.S. electricity in 2023 and are expected to consume approximately 6.7 to 12% of total U.S. electricity by 2028." The unprecedented increase in AI applications is responsible for much of this surge, with no end in sight.

Rising Power Density: Power Racks are enclosures that house multiple server boards, with modern versions exhibiting power density of 20-50 kW racks becoming standard. Even with power train efficiencies of 98% and better, there is still a need for additional power that drives the need for direct liquid or precision air cooling to handle these increased power needs.

DATA CENTER MARKET TRENDS

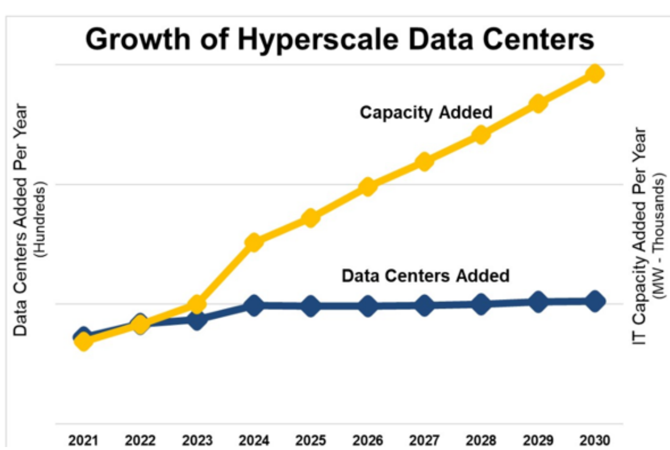
Explosive Growth in Data Traffic

The advent of the internet over three decades ago heralded a paradigm shift in software distribution and access. Industry pioneers swiftly recognized the economic advantages of centralized, online hosting for large-scale commercial software packages, facilitating more efficient user access. This realization gave birth to cloud computing and the modern data center concept.

The digital landscape has evolved rapidly, driven by transformative technologies. The Internet of Things (IoT) revolutionized machine-to-machine and human-machine communication, while the proliferation of e-commerce, social media, and online gaming reshaped consumer behavior. Cryptocurrency emergence further strained data infrastructure. Now, Artificial Intelligence (AI) presents unprecedented demands on data centers, pushing the boundaries of computational power and necessitating innovative solutions in data center design and operation. This technological convergence has dramatically intensified data center demands, catalyzing a new era of digital infrastructure.

Projected Market Size

Synergy Research Group estimates that the total capacity of all operational hyperscale data centers will grow almost threefold by 2030.



Explosive Energy Demand

- Data centers consumed 4.4% of U.S. electricity in 2023 (U.S. DOE), projected to reach 6.7–12% by 2028, driven by AI workloads.
- The total capacity of all operational hyperscale data centers is expected to grow threefold by 2030.

Power Grid Strain

- Data centers absorbed 4–5% of U.S. generating capacity (1,250 gigawatts in 2024), causing"power harmonics" that disrupt AC power quality within a 20-mile radius.
- Fluctuating data traffic creates variable energy demands, stressing aging grid infrastructure.

Rising Energy Consumption and Sustainability

- Carbon neutrality is critical to counter CO_2 emissions from hydrocarbon-based electricity, which contribute to global warming.
- Reducing energy consumption is essential, as data centers are no longer a minor energy consumer.

Increasing Power Density

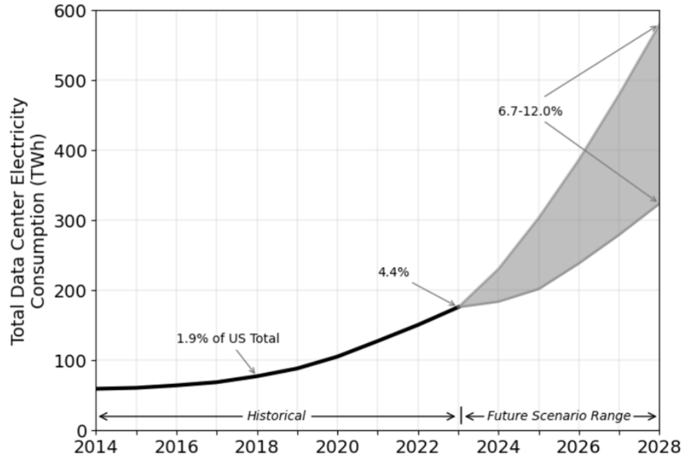
- Modern power racks operate at 20–50 kW, with AI-driven racks approaching 100 kW or more, requiring advanced cooling (e.g., liquid or precision air).
- Busbars, with lower resistance than cables, integrate with liquid cooling to manage heat, but demand is outpacing traditional designs.

Modularity and Scalability Needs

- Traditional 48V systems struggle with high-power racks (e.g., 450 pounds of copper wiring per rack, per Texas Instruments).
- Modular, plug-and-play expansion modules are vital for cost-effective scaling to meet growing data traffic.

Reliability as a Utility Standard

- Data centers, critical for e-commerce, IoT, and AI, must ensure zero downtime, akin to electric utilities.
- Reliable infrastructure supports social sustainability by reducing greenhouse gas emissions.



Total U.S. data center electricity use from 2014 through 2028

2024 United States Data Center Energy Usage Report

Arman Shehabi, Sarah J. Smith, Alex Hubbard, Alex Newkirk, Nuoa Lei, Md Abu,Bakar Siddik, Billie Holecek, Jonathan Koomey, Eric Masanet, and Dale Sartor

Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory, December 2024

DATA CENTER POWER ARCHITECTURES COMPARISON

Traditional AC Power Distribution Systems

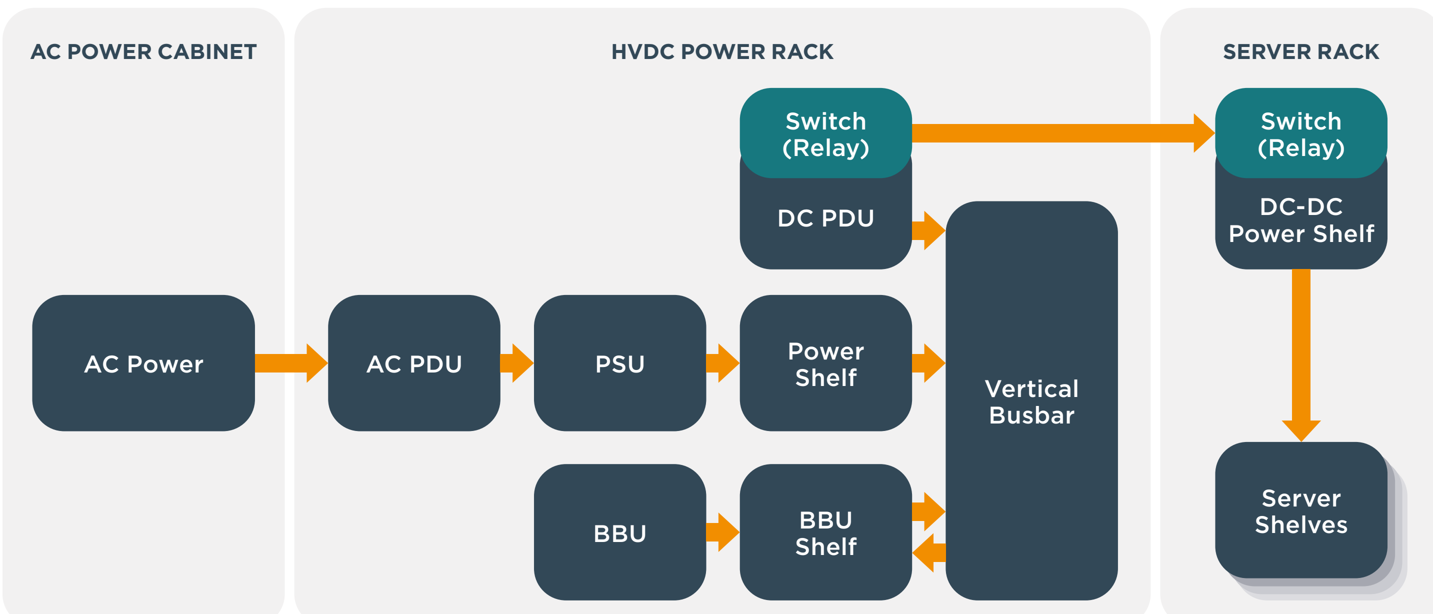
- Use panelboards and PDUs for AC distribution with multiple inefficient AC-to-DC conversions.
- Rely on bulky components and low-voltage AC, requiring thicker cables.
- Challenges: High power loss, heat, and complex renewable integration due to phase matching.

Hybrid AC-DC Systems

- Combine both AC and DC power paths, reducing conversion stages.
- Support both AC and DC inputs/outputs for a balanced approach.
- Challenges: Moderate efficiency (5-10%), 10-20% space savings, and complex renewable integration.

HVDC Architecture

- Converts AC to DC via PSUs, with DC-to-DC adjustments only.
- Uses higher voltages (e.g., ±400V) to reduce current, heat, and power loss.
- Delivers DC directly to racks, saving space and simplifying renewable integration.



Typical HVDC System Architecture

Power Distribution	Efficiency Gain	Space Savings	AC-DC Conversion	Integration with Renewables
Traditional AC	Baseline	Baseline	Multiple stages	Challenging (phase matching)
Hybrid AC-DC	5-10% gain over baseline	10-20% gain over baseline	Fewer stages	Moderate
HVDC	10-20% gain over baseline	30-50% gain over baseline	Single stage	Seamless

Data Center Architecture Comparison

HVDC SOLUTIONS

Intra-Rack HVDC Systems

- Power shelves, compute/server units, and networking shelvesare housed within the same rack.
- Each rack has its own power shelf, where input AC voltage is converted to DC.
- DC is then stepped down to 48 VDC for server board usage.
- Up to 750 kW of power may be needed per rack.
- Current levels can exceed 10,000 amps.
- Copper or aluminum busbars are used instead of cables dueto high current, offering greater cross-sectional area and betterheat dissipation and requiring less copper than cables.
- High heat generation may necessitate liquid cooling, implementable in busbars.

Intra-Rack Systems

Inter-Rack Systems

Inter-Rack HVDC Systems

- Power conversion centralized in a Power Rack that handles AC and DC power paths and reduces number of AC-DC conversions.
- Server Rack contains compute, server, and networking components.
- Inter-rack cabling delivers power from Power Rack to Server Rack.
- Uses HVDC Trunk Cabling (heavy, insulated copper or aluminum conductors), routed via underfloor transits or through busbars with bundled multi-core cables.
- Even with wide cross-section conductors and cooling, present-day busbars may be insufficient.
- Megawatt-level power per server rack is anticipated, requiring optimized busbar solutions
- Grid-supplied AC power can be 13.8 kV or more with direct conversion to 800 VDC.

HVDC ADVANTAGES

- **Higher Energy Efficiency:** HVDC systems consume less energy than traditional AC-based system, reducing overall power usage and improving sustainability.
- **Reduced Power Loss & Heat:** With fewer conversions and lower current at equivalent power levels, HVDC minimizes parasitic heat—allowing more compute density in less space.
- **Modular & Scalable:** HVDC architectures are inherently more modular, making them easier to scale as data center demands grow.
- **Improved Reliability:** Direct AC-to-DC conversion eliminates multiple transformation stages, reducing failure points and simplifying maintenance.
- **Renewable Integration:** HVDC systems efficiently incorporate renewable energy sources and support battery backup units (BBUs) for enhanced resilience.
- **Lower Transmission Losses:** HVDC cables experience less energy loss than AC cables, contributing to a 10–20% potential power savings.
- **Better Power Usage Effectiveness (PUE):** By minimizing energy wasted in transmission, HVDC improves PUE—an essential metric for data center efficiency.
- **Space Optimization:** HVDC designs can reduce physical infrastructure needs by 30–50% compared to AC-based systems.

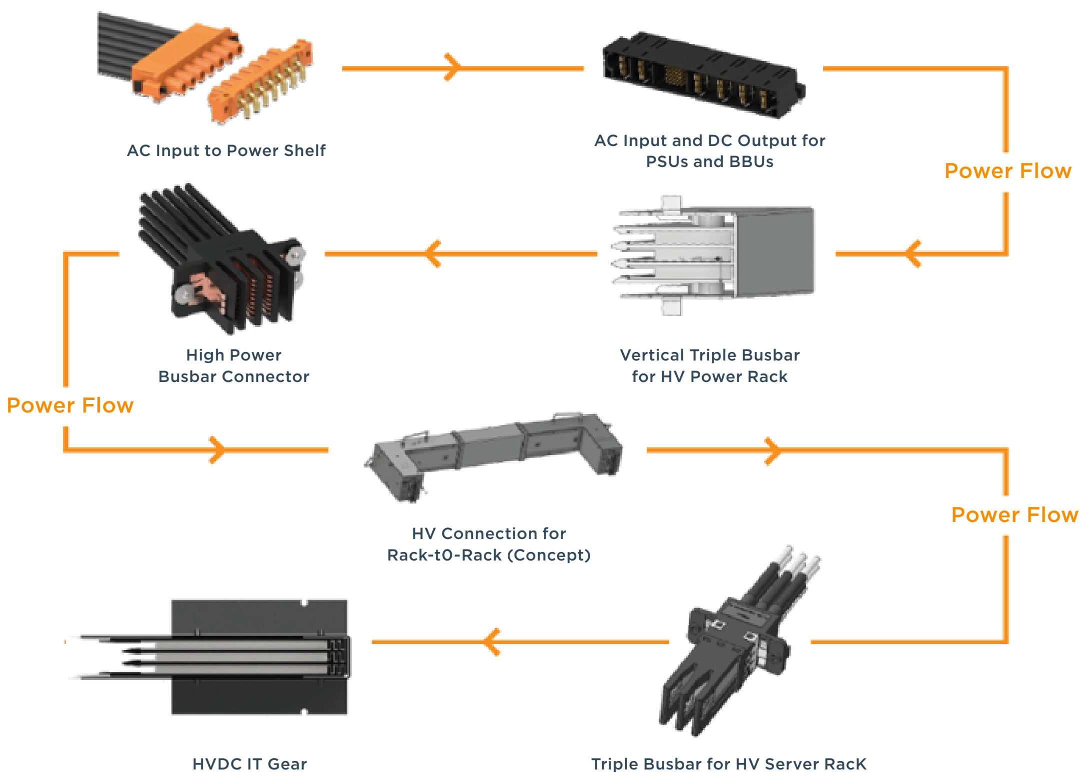
HVDC CONNECTORS

Transferring the power from the busbar to each shelf within the rack is handled by power connectors. All TE HVDC connector solutions are compliant with the Open Compute Project (OCP) specifications, ensuring interoperability.

In HVDC, there is the potential for electricity to "arc" through the air. The greater the distance between conducting pins, the less chance there is for arcing to occur. The International Electrotechnical Commission (IEC) defines the minimum distance that must exist between electrically active pins, known as "creepage" or "clearance".

All of TE's advanced HVDC connectors meet the mandated creepage/clearance distances for the increased voltage levels in HVDC systems. In data centers, space is at a premium, so TE connectors have a small form factor, offer very little electrical resistance, and minimize the generated heat. They also attach with great force, so there is little chance of them coming loose with normal use.

TE's plug-and-play Heavy Duty Connectors (HDC) connectors provide easy data center scalability. HVDC connectors meet the IEC 61984 Connector Standard which applies to connectors purposed for AC or DC voltages ranging from 50 to 1000 VAC, and for as much as 125 amps per pin contact.



CONCLUSION

Evolution to HVDC

Data centers will, invariably, consume a greater proportion of the world's energy. Using HVDC power distribution will allow the same amount of computation at a far lower energy cost. This will lower the need for electrical power and cause less CO_2 emissions during energy generation.

An important economic need for modern data centers is the ability to quickly expand capacity, often done using pre-designed data center modules which can just be "plugged in" to the existing data center. Because HVDC systems convert AC to DC only once, they are modular by nature and can easily accomplish this goal with a minimum of cost and effort.

In today's interconnected world, unplanned downtime is not an option, and reliability is one of the most important considerations. Data centers based on HVDC architecture reliable and provide the greatest social sustainability.

Data center market evolution also includes wall-mounted panelboards around the data center, to which power is distributed, enhanced and simplified using HVDC systems. HVDC modularity is improved since AC is immediately converted to HVDC by the PDU and then distributed to server racks over efficient busbars.

Finally, HVDC systems will enable meeting environmental, economic and social sustainability goals.

Call to Action: Explore HVDC solutions with TE

The HVDC portfolio of whips, busbar, cable assemblies and connectors offered by TE Connectivity offer less internal resistance than previous versions, saving power and thereby reducing the generation of parasitic heat. TE units are also continually becoming smaller and more efficient, contributing to the effort to save energy and to improve reliability. Contact our experts at TE Connectivity for more details.

Connect with us to get support on Data Center & AI Solutions

Additional Resources

Empowering AI & Data Center Connectivity
For Next-Gen Speed, Efficiency and Reliability

VISIT THE WEBSITE

Connectivity Solutions Empowering the AI Evolution
Learn how TE is helping to empower the AI evolution with our robust portfolio of interconnect solutions

WATCH THE VIDEO

The Evolution of Data Centers and the Future of Cooling and Connectivity
Explores how data centers are evolving to meet increasing power and cooling demands, with a focuson new design approaches and connectivity solutions.

READ THE TREND PAPER

A More Sustainable Data Center
With the rise of generative AI, data centers have become a growing consumer of electricity.

READ THE TREND INSIGHT

Thermal Performance
Design challenges for increasing computing performance in higher-power data racks while managing thermal performance.

READ THE TREND INSIGHT

Connect With Us

We make it easy to connect with our experts and are ready to provide all the support you need.
Visit **te.com/support** to chat with a Product Information Specialist.

te.com

10-25