

Powering the AI factories of the future

Enabling gigawatt-scale AI data centre infrastructure with solid-state transformers

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Contents

Foreword	6
Abbreviations	8
Executive summary	9
The power challenge	10
Rising power demand	10
The need for new power infrastructure	11
Solid-state transformers for AI data centres	12
Architecture and operation	12
Role of SSTs in high-density AI data centres	13
Enabling 800 VDC and 1500 VDC power architectures with SSTs	16
Wideband gap (WBG) semiconductors enabling SSTs for high-voltage DC architectures	18
Future technology watch: Vertical GaN	19
NVIDIA's role in shaping future AI power architectures	20
Modular SST architectures for AI infrastructure	21
Active front-end (AFE) rectifier and isolated DC-DC stage topologies	22
Technical spotlight: Active Neutral Point Clamped (ANPC) converter	23
Challenges and enablers for adoption	25
System-level barriers	25
Technical challenges	26

Building momentum for SST deployment	27
Readiness and deployment pathway	28
Semiconductor Catapult at the forefront of SST development	29
AI-assisted optimisation of the SST cell	30
High-frequency transformer development and validation	32
Integration with SiC power converters	33
Project highlight: ASSIST – Advanced SiC for solid-state transformer	34
High-fidelity double pulse testing at the Semiconductor Catapult	36
SST scaling concepts for future AI infrastructure	37
Conclusion	38
Further reading	39

Foreword

AI is transforming the digital landscape and the economy at unprecedented speed. As AI models scale and become more computationally intensive, the infrastructure supporting them must evolve rapidly. This is creating the next generation of AI data centres with unprecedented requirements for power, performance and scalability.

Meeting this demand is not simply a question of increasing supply of electricity, rack power densities and dynamic AI workloads. Growing pressure on electricity networks is challenging the way power is delivered and managed within data centres. As facilities move towards increasingly power-dense architectures, improving the efficiency, flexibility and intelligence of power infrastructure will become critical to enabling continued growth and removing bottlenecks.

This report from the Semiconductor Catapult explores how solid-state transformers (SSTs) could contribute to this transition. In summary, SSTs are advanced power-electronic systems that replace conventional low-frequency transformers with a combination of power electronics and high-frequency transformers to transform voltage, manage power flow, and provide galvanic isolation.

By combining voltage transformation with advanced power electronics and digital control, SSTs have the potential to enable actively controlled power delivery and provide an interface between medium-voltage grid connections and emerging DC architectures. In particular, the development of 800 VDC, and potentially higher-voltage DC systems, creates new opportunities for advanced power electronics within next-generation AI infrastructure and bidirectional capabilities for data centres with alternate power suppliers to facilitate integration of energy storage, renewables and flexible energy management.

Early commercial deployments of SST-based data centre power systems are already emerging, although further development is still required before SSTs can be deployed widely in data centres, but broader deployment is anticipated by 2030. Reliability, scalability, standards, safety and commercial readiness remain important challenges that must be addressed before large-scale deployment.

However, advances in power electronics, wide-bandgap semiconductors, high-frequency magnetics and control technologies are creating a pathway towards increasingly capable systems. For the UK, the opportunity is clear: to build a supply chain, based on existing strengths across semiconductors, power electronics, advanced packaging and power systems engineering.

Specifically, SSTs could deliver beyond the fence line:

- **More compute per megawatt connected.** Reduced power-conversion losses could allow a greater fraction of available grid capacity to reach computing loads.
- **Data centres as active energy participants.** Bidirectional flow and a DC link can let solar, batteries and microgrids connect directly, so facilities can manage peak demand and operate more flexibly within the wider energy system.
- **Cleaner power at the point of connection.** Active control can regulate voltage and suppress harmonics, easing the strain AI loads put on distribution networks.

- **Alignment with wider electrification.** Emerging 800 VDC architectures align with developments in electric vehicles, energy storage and industrial electrification, potentially strengthening supply-chain synergies.
- **UK industrial leadership.** Growing SST adoption will create opportunities across UK semiconductors, power electronics and high-frequency magnetics.

At the Semiconductor Catapult, we are working with industry to develop, integrate and validate the technologies needed to translate SST concepts into solutions.

We hope this report provides a useful perspective on how data centre power infrastructure is evolving, the role SSTs could play in that transition, and the opportunities this creates for industry in the UK.



Caroline O'Brien

Chief Executive Officer, Semiconductor Catapult

Abbreviations

AC	Alternating Current
AFE	Active Front-End
AI	Artificial Intelligence
ANPC	Active Neutral Point Clamped
BESS	Battery Energy Storage System
CSA	Compound Semiconductor Applications
DAB	Dual Active Bridge
DC	Direct Current
EMI	Electromagnetic Interference
EV	Electric Vehicle
GaN	Gallium Nitride
GPU	Graphics Processing Unit
HFT	High-Frequency Transformer
HVDC	High-Voltage Direct Current
IGBT	Insulated Gate Bipolar Transistor
IT	Information Technology
kV	Kilovolt
kW	Kilowatt
LVDC	Low-Voltage Direct Current
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MW	Megawatt
NPC	Neutral Point Clamped
RF	Radio Frequency
Si	Silicon
SiC	Silicon Carbide
SST	Solid-State Transformer
TWh	Terawatt-hour
UPS	Uninterruptible Power Supply
VDC	Volts Direct Current (used to denote DC voltage, e.g. 800 VDC)
WBG	Wide-Bandgap
ZVS	Zero-Voltage Switching

Executive summary

Artificial intelligence (AI) is reshaping data centre power requirements. Future AI racks could approach 1 MW, while next-generation facilities are expected to exceed 1 GW per site. Delivering power at this scale will require more efficient, compact and controllable power infrastructure to support increasingly power-dense AI systems.

This report examines the potential role of solid-state transformers (SSTs) in future AI data centre power infrastructure, including emerging DC architectures, enabling technologies, deployment challenges and the Semiconductor Catapult's capabilities in supporting their development and commercialisation.

SSTs could play an important role in the evolution of AI data centre power infrastructure. Potential benefits include:

- Higher power density through compact power conversion
- Active voltage and power control
- A pathway to 800 VDC and potentially 1500 VDC
- Integration of energy storage and renewables

The move towards 800 VDC distribution creates a particularly significant opportunity for SSTs. By providing a controlled interface between medium-voltage grid connections and DC distribution, SSTs could enable architectures with fewer conversion stages, improve system efficiency and support increasingly power-dense AI infrastructure.

Recent advances in enabling technologies are accelerating SST development. Wide-bandgap semiconductors support higher switching frequencies and voltages, improving efficiency and enabling more compact power conversion systems. Developments in high-frequency magnetics, advanced converter topologies, digital control systems and AI-assisted design tools are further improving SST performance and practicality for high-power applications.

SSTs are now moving into commercial deployment in data centres, marking an important step beyond prototype and pilot systems. Continued technology development, operational experience, industry standards and supply chain maturity will be important as deployment scales.

The Semiconductor Catapult capabilities supporting SST development include:

- AI-assisted SST design and optimisation
- High-frequency transformer design and validation
- SiC power electronics development and integration
- Hardware prototyping, validation and scalable architecture exploration

Through these capabilities, the Semiconductor Catapult helps industry de-risk and accelerate SST development while supporting end-to-end UK supply chains for SST and power electronics technologies.

The power challenge

The rapid growth of AI is creating unprecedented demands on data centre power infrastructure. Unlike traditional enterprise workloads, AI training and inference rely on highly parallel architectures built around large clusters of graphics processing units (GPUs) and specialised accelerators. As these systems scale, rack-level power demand is rising rapidly.

Rising power demand

Traditional data centres typically operated at rack power densities of 5–15 kW. Early GPU-based AI systems increased this to 20–40 kW, while current AI deployments can exceed 100 kW, as shown in Figure 1.^{1,2}

Evolution of power rack density

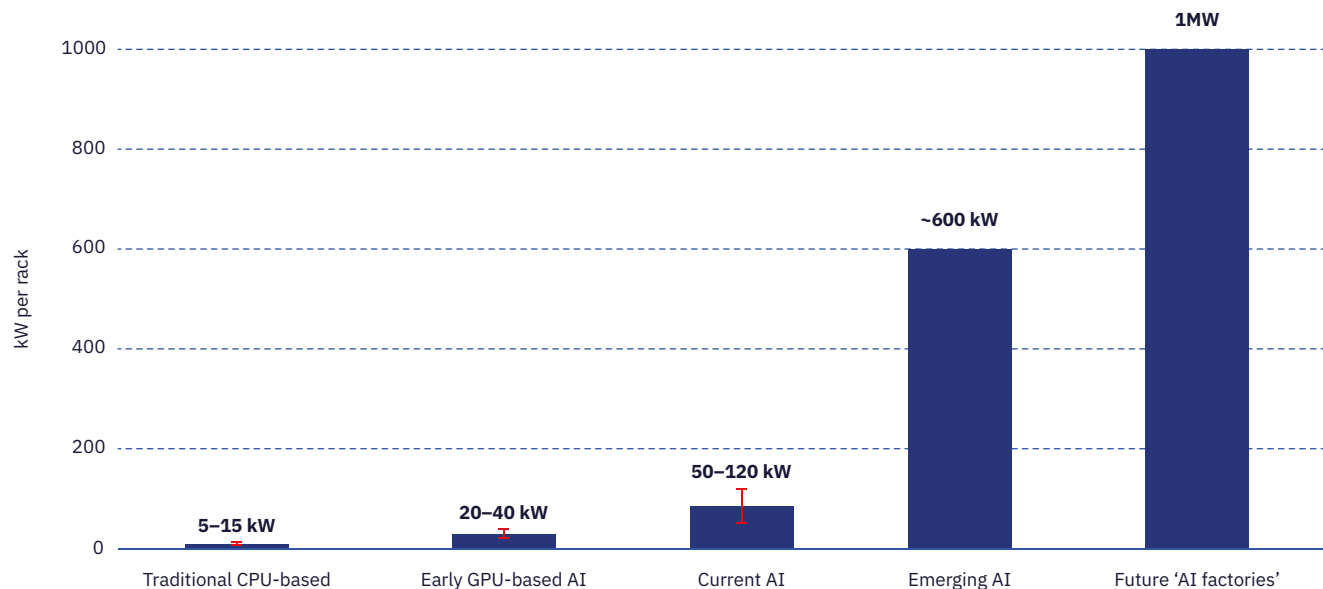


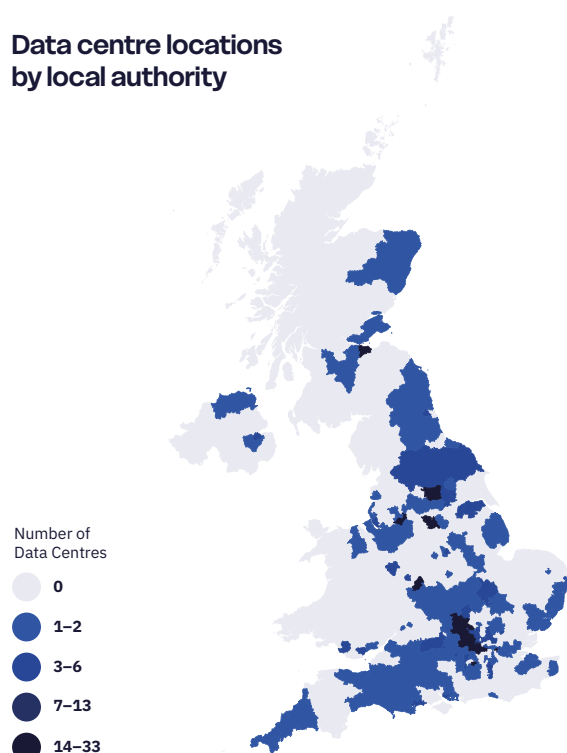
Figure 1: Evolution of rack power density in data centres, illustrating the rapid increase from traditional enterprise infrastructure to projected megawatt-scale AI racks.¹⁻³

Industry roadmaps indicate that next-generation AI racks could exceed 600 kW, with future rack systems potentially approaching 1 MW as compute density continues to increase.³

Alongside this increase in rack-level demand, the rapid growth of AI data centre infrastructure is also increasing overall electricity demand. There are now more than 12,000 data centres in operation worldwide.⁴ Global data centre electricity demand is projected to more than double, from 415 TWh in 2024 to around 945 TWh by 2030, driven largely by AI workloads.⁵

The UK has more than 500 data centres.⁶ In Great Britain specifically, data centres consumed an estimated 7.6 TWh of electricity in 2024, with demand potentially rising to 20–41 TWh by 2035, as shown in Figure 2.⁷

**Data centre locations
by local authority**



**GB data centre electricity
demand (TWh)**

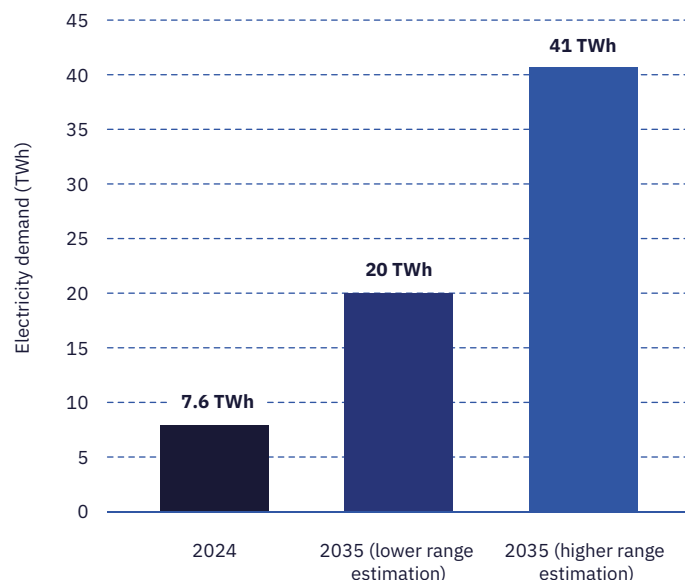


Figure 2: Distribution of data centre locations, with the highest concentrations around London and the Southeast;⁸ and projected growth in GB data centre electricity demand, highlighting a substantial increase expected over the coming decade.⁷

This growth is placing additional pressure on transmission and distribution networks. In many regions, access to high-capacity grid connections is limited, leading to longer connection timelines and greater competition for available capacity.⁹

In addition to increasing power demand, AI workloads can introduce rapid fluctuations in power consumption, placing greater demands on power stability and voltage regulation. Increasing rack power densities also generate greater thermal loads, requiring power delivery and cooling to be considered together in the design of high-density AI data centres.

The need for new power infrastructure

The trends outlined above expose a growing mismatch between the power requirements of AI data centres and the capabilities of conventional power infrastructure. Traditional low-frequency transformers and legacy AC distribution systems were designed for relatively stable enterprise environments, rather than the dynamic, high-density conditions associated with AI workloads.

Conventional low-frequency transformers remain widely used due to their reliability, efficiency and long operational life, but their passive operation limits functions such as active voltage regulation, real-time monitoring and power conditioning. Their grid-frequency operation also requires relatively large magnetic components.

At the system level, conventional AC-based distribution requires multiple conversion stages to interface with DC-native loads, increasing losses, heat generation and system complexity, while also limiting direct integration with distributed energy resources. Together, these factors are driving interest in alternative approaches such as solid-state transformers.

Solid-state transformers for AI data centres

Solid-state transformers (SSTs) are advanced power electronic devices that combine power semiconductors, high-frequency transformers and control circuitry to convert and transfer electrical energy.¹⁰ Unlike conventional transformers, which rely solely on passive electromagnetic coupling at grid frequency, SSTs employ actively controlled power electronic conversion stages that enable voltage regulation, dynamic system operation and bidirectional power flow.¹¹

Architecture and operation

An example SST architecture is shown in Figure 3 and consists of a series of interconnected power conversion stages.

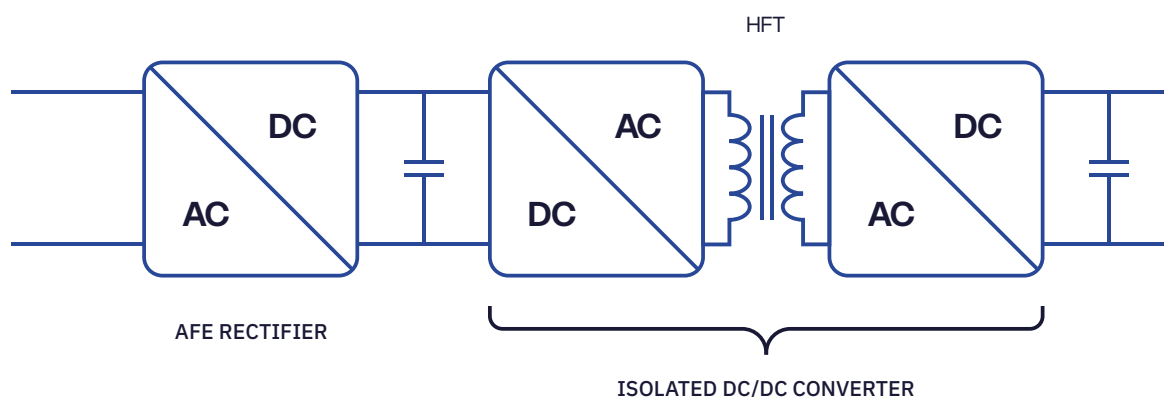


Figure 3: Example SST architecture showing an active front-end (AFE) rectifier and an isolated DC/DC conversion stage incorporating a high-frequency transformer (HFT).

Power conversion begins with an active front-end (AFE) rectifier, which converts incoming medium-voltage AC supply to DC, and enables the control of input current, power factor and DC-link voltage.¹²

The DC is then transferred to an isolated DC-DC converter, where it is converted to high-frequency AC, passed through a high-frequency transformer (HFT), and rectified back to DC at the required voltage. The high-frequency link provides galvanic isolation and voltage transformation while enabling smaller magnetic components than conventional grid-frequency transformers. Depending on the application, the output can be supplied as regulated DC or converted back to AC.

Power conversion across these stages can use conventional semiconductor devices such as insulated gate bipolar transistors (IGBTs), or wide-bandgap (WBG) devices such as silicon carbide (SiC). WBG devices can support higher switching frequencies, lower losses and operation at higher voltages and temperatures, contributing to more compact and efficient SST systems.

Role of SSTs in high-density AI data centres

The limitations of conventional transformers are driving increasing interest in SSTs as a potential solution for next-generation AI infrastructure.

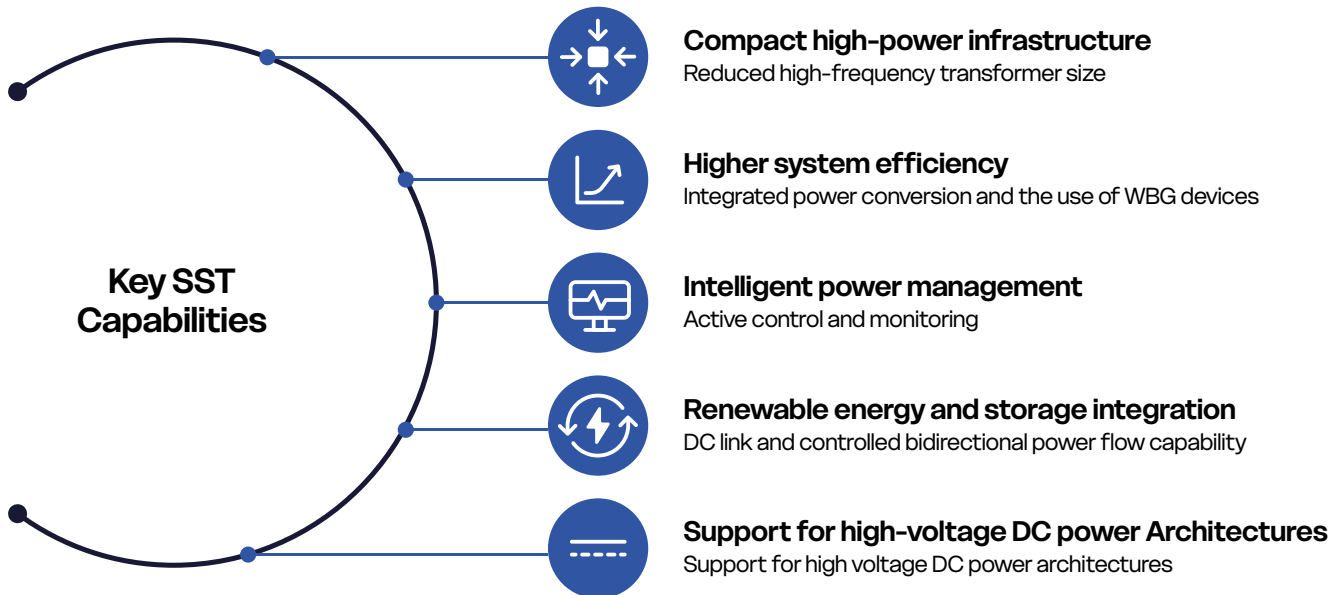


Figure 4: Key SST capabilities in AI data centres. High-voltage DC here refers to emerging 800 VDC and 1500 VDC data centre power distribution architectures rather than long-distance utility transmission systems.

Compact high-power infrastructure

One of the main advantages of SSTs is their high-power density. Conventional transformers operate at grid frequencies of 50–60 Hz and require large magnetic cores and bulky passive components. In contrast, SSTs operate at much higher switching frequencies, significantly reducing transformer size and weight. SSTs can reduce volume by up to 80% compared to traditional low-frequency transformers.¹³ The reduced transformer size enables a more compact electrical infrastructure footprint, allowing greater utilisation of valuable data centre space for compute equipment.

Higher system efficiency

SSTs have the potential to improve overall system efficiency by integrating multiple power-conversion functions within a single platform and enabling more efficient power-distribution architectures. WBG semiconductor devices can further contribute through lower switching losses and improved high-temperature performance. Higher system efficiency reduces electrical losses throughout the power delivery chain, lowering energy consumption and reducing the heat generated by power conversion equipment.

Intelligent power management

Unlike conventional transformers, SSTs provide active control of voltage, current and power flow through integrated power electronics and digital control systems. This enables real-time monitoring, fast system response and enhanced power-quality management. SSTs can regulate voltage, mitigate harmonics, and respond rapidly to changing load conditions, helping maintain stable operation of large-scale AI compute infrastructure.

Renewable energy and storage integration

As AI facilities scale up, operators are increasingly exploring on-site renewable generation and battery energy storage systems to improve resilience, manage peak demand and support sustainability objectives.

SSTs are well-suited to these architectures through their DC-link capability and support for bidirectional power flow. This enables efficient integration of battery systems, renewable energy sources, such as photovoltaics, and hybrid AC/DC infrastructure, while allowing energy to be exchanged dynamically between generation, storage, the grid and data centre loads, as illustrated in Figure 5.

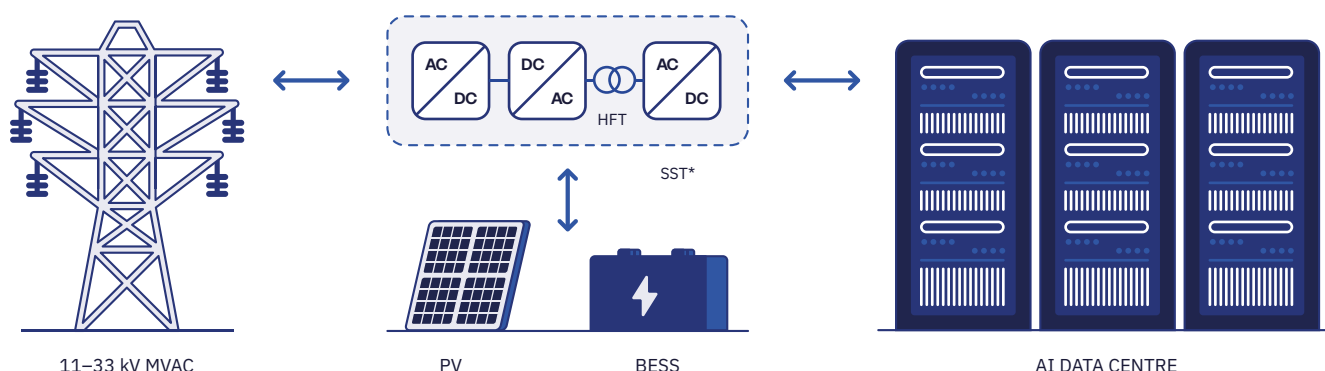


Figure 5: Illustration of an SST providing a bidirectional power interface between the medium-voltage grid, AI data centre, renewable energy sources, and battery energy storage systems (BESS).

Support for DC power architectures

SSTs can also support emerging 800 VDC and future 1500 VDC distribution architectures being explored for AI data centres. The following section discusses these architectures and their implications for future data centre power systems.

Future vision of AI hardware infrastructure

The scenario below presents a conceptual vision of future AI hardware infrastructure, illustrating how multiple advanced technologies could converge to support next-generation AI data centres. At the foundation of the architecture, SSTs provide medium-voltage power conversion to 1500 VDC distribution, supplying high-density compute platforms with efficient and intelligent power delivery. Building on this foundation, photonics, RF and quantum technologies, edge computing and satellite connectivity form an integrated ecosystem, while AI-assisted optimisation and cybersecurity enable intelligent operation, resilience and resource management across the wider infrastructure.

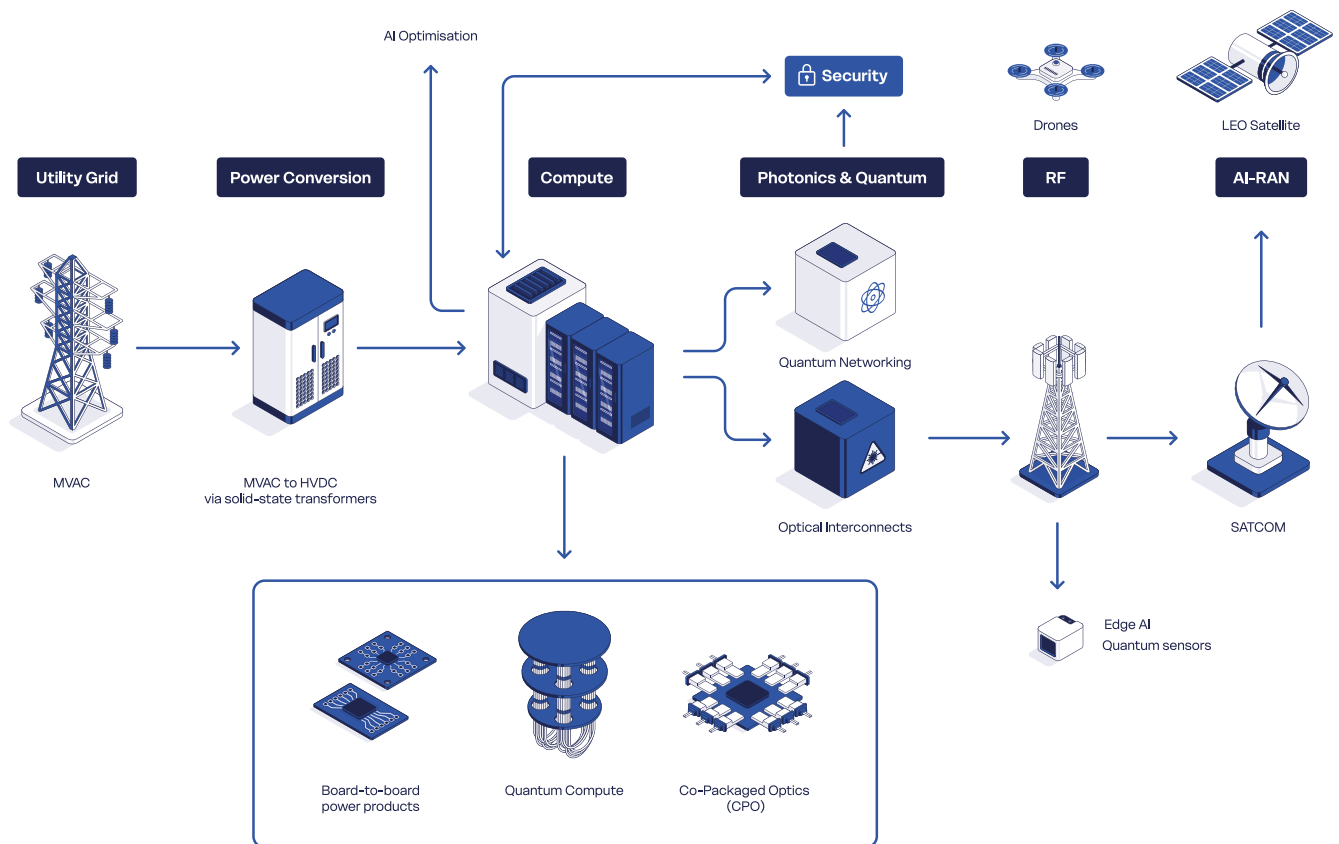


Figure 6: Conceptual architecture for next-generation AI data centres, illustrating the convergence of SST-enabled power delivery, compute, photonics, and RF and quantum technologies across the AI infrastructure stack.

Note: In this context, HVDC refers to emerging 800 VDC and 1500 VDC data centre power distribution architectures rather than long-distance utility transmission systems.

Enabling 800 VDC and 1500 VDC power architectures with SSTs

As established earlier, increasing power densities in AI data centres are beginning to expose the limitations of conventional AC-based power architectures. In response, there is growing industry interest in 800 VDC power distribution architectures as a potential approach to supporting future ultra-high-density compute environments.

Conventional AC-based power architectures typically rely on multiple AC-DC and DC-DC conversion stages throughout the power chain, resulting in cumulative efficiency losses, additional thermal loading and increased system complexity. As AI facilities scale towards hundreds of megawatts, these inefficiencies become increasingly significant.

SSTs have the potential to become a key enabling technology for the transition to 800 VDC power distribution architectures. Unlike conventional transformer-based systems, SSTs can convert medium-voltage AC into a regulated 800 VDC output, creating a DC power distribution backbone within the data centre. In this architecture, the power chain can be simplified by reducing the number of conversion stages between the utility connection and the compute load, while also providing greater control over power flow and system operation. Local DC-DC converters can then supply processors and accelerators at the rack level.

A comparison between conventional AC and SST-enabled 800 VDC power distribution architectures is shown in Figure 7.

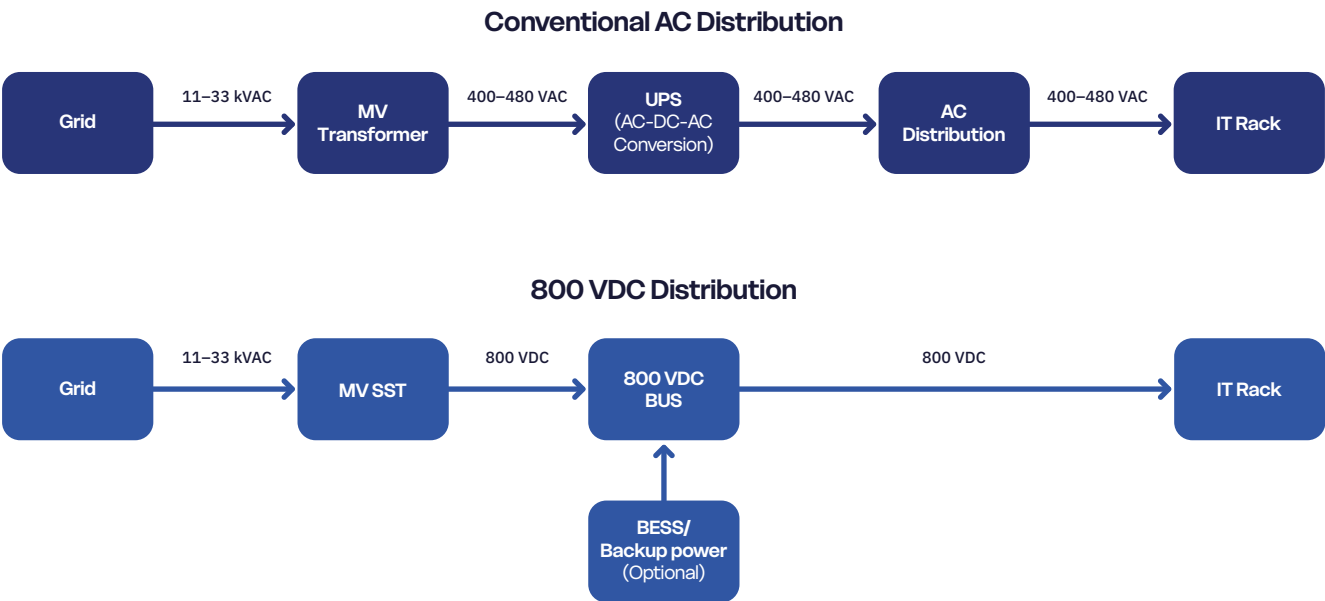


Figure 7: Simplified comparison of conventional AC-based AI data centre power distribution and an SST-enabled 800 VDC architecture. The configurations illustrate key architectural differences rather than a component-by-component comparison.

By reducing the number of power conversion stages, SST-enabled 800 VDC architectures can improve overall efficiency while reducing thermal losses and system complexity. Additionally, at a given power level, an 800 VDC distribution bus carries less current than conventional lower-voltage systems, thereby reducing resistive losses and the need for larger conductors. Furthermore, 800 VDC aligns with voltage ranges increasingly adopted in electric vehicle infrastructure, potentially benefiting from broader ecosystem development.

The reported benefits of 800 VDC over conventional AC-based data centre power distribution are summarised in Table 1.

Table 1: Reported benefits of 800 VDC architecture compared with conventional AC-based data centre power distribution.¹⁴

Parameter	800 VDC system
Rack power scalability	Supports 100 kW to >1 MW racks
End-to-end efficiency	Up to 5% improvement compared with current 54 VDC systems
Power transmission	Up to 85% more power through the same conductor size than 415 VAC
Copper requirement	Up to 45% lower for the same load
Maintenance cost	Up to 70% lower
Total cost of ownership	Up to 30% lower
Copper busbar mass	Avoids the requirement for up to 200 kg of copper busbar associated with 54 VDC distribution in a 1 MW rack

Looking further ahead, 1500 VDC architectures are also being explored to support future AI facilities with even higher power densities. The primary motivation is to reduce the current required to deliver high power levels. For example, delivering 1 MW at 800 V requires approximately 1250 A, whereas supplying the same load at 1500 V requires approximately 667 A. This substantial reduction in current can reduce resistive losses, lower conductor requirements, minimise thermal loading and potentially improve overall system efficiency.

As AI facilities continue to scale, SST-enabled DC power architectures offer a practical pathway towards more efficient and scalable data centre power infrastructure, with 800 VDC representing the current direction of travel and 1500 VDC a potential future evolution.

Wideband gap (WBG) semiconductors enabling SSTs for high-voltage DC architectures

The practical deployment of SSTs in high-voltage DC power distribution networks in data centres is closely linked to advances in power semiconductor technology.ⁱ

Conventional silicon (Si) devices, including IGBTs, remain widely used in medium-voltage power conversion and are suitable for many cost-sensitive applications. However, their switching performance and operating characteristics constrain the efficiency, power density and scalability achievable in SST-based systems.

As discussed earlier, WBG semiconductors, particularly SiC, offer significant advantages over conventional Si devices. Figure 8 summarises the key material characteristics of Si, SiC and gallium nitride (GaN). The combination of higher critical breakdown field, wider bandgap and improved thermal conductivity enables higher-voltage and higher-frequency operation, which is fundamental to the practical implementation of SSTs in data centres.

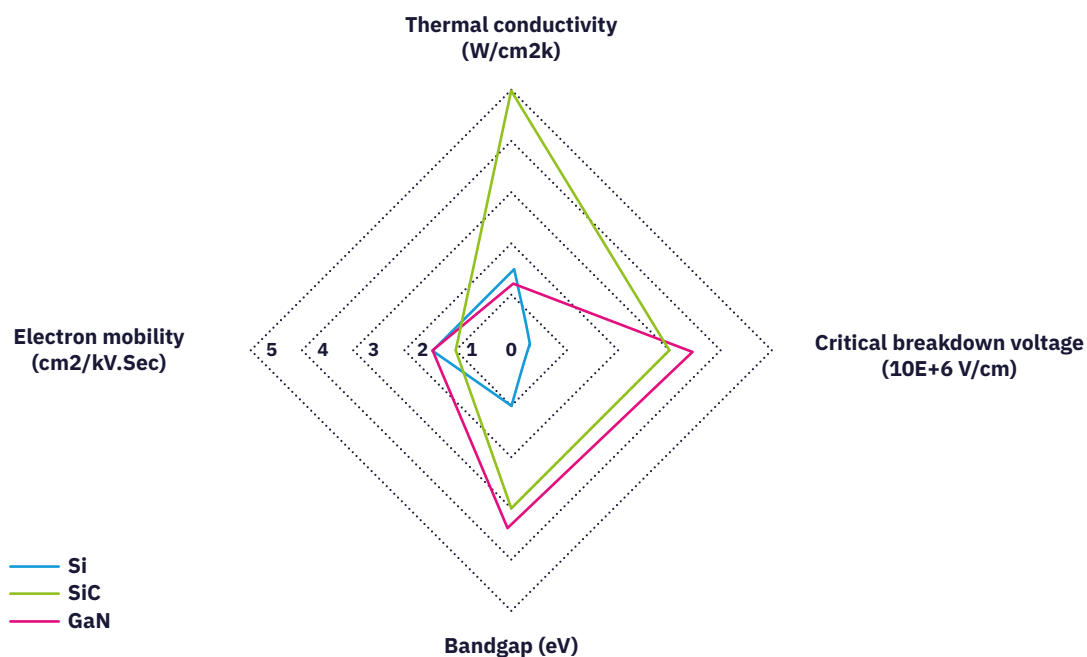


Figure 8: Comparison of the key material properties of silicon (Si), silicon carbide (SiC) and gallium nitride (GaN), highlighting the advantages of wide-bandgap semiconductors for high-power electronic applications.¹⁵

Commercial SiC MOSFETs are now available with voltage ratings up to 3.3 kV,¹⁶ with the recent introduction of the first commercially available 10 kV SiC MOSFET marking a further advance in high-voltage WBG technology.¹⁷ Higher-voltage devices can reduce the number of converter stages, simplifying SST architectures while improving power density. Combined with the higher switching frequencies achievable with SiC, this also enables smaller high-frequency transformers and passive components, supporting more compact and efficient SST systems.

GaN offers further potential for very high switching frequencies and may play an increasing role in lower-voltage conversion stages. However, its application in high-power, medium-voltage SST systems remains relatively limited due to its lower commercially available voltage ratings. As a result, SiC currently represents the most mature WBG technology for these applications.

ⁱ In this context, high-voltage DC refers to emerging 800 VDC and 1500 VDC data centre power distribution architectures rather than long-distance utility transmission systems.

Future technology watch: Vertical GaN

The Semiconductor Catapult's earlier report, **Vertical Gallium Nitride (GaN) Technology: Unlocking High-Voltage Potential for Net Zero Applications**, highlighted the potential of vertical GaN to extend GaN into higher-voltage power conversion. Although the technology remains at an early stage of commercialisation, continued advances could enable a new generation of compact, high-efficiency, high-voltage power electronic systems.

Key developments highlighted in the report include:

- Higher voltage capability through vertical GaN-on-GaN device structures, overcoming the voltage limitations of commercially available lateral GaN devices
- Ultra-high switching frequencies of up to 10 MHz, enabling further reductions in transformer and passive component size while increasing power density
- Reduced crystal defects and improved thermal stability through native GaN substrates, supporting improved reliability for high-voltage operation
- Compact, high-power devices, with reports of devices up to 95% smaller than Si equivalents, enabling more compact power conversion systems
- Growing commercial momentum, although widespread adoption will depend on further advances in wafer cost, packaging and long-term reliability

NVIDIA's role in shaping future AI power architectures

NVIDIA has emerged as a significant driver of next-generation AI power infrastructure through its roadmap for 800 VDC AI factory architectures, designed to support future platforms such as Rubin Ultra and Kyber, with rack power levels approaching 1 MW. As a result, a growing ecosystem of power, cooling and electrical infrastructure suppliers is aligning product development around emerging high-voltage DC requirements. Table 2 highlights recent industry activity and developments.

Table 2: Examples of industry activity supporting 800 VDC AI data centre infrastructure.

Company	800 VDC data centre developments
NVIDIA	Introduced an 800 VDC AI factory power architecture targeting up to 1 MW AI racks for future Rubin Ultra and Kyber systems, aimed at improving efficiency and reducing conversion losses. ¹⁸
Vertiv	Developing an end-to-end 800 VDC power and cooling portfolio in collaboration with NVIDIA, with commercial solutions planned from 2026 to support next-generation AI factories. ¹⁹
Schneider Electric	Collaborating with NVIDIA on 800 VDC power systems and sidecar architectures capable of supporting AI racks up to 1.2 MW, alongside integrated power distribution and management platforms. ²⁰
Delta Electronics	Collaborating with NVIDIA on 800 VDC AI factory infrastructure, including high-efficiency power shelves, DC-DC converters and grid-to-chip power solutions for next-generation AI data centres. ²¹
Eaton	Collaborating with NVIDIA to develop 800 VDC-compatible UPS, protection and power distribution technologies for next-generation AI factories. ²²
ABB	Partnering with NVIDIA to develop next-generation AI factory infrastructure, including advanced electrification, 800 VDC power distribution and high-efficiency power systems for gigawatt-scale AI facilities. ²³
Hitachi	Developing simulation capabilities using the NVIDIA Omniverse Blueprint to model 800 VDC power architectures and accelerate the design of gigawatt-scale AI factories. ²⁴

While large-scale deployment of 800 VDC architectures remains in its early stages, growing activity among equipment manufacturers, power system suppliers and infrastructure vendors indicates increasing industry momentum towards 800 VDC for future AI facilities.

Modular SST architectures for AI infrastructure

SSTs can be realised using a range of architectural approaches. These architectures are shaped by practical design constraints, including semiconductor voltage limits, efficiency requirements and system scalability.

One of the main architectural trends is the use of modular SST systems. Rather than relying on a single high-power converter, modular SST architectures use multiple smaller converter cells operating together as a distributed power conversion system.

Future AI data centres are expected to connect directly to medium-voltage distribution networks operating at 11–33 kV. However, semiconductor devices have practical voltage limitations that prevent a single converter from directly handling these voltages. By connecting multiple converter cells in a cascaded configuration, the total system voltage is shared across the individual cells, allowing the SST to operate at medium-voltage levels while keeping the voltage across each cell within the capabilities of commercially available semiconductor devices.

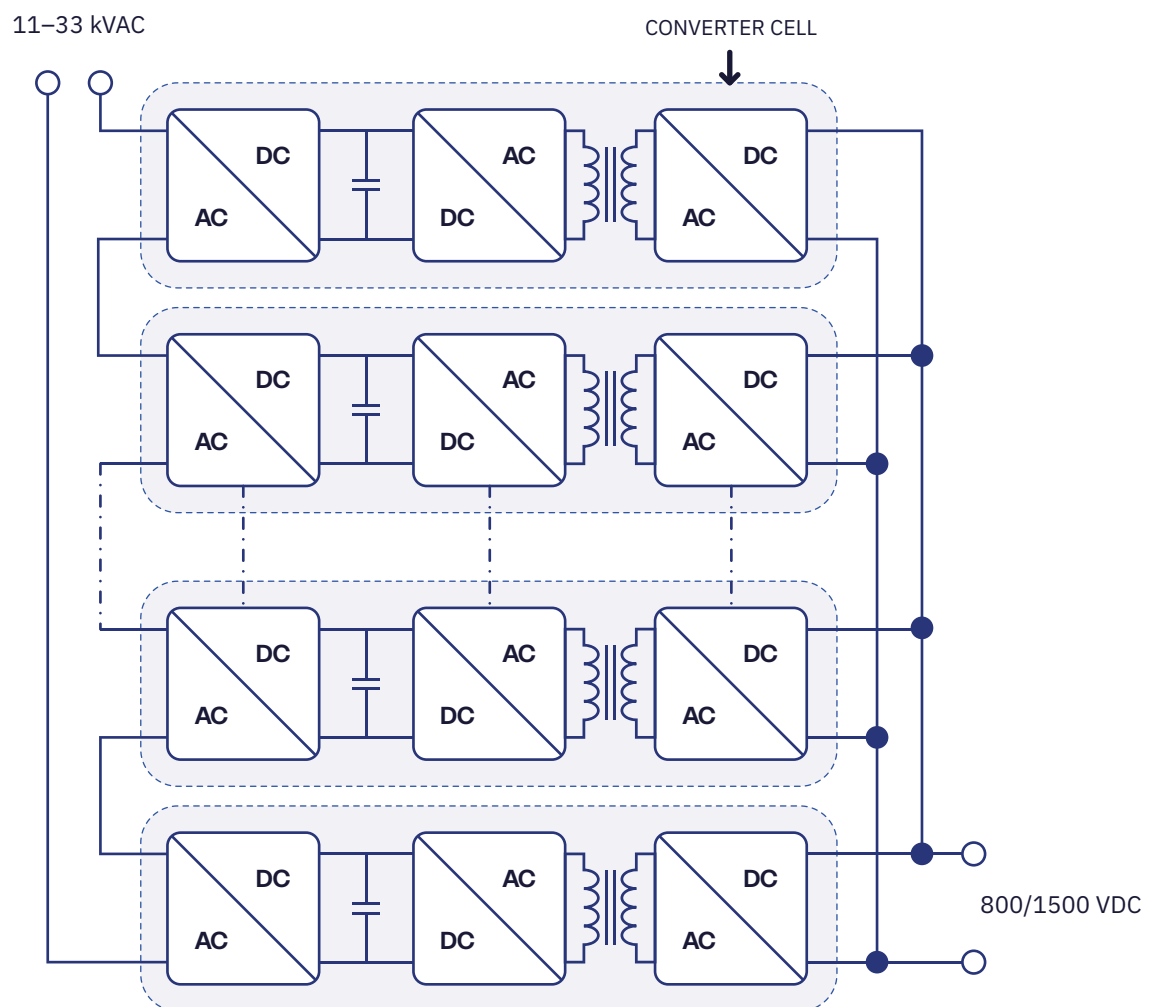


Figure 9: Simplified representation of a modular cascaded SST architecture, showing series-connected converter cells on the medium-voltage side and paralleled isolated outputs supplying an 800/1500 VDC bus.

This modular cascaded approach, illustrated in Figure 9, offers several advantages for AI infrastructure, including:

- scalability from kilowatt to megawatt-scale systems
- flexible system expansion
- improved fault tolerance and redundancy
- distributed thermal management
- simplified maintenance and servicing

Modular SST architectures can improve system resilience through redundancy. Following a fault in an individual converter cell, the remaining cells may continue operating, potentially at reduced capacity, depending on the system design.

The number of cascaded converter cells can also be adjusted according to grid voltage level, power requirements, semiconductor voltage class and redundancy requirements, enabling scalable SST deployment for future high-density AI infrastructure.

The following section examines the power conversion stages and topologies within an individual SST converter cell.

Active front-end (AFE) rectifier and isolated DC-DC stage topologies

Each SST converter cell comprises individual power conversion stages that can be implemented using different topologies. Figure 10 shows an example converter cell architecture comprising the AFE and isolated DC-DC stages discussed below.

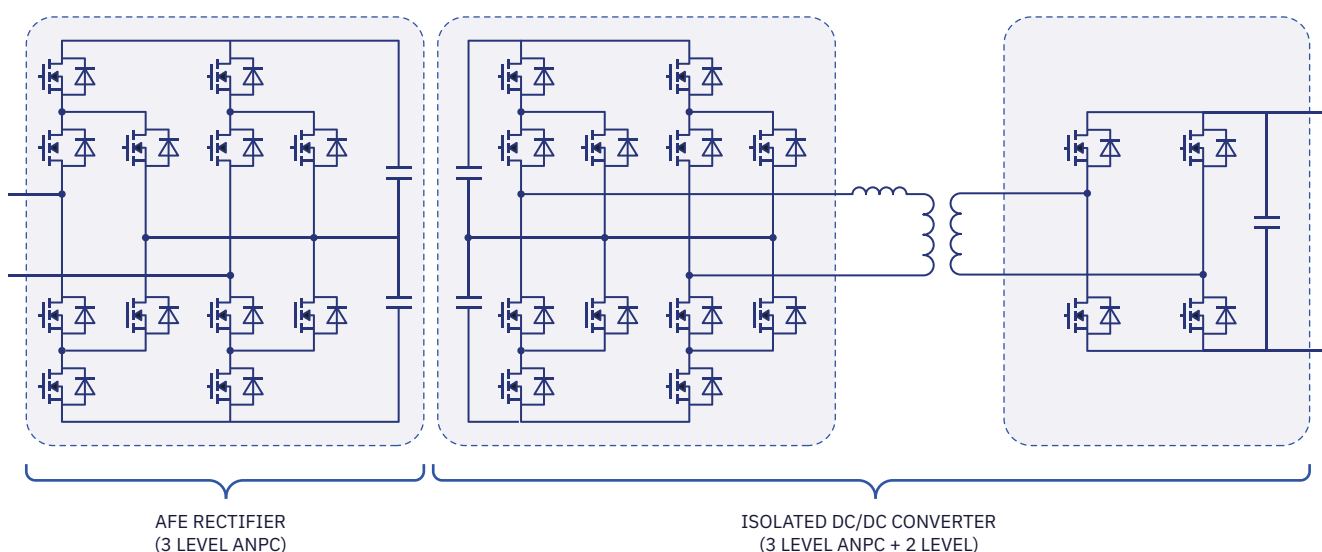


Figure 10: Example SST converter cell architecture comprising a three-level ANPC active front-end rectifier and an isolated DC-DC conversion stage based on a three-level ANPC bridge and a two-level bridge connected through a high-frequency transformer.

AFE rectifier

The AFE rectifier serves as the first power conversion stage in a multi-stage SST, converting the incoming medium-voltage AC supply into a controlled DC output for subsequent stages. In addition to rectification, the AFE regulates the DC-link voltage, controls power flow, and supports high input power quality through active control of voltage and current. Its performance has a significant influence on the overall efficiency, reliability and dynamic response of the SST.

A range of converter topologies has been proposed for the AFE stage, each offering different trade-offs in voltage capability, efficiency, complexity and controllability. Among these, multilevel converter topologies such as the ANPC converter are increasingly being explored for medium-voltage SST applications.

Technical spotlight: Active Neutral Point Clamped (ANPC) converter

ANPC is a multilevel bridge topology developed as an evolution of the conventional Neutral Point Clamped (NPC) converter. By incorporating actively controlled clamping switches, ANPC converters enable more flexible modulation and improved balancing of switching losses among semiconductor devices. Like other multilevel converter topologies, ANPC converters generate stepped output voltage waveforms, reducing semiconductor voltage stress while improving output waveform quality and reducing harmonic distortion.

ANPC topologies offer several advantages for medium- and high-power SST applications, including:

- support for higher system voltages through reduced device voltage stress
- lower switching losses and higher conversion efficiency
- improved power flow control and greater potential for zero-voltage switching (ZVS)
- lower dv/dt and reduced stress on transformers and insulation systems
- fewer auxiliary circuits, communication links and maintenance points
- potential for a simpler overall system despite increased cell-level complexity^{25,26}

These characteristics become increasingly important as AI data centre power systems continue to scale towards higher voltages and power levels. Although highlighted here in the context of the AFE rectifier stage, ANPC is a bridge topology that may also be employed within isolated DC-DC converter topologies, including Dual Active Bridge converters, depending on the voltage and performance requirements.

Isolated DC-DC conversion

The isolated DC-DC stage is the defining functional element of an SST, incorporating a high-frequency transformer that replaces the conventional line-frequency transformer while providing galvanic isolation, voltage conversion and controlled bidirectional power transfer.

Depending on the overall SST architecture, the isolated DC-DC stage may interface either with the DC outputs of series-connected rectifier cells or with a shared medium-voltage DC link provided by a central rectifier. Among the available isolated DC-DC converter topologies, the Dual Active Bridge (DAB) is one of the most widely used for this function.

A DAB converter consists of two actively controlled bridge circuits connected through a high-frequency transformer. Power transfer is regulated by controlling the phase shift between the two bridges, enabling dynamic control of power flow and bidirectional operation.²⁷ Depending on the voltage and performance requirements, these active bridges may themselves be implemented using two-level or multilevel bridge topologies, including ANPC, as illustrated in Figure 10.

DAB converters offer several characteristics suitable for future AI power systems, including:^{28, 29}

- high-frequency transformer integration
- modular scalability
- bidirectional power flow
- high conversion efficiency
- support for soft-switching operation
- compatibility with battery energy storage systems

With appropriate design and control, DAB converters can achieve ZVS over a wide operating range, reducing switching losses and improving efficiency at high switching frequencies.

Since both converter bridges are actively controlled, DAB converters can rapidly regulate power transfer under varying load conditions and support fast transient response. This characteristic is particularly important for future AI systems, where rapid changes in compute utilisation can produce significant fluctuations in power demand.

Together, these architectural building blocks form the foundation of future SST-based power distribution systems for AI infrastructure. However, translating these concepts into deployable AI data centre infrastructure will require overcoming a range of system-level and technical challenges, as discussed in the next section.

Challenges and enablers for adoption

Despite their potential, SSTs face a range of challenges that currently limit widespread adoption. These challenges span system-level considerations such as cost, infrastructure readiness and operational maturity, as well as technical constraints associated with high-voltage, high-frequency power conversion. The principal challenges and enabling technologies are summarised in Figure 11.

Barriers

Pathways to adoption

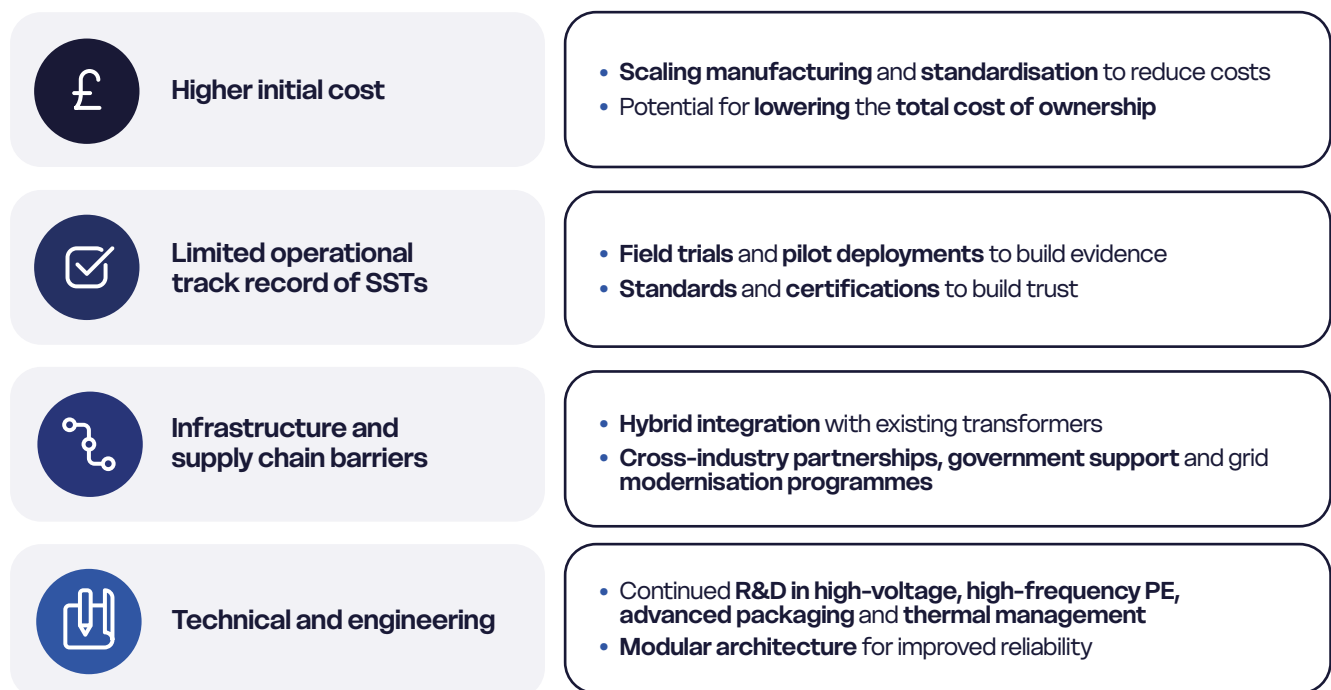


Figure 11: Overview of the key barriers to SST adoption and the corresponding pathways to enable widespread deployment.

System-level barriers

A key constraint is the higher initial cost of SST systems compared with conventional transformer-based solutions. The use of advanced power electronic converters, high-frequency magnetic components, WBG semiconductor devices and digital control systems increases cost. Over time, scaling manufacturing volumes, improving standardisation and maturing supply chains may help reduce these costs, while improved efficiency and reduced footprint offer potential long-term system benefits.

Operational maturity remains an important consideration. Compared with conventional transformers, SSTs currently have a more limited track record, particularly in large-scale, continuously operating applications such as AI data centres. Growing operational experience, continued validation at scale, and the development of standards and certification frameworks will be important in building confidence and supporting wider adoption.

Infrastructure and supply chain limitations also present challenges. SST deployment depends on specialised semiconductor devices, advanced packaging technologies and high-frequency magnetic materials, with supporting manufacturing capabilities still developing. Approaches such as hybrid integration with existing transformer infrastructure, combined with cross-industry collaboration, government support and grid modernisation programmes, can help to reduce deployment barriers and strengthen supply chains.

While these system-level factors influence the commercial viability of SSTs, several technical challenges must also be addressed before large-scale deployment is achievable.

Technical challenges

Reliability remains a key challenge for SSTs due to their reliance on power semiconductor devices and associated control electronics compared with conventional transformers. While this enables advanced control and functionality, it can introduce additional failure mechanisms. Limited short-circuit withstand capability, semiconductor voltage stresses, insulation reliability, and the need for sophisticated protection systems further increase system complexity. Advances in semiconductor devices, thermal management, insulation technologies and fault-tolerant control architectures are expected to improve long-term reliability.

High-frequency switching in SSTs can generate electromagnetic interference (EMI) and increase the complexity of gate-driver design, control and protection. Fast-switching power semiconductor devices also require rapid fault detection to prevent device damage.

Reliable operation therefore requires advanced gate drivers, coordinated protection mechanisms and robust digital control systems. Ongoing improvements in power electronics design, filtering techniques and integrated protection technologies are helping to simplify system integration and improve overall robustness.

Building momentum for SST deployment

Several converging regulatory, market and technological trends are strengthening the case for SSTs in future AI data centre infrastructure. The key drivers are summarised in Figure 12.



Figure 12: Overview of the key regulatory, market, investment and technological drivers supporting the adoption of solid-state transformers.

Policy and regulatory drivers are accelerating this shift. Net Zero targets, energy decarbonisation, AI strategies, and the transition to electric vehicles are increasing pressure on electricity networks, driving demand for more flexible and intelligently controlled power systems.

At the same time, substantial investment is being directed towards energy and digital infrastructure. In the UK, over £100 billion of private investment has been committed to clean energy,³⁰ while more than £43 billionⁱⁱ of investment in UK data centre construction has been announced since 2023.³¹ AI growth zones are expected to unlock up to £100 billion in additional investment,³² creating favourable conditions for advanced power technologies.

ⁱⁱ Converted from USD to GBP using an exchange rate of USD 1.00 = GBP 0.7378 on 19 August 2026.

Demand for high-capacity power infrastructure is also increasing. The number of data centres continues to grow, with over 500 facilities in the UK,⁶ while the expansion of ultra-fast EV charging is placing additional strain on distribution networks. Together, these trends are pushing conventional infrastructure towards its limits.

In parallel, advances in WBG semiconductor technologies are enabling more practical SST implementations, supporting higher efficiency, increased power density, and more compact system designs.

Readiness and deployment pathway

SSTs are progressing from prototype development and system-level validation into early commercial deployment. The first SST-based power systems are beginning to enter commercial operation in data centres, demonstrating progress beyond the prototype stage. Further development, validation at scale and operational experience will be important to establish the long-term reliability and economics needed for wider adoption.

Progress towards deployment is being supported by advances in WBG devices, which can improve efficiency and voltage capability, and by modular, cascaded architectures that provide a practical route to medium-voltage systems. At the same time, growing industry momentum behind 800 VDC power distribution is increasing demand for SST development and commercialisation, particularly for new high-density AI data centres.

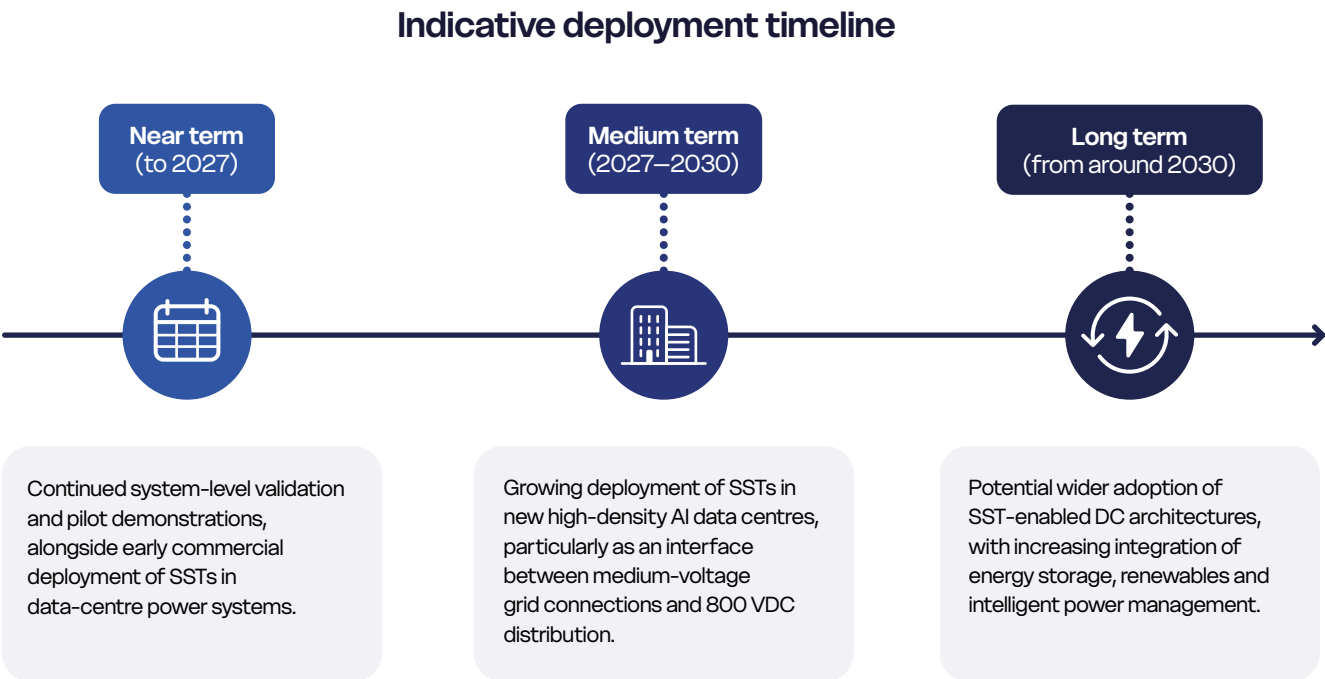


Figure 13: Indicative timeline for SST integration into data centre architectures.

Note: The timelines shown are indicative and may change as technology development, industry requirements and deployment strategies evolve.

The Semiconductor Catapult is helping to accelerate this transition through its ongoing work in SST development and validation.

Semiconductor Catapult at the forefront of SST development

The Semiconductor Catapult accelerates the commercialisation of breakthrough semiconductor technologies, helping organisations reduce risk, secure supply chains and bring products to market faster. Combining world-class engineering expertise, specialist facilities and practical know-how, it connects R&D, industry and supply chains to scale UK innovation and deliver long-term economic benefit.

The Catapult provides end-to-end system-level solutions for silicon and compound semiconductors, supporting organisations from concept through to product commercialisation. Working with start-ups, SMEs and larger businesses, it enables complex system development and product commercialisation through multidisciplinary co-design and integration, all under one roof.

Operating from Newport, Bristol and Glasgow, the Semiconductor Catapult helps strengthen sovereign supply chains, accelerate design wins and increase the adoption of UK-designed semiconductors in AI hardware, defence and other strategic markets. It brings together multidisciplinary expertise in RF and microwave technologies, photonics, power electronics and advanced packaging, supported by specialist facilities, proprietary processes, intellectual property and highly skilled engineers. As the UK's leading centre for semiconductor innovation and supply-chain development, it enables organisations to move from concept to market faster, with lower risk and greater confidence.

Work with the Semiconductor Catapult

The Semiconductor Catapult provides engineering services to accelerate the development and commercialisation of SSTs and related power conversion technologies. Our services include:

- **SST architecture development:** Feasibility studies, converter topology evaluation and architecture selection.
- **AI-assisted converter optimisation:** Multi-objective optimisation to balance efficiency, power density, thermal performance, size and cost.
- **High-frequency transformer development:** Electromagnetic and thermal design, prototyping and experimental validation.
- **Wide-bandgap power electronics:** SiC-based converter design, device selection, integration and control implementation.
- **Engineering simulation and analysis, and testing:** Electrical, thermal and magnetic modelling, power-loss analysis and design optimisation through bespoke high fidelity testing regimes.
- **Prototype development and validation:** Hardware development, testing and experimental verification under representative operating conditions.
- **Advanced packaging:** Power module packaging, thermal management, interconnect technologies and package integration.
- **Collaborative R&D:** Joint technology development, demonstration and technology de-risking to accelerate commercialisation.

At the Semiconductor Catapult, significant work has been undertaken to develop and validate SSTs. Our technical capabilities include SST cell development, optimisation of isolated DC-DC conversion stages, high-frequency transformer design, thermal and magnetic validation, integration of SiC converters, and the development of scalable SST system concepts suitable for higher-power operation.

The following sections highlight key areas of the Semiconductor Catapult's SST capability, showing how advanced modelling, optimisation, hardware development, and experimental validation are being applied to address the technical challenges of next-generation power conversion systems.

AI-assisted optimisation of the SST cell

The Semiconductor Catapult has developed optimisation frameworks that combine conventional optimisation algorithms with machine-learning-based models to accelerate the design of SST converter cells and efficiently evaluate large numbers of converter configurations.

These frameworks incorporate databases of converter components, including capacitors, SiC MOSFETs and high-frequency transformer models. Machine-learning models are used to predict key electrical, thermal and system-level performance metrics, including voltage ripple, semiconductor junction temperature, efficiency, converter volume, system weight and overall cost.

To evaluate competing design objectives simultaneously, the Semiconductor Catapult employs multi-objective optimisation approaches based on genetic algorithms, as illustrated by the workflow in Figure 14. This enables the generation of Pareto-optimal converter designs that represent different trade-offs among efficiency, thermal performance, volumetric power density and cost.

The optimisation framework can also determine key design variables and component selections, including switching frequency, control parameters, capacitor and MOSFET selection, and transformer leakage inductance requirements, while estimating transformer core and copper losses. These outputs support the rapid evaluation and refinement of converter designs before detailed simulation and hardware implementation.

Such optimisation capability is particularly relevant to future AI data centre power systems, where achieving high power density while maintaining efficiency and effective thermal management will become increasingly important.

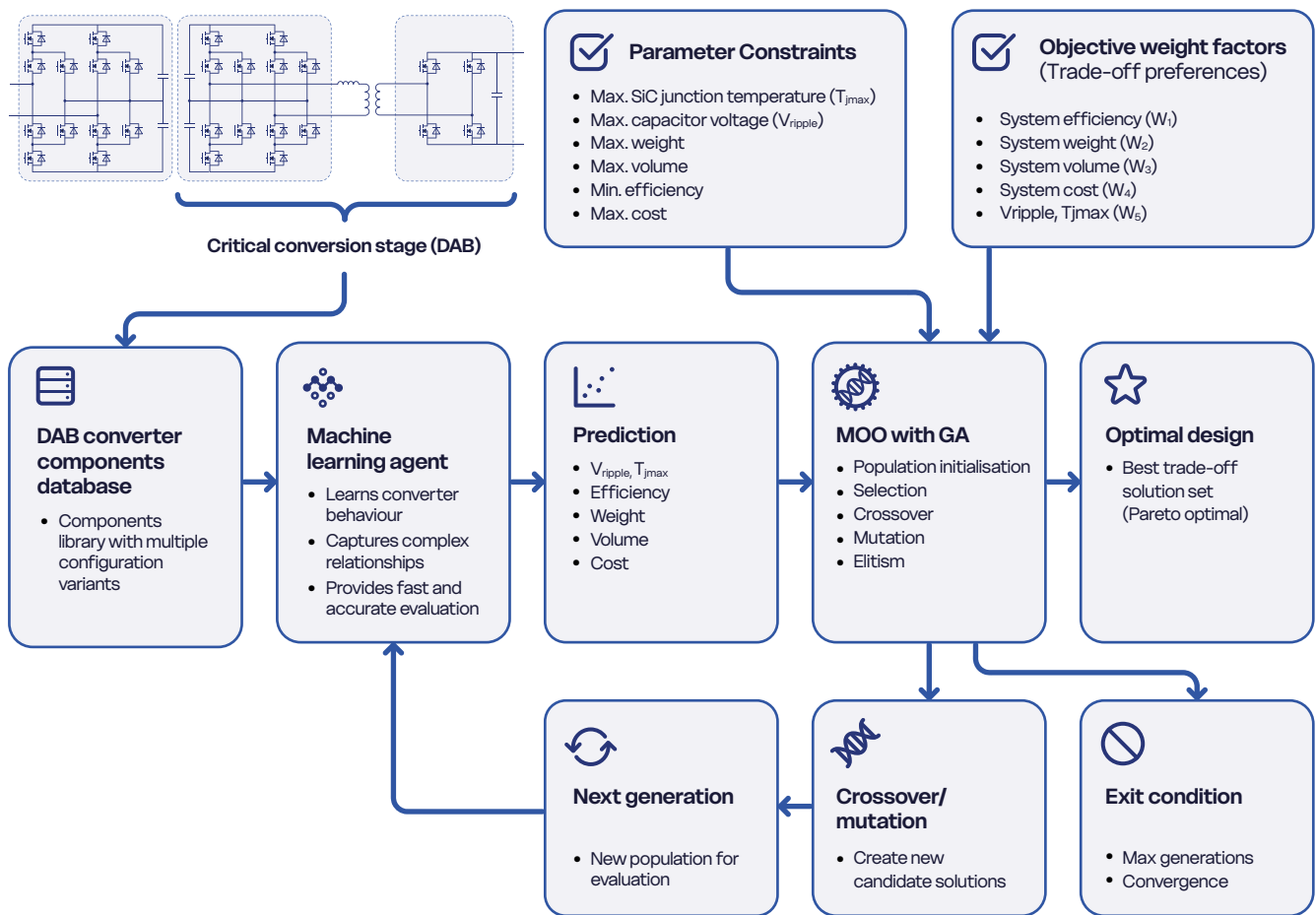


Figure 14: Multi-objective optimisation (MOO) workflow for SST cell design, integrating machine-learning prediction models with genetic algorithms to identify Pareto-optimal converter configurations.

Multi-objective optimisation capabilities

"The Semiconductor Catapult offers multi-objective optimisation services tailored to the development of advanced power electronic systems such as SSTs. By integrating sophisticated modelling tools with industry-relevant algorithms, the Semiconductor Catapult enables engineers to systematically explore complex design trade-offs and identify optimal configurations that align with performance, cost and compliance requirements, ultimately accelerating innovation and deployment in the energy sector."

Chris Davies, Head of Product Marketing

High-frequency transformer development and validation

The Semiconductor Catapult also supports the design, simulation, prototyping and experimental validation of high-frequency transformers for SST applications. Thermal and electromagnetic simulations are used to evaluate cooling performance, temperature distribution and magnetic flux density, supporting the optimisation of transformer designs for high-frequency operation. Examples of these simulation activities are shown in Figure 15.

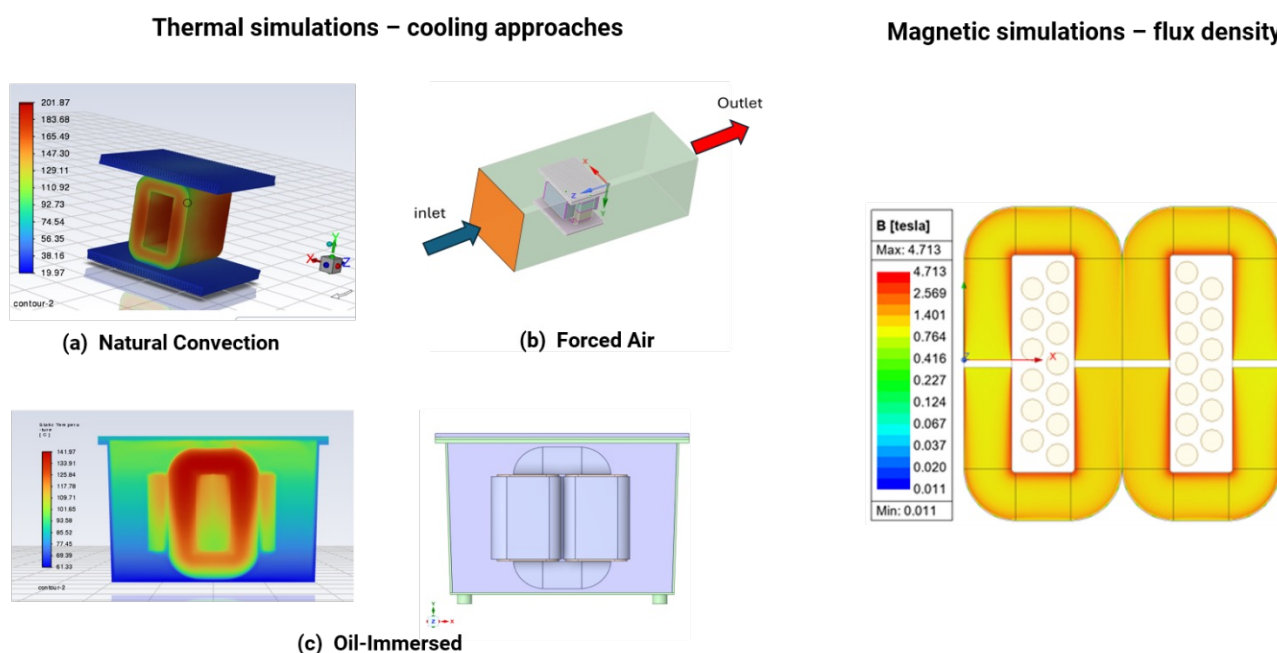


Figure 15: Example thermal and magnetic simulation activities carried out during SST high-frequency transformer development and validation. Thermal simulations were used to evaluate the temperature distribution and cooling performance under natural convection, forced-air cooling and oil-immersed operating conditions, while magnetic simulations were performed to assess transformer flux density and ensure operation below the magnetic core saturation limit. These simulation activities were also used to validate machine-learning-assisted optimisation models prior to progressing to hardware prototyping. (Source: Semiconductor Catapult simulation results)

The Semiconductor Catapult has developed and evaluated several high-frequency transformer prototypes for SST applications, covering a range of leakage inductance and isolation requirements through different winding arrangements and insulation strategies.

Experimental activities include thermal testing, evaluation of transformer saturation behaviour, and comparison of measured performance with simulation results and machine-learning predictions. Together, these activities support the validation of both transformer designs and optimisation methodologies under practical operating conditions.

Advanced packaging capabilities

"At our centre, we are investing in next-generation packaging capabilities – including power module design, 3D heterogeneous integration, and advanced thermal management to support SST development. This is complemented by our expanding facility ecosystem, equipped for high-voltage reliability testing, precision assembly and materials characterisation. Equally important is the development of a highly skilled talent pool. We are actively building expertise in power device packaging, design-for-manufacture and thermal-electrical co-design through dedicated training and partnerships. With the right mix of infrastructure, skills and innovation, advanced packaging will be a key differentiator in delivering scalable, high-performance SST solutions."

Jayakrishnan Chandrappan, Head of Packaging

Integration with SiC power converters

The Semiconductor Catapult additionally develops and validates SiC converter technologies for SST applications. This includes integration of high-frequency transformers with SiC-based power converter architectures to form complete SST cells.

For example, development activities have included three-level ANPC converters using 2 kV SiC devices for medium-voltage operation at around 2.5 kV DC input levels. Secondary-side investigations have also included 800 V-rated two-level SiC converter architectures using 1.2 kV SiC modules, as shown in the representative converter platforms in Figure 16. The use of 800 V output architectures aligns with the increasing industry transition towards higher-voltage AI data centre power distribution systems.

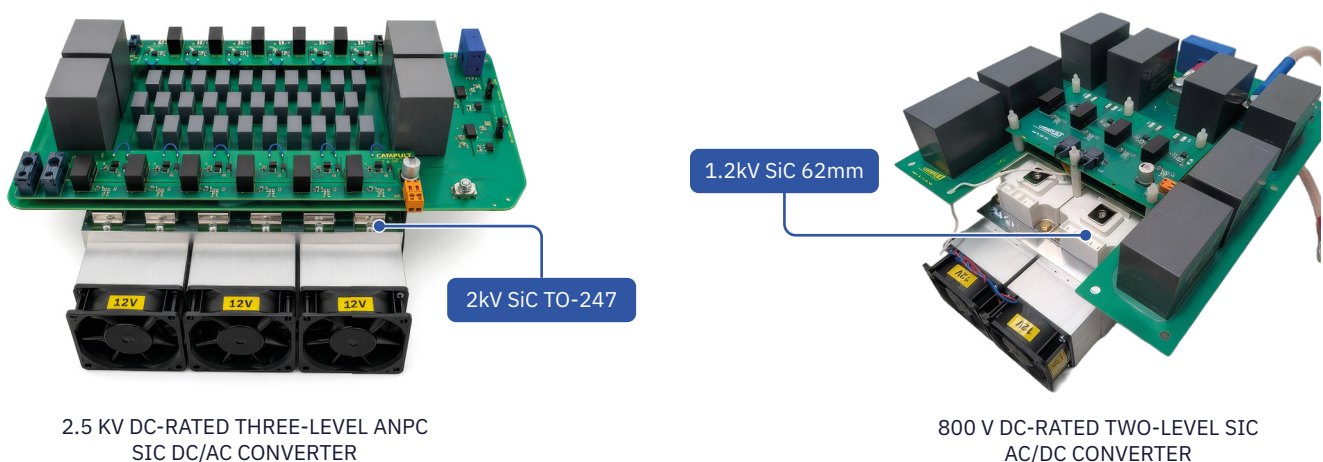


Figure 16: Representative SiC converter platforms, including a 2 kV SiC three-level ANPC converter (left) and an 800 V-rated two-level converter using 1.2 kV SiC modules (right). (Image source: Semiconductor Catapult)

Project highlight: ASSIST – Advanced SiC for solid-state transformer

Partners: Turbo Power Systems, Clas-SiC Wafer Fab, Alter Technology UK and Semiconductor Catapult

ASSIST aims to establish a sovereign UK supply chain for high-voltage SiC devices with voltage and current ratings that are significantly different from those of devices currently available on the market.

Bringing together Turbo Power Systems, Clas-SiC Wafer Fab, Alter Technology UK and Semiconductor Catapult, the project will establish manufacturing readiness across three levels of the supply chain. It creates end-to-end capability that covers wafer fabrication, device packaging and power electronic converter manufacture.

The high-voltage, high-current SiC MOSFETs developed through the project will transform the proposition for SSTs. It will realise a cost-effective and highly efficient compact solution to help meet future electricity demands.

With the widespread adoption of heat pumps and electric vehicles in the UK, power electronics will play a central role in delivering solutions that provide the necessary flexibility for the electricity distribution network to meet the increased demand.

Experimental waveform measurements are used to validate converter operation and control performance, including phase-shift-controlled power transfer in isolated DC-DC converter stages and active voltage balancing in three-level converter topologies.

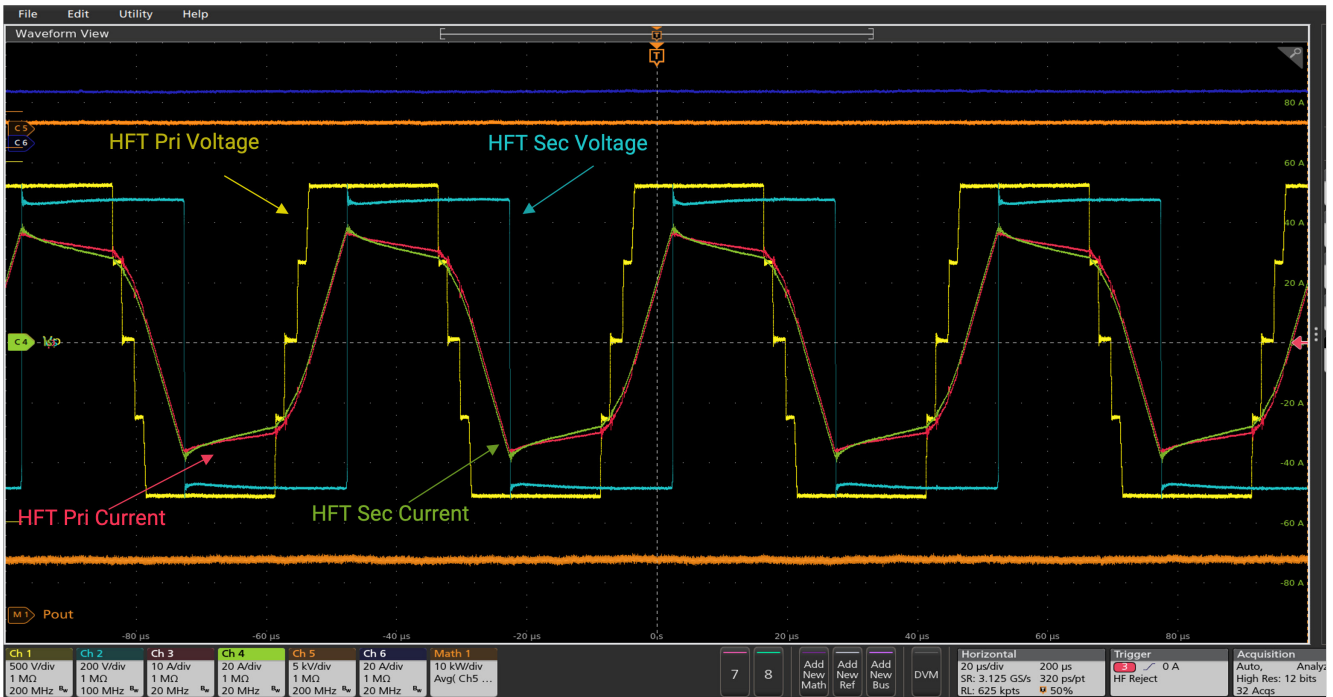


Figure 17: Example waveform measurement results obtained during SST cell testing, showing high-frequency transformer primary and secondary voltages and currents during converter operation. (Source: Semiconductor Catapult experimental data)

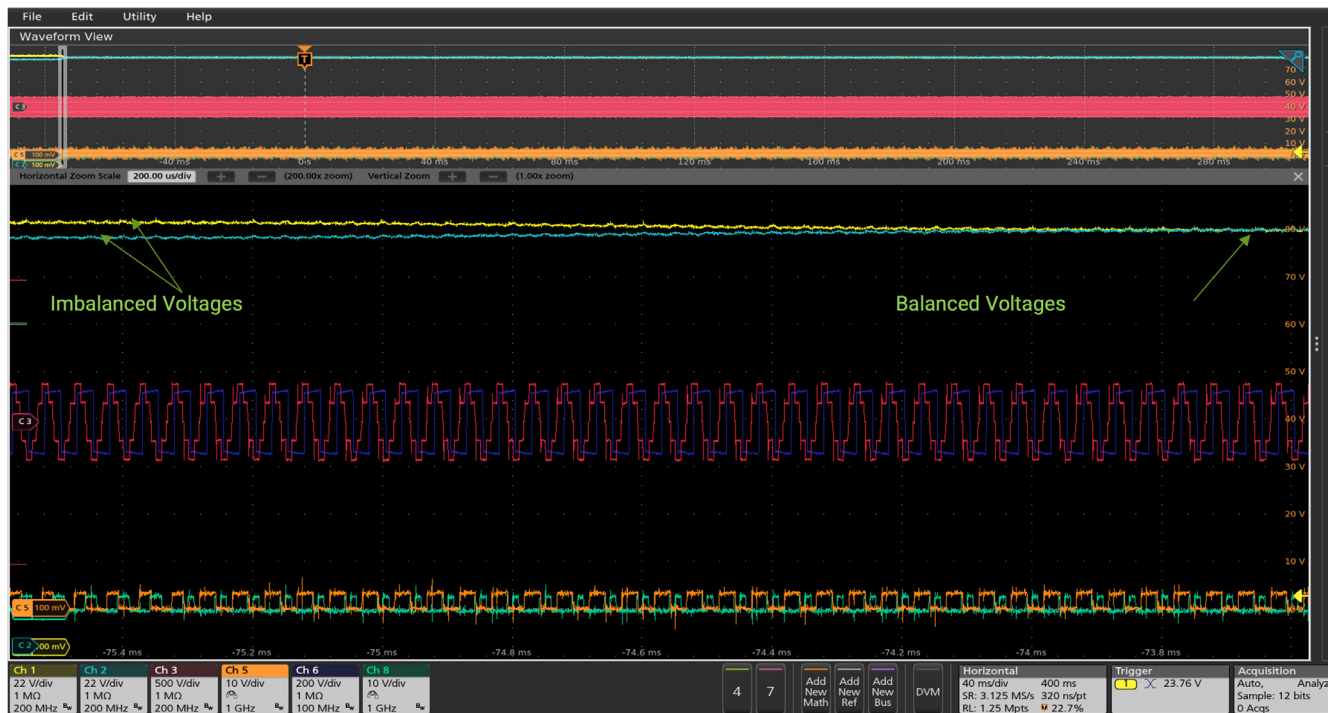


Figure 18: Example voltage-balancing validation results obtained during SST converter testing. (Source: Semiconductor Catapult experimental data)

High-fidelity double pulse testing at the Semiconductor Catapult

The Semiconductor Catapult has launched an advanced double pulse testing service to support the characterisation and optimisation of power semiconductor devices. The platform provides automated extraction of key switching parameters under realistic operating conditions, enabling accurate modelling of switching losses, device behaviour and thermal performance.

Designed to support applications such as AI data centres and emerging higher voltage DC power architectures, the service enables faster device selection, improved system optimisation and reduced technical risk through high-confidence experimental data and hardware validation.

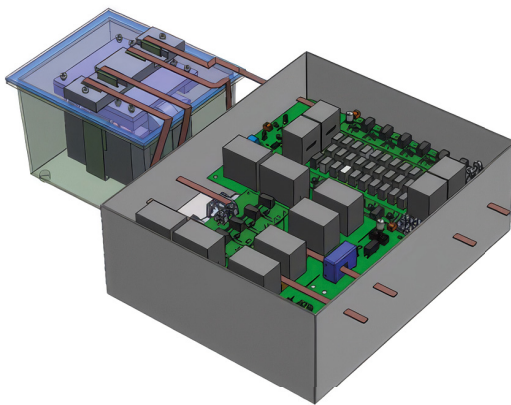
"We have engineered this capability to reflect real world operating conditions, not idealised lab scenarios. We enable accurate modelling and faster design cycles which directly impacts time to market."

Ingo Ludtke, Head of Power Electronics

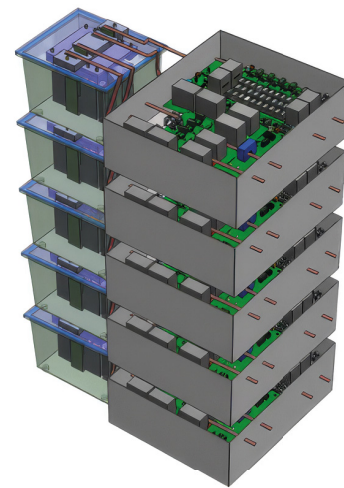
SST scaling concepts for future AI infrastructure

In addition to cell-level development, the Semiconductor Catapult is investigating scalable SST architectures for future medium-voltage and high-power applications. This includes concept studies of compact SST cell structures rated at approximately 100 kW and modular architectures that combine multiple SST cells for higher-power operation.

For example, proposed scaling approaches have investigated modular SST architectures in which converter cells are connected in series on the medium-voltage input side to distribute the input voltage, while their low-voltage DC outputs are connected in parallel to increase overall system power capability. System-level studies indicate that a five-cell configuration could support approximately 500 kW of output power. Increasing the capability of each SST cell to 200 kW could enable the same five-cell architecture to deliver approximately 1 MW of output power.



100 kW* SST CELL INTEGRATION CONCEPT



500 kW* SST SYSTEM INTEGRATION CONCEPT

*Images are illustrative only and do not represent final hardware implementation

Figure 19: Example scalable SST system concepts investigated for future medium-voltage and high-power applications. The figures illustrate compact SST cell integration concepts (left) and modular multi-cell stacking approaches (right) intended to support increased power capability through series- and parallel-connected SST architectures for future high-density power conversion systems. (Image source: Semiconductor Catapult)

Collectively, these capabilities demonstrate expertise spanning the design, optimisation, integration and validation of next-generation SST technologies. By combining expertise in compound semiconductors, power electronics, advanced packaging and intelligent design methodologies, Semiconductor Catapult is helping to accelerate the development and commercialisation of SSTs for future high-density power infrastructure.

Conclusion

AI is no longer simply increasing data centre power demand; it is redefining how power infrastructure must be designed, controlled and integrated. As rack-level power densities move towards megawatt-scale systems, conventional AC-based architectures are becoming increasingly constrained, driving a reassessment of power delivery across future facilities and creating new opportunities for technologies such as SSTs.

The industry is entering a period of significant architectural transition. While AC will remain relevant, particularly in lower-density environments, the industry is moving towards DC power distribution architectures for future high-density AI infrastructure to address efficiency, scalability and thermal challenges. 800 VDC is emerging as a key architecture for next-generation systems, with higher-voltage DC architectures under consideration as power requirements increase.

Within this transition, SSTs are emerging as enabling technologies at the interface between medium-voltage grids and controlled DC distribution. Their value lies in combining voltage transformation, isolation and active control within a single system. This aligns with the needs of high-density AI infrastructure, where dynamic load behaviour, power quality and system-level integration are becoming primary design constraints.

Despite this potential, SST adoption in data centres remains at an early stage. The technology is beginning to move from prototype and pilot systems into commercial deployment, but wider adoption will depend on further validation at scale, operational experience and continued improvements in long-term reliability and system economics.

The direction of industry development is nonetheless clear. SST technology continues to advance alongside growing industry momentum around next-generation data centre power architectures, creating a potential pathway for SSTs to support future medium-voltage to DC power conversion.

For the UK and the wider semiconductor and power electronics ecosystem, this transition also represents a significant opportunity. The shift towards SST-enabled 800 VDC systems, with the potential to evolve towards 1500 VDC in the future, places semiconductor technologies, high-frequency magnetics and advanced power electronics at the centre of future AI data centre power infrastructure.

The Semiconductor Catapult addresses a critical gap in the UK's AI hardware and semiconductor infrastructure by combining world-class engineering expertise, specialist facilities and practical know-how.

The Catapult's role within this landscape is to help bridge the gap between emerging technology and deployable systems. This includes supporting industry in three critical areas: evaluating future power architectures, accelerating the design and optimisation of SST-based systems using AI-driven tools, and de-risking deployment through prototyping, validation and system-level integration.

Ultimately, the next phase of AI infrastructure will be defined not only by advances in compute but by the ability of power systems to evolve alongside it. Continued development and validation will be critical to determining the role that SSTs can play in enabling the next generation of high-density AI data centre power infrastructure.

Further reading

For readers interested in the wider role of solid-state transformers beyond AI data centres, the Semiconductor Catapult previously published **Solid-State Transformers: The Next Evolution in Power Grids and Electrification**, which examines SST fundamentals, architectures, applications, market developments and future opportunities across sectors including power grids, EV charging, rail, marine and aerospace.

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POWERING THE AI FACTORIES OF THE FUTURE

ENABLING GIGAWATT-SCALE AI DATA CENTRE INFRASTRUCTURE WITH SOLID-STATE TRANSFORMERS



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