GE
Grid Solutions

High Voltage Direct Current Systems

imagination at work

Today's Environment

Globally the utility environment is becoming more complex and utilities are having to manage new challenges such as:

- Increasing demand for electricity
- Connection of remote generation
- Growth of distant offshore wind
- Integration of variable renewable generation
- Need for security of supply
- Reduce carbon footprint
- Land costs becoming more expensive
- New right-of-way access permits increasing difficult to obtain

The only choice for many utilities is to restructure their grid systems to manage these challenges. Utilities are looking for cost effective solutions to transfer power and to improve the quality, stability and reliability of the grid which will anticipate their needs for the next 20 to 50 years.

HVDC Overview

High Voltage Direct Current (HVDC) solutions are ideal for supporting existing AC transmission systems or for building new power highways. HVDC is a system which interconnects two AC networks, converting AC voltage to DC voltage, and DC voltage to AC voltage utilizing power electronics technology. HVDC systems enable transfer of power, interconnection of grids, integration of renewables and maximize grid performance.

Move more power, further

Ultra HVDC can operate at voltages up to 800kV enabling bulk transport of electricity over long distances. HVDC systems have lower losses than AC systems and can transmit up to 3 times more power than AC networks. HVDC systems are more economical than HVAC for schemes with transmission distances more than approximately 700 km(~400 miles). The use of insulated cables in both submarine and underground applications, in combination with HVDC, allows more power to be transmitted across long water crossings, or buried out of sight adjacent to roads, railways and tunnels, which may accelerate the permitting process compared to AC or overhead DC transmission alternatives.

Integrate renewables

HVDC is a versatile and flexible technology, making it an ideal solution for integrating renewable energy in modern grids such as remote windfarms, both offshore and onshore. HVDC can provide additional controllability to network operators to support efficient management of transmission of mixed energy sources, including the increasing use of renewables combined with energy storage.

Interconnect grids

HVDC enables the exchange of energy between two AC networks. In some cases, this is the only means of neighboring utilities exchanging energy since they operate at different frequencies or may not be synchronized. An HVDC interconnection has many benefits, such as allowing neighboring utilities to reduce and share 'spinning reserve', giving access to other lower cost sources of energy.

Improve quality, stability and maximize network performance

All HVDC solutions provide a 'firewall' to prevent disturbances propagating from one network to another. They provide fast and highly controllable power transfer and today can provide reactive power into the local AC network to improve stability and quality.

Back to Back HVDC Interconnection

The GE Advantage

GE is globally recognized for designing, manufacturing and delivering customized HVDC solutions for utilities worldwide. GE offers two HVDC technologies, Line Commutated Converters (LCC) and Voltage Source Converters (VSC), for a broad range of applications and available in a range of schemes including overhead line (point to point), back to back, submarine/land cable and offshore.

Every HVDC solution is tailored and designed based on a project-by-project assessment of the customers' individual requirements, whether it's for long distance power transmission, energy trading between independent networks or connection between asynchronous networks. GE offers the complete package including early feasibility studies, project management from network analysis and design, to commissioning. GE is globally recognized for partnering with customers to deliver technically challenging projects for more than 50 years and provides customers with the following benefits:

Robust leading edge technology designed and built in advanced automated manufacturing and testing facilities to maximize quality and system performance

- Customer value driven innovation built on foundational engineering practices that have been developed for more than 50 years
- New, advanced automated manufacturing and test facilities delivering precision, repeatability and quality to meet the exacting requirements of the HVDC industry
- Significant investment in quality systems and resources including one of the largest VSC HVDC demonstration laboratories in the world, state-of-the-art valve test facilities and one of the only HVDC cable ageing laboratories in the industry, ensuring superior technical performance of installed systems
- Pioneered flexible HVDC control methods, for complex applications such as de-icing, and multi-terminal HVDC

Trusted project partner with a collaborative customer engagement model, extensive technical domain expertise resulting in optimized solutions that exceed customer expectations

- Recognized in the industry as having one of the most flexible, engaging and educational collaborative customer models among all HVDC providers, ensuring transparency in all aspects of project execution
- Deep domain expertise, including multiple Uno Lamm award recipients across our global HVDC centers in the USA, India and South Korea, coordinated from our HVDC Center of Excellence in Stafford, UK
- Global EPC capability that leverages GE's combined transmission and power generation project execution excellence through shared partner networks, localized supply chain and industry leading project management practices

State-of-the-art Model Based Design Control System that minimizes project risk and ensures optimal and accurate performance by direct deployment into the system software

- Model based design provides rapid technical responsiveness and support to the customer throughout the project life
- Intuitive graphical interface allows fast, automatic, and error free code generation from control models, providing a greater level of confidence to the customer
- Easy integration of control system software with power system modelling tools such as PSCAD® providing an accurate representation of the power system performance for planning and troubleshooting analysis
- Control system hardware utilizing a modular design, based on commercial-off-the-shelf components, which provides extensive scalability to any project rating while maintaining quick system delivery time and simple life-cycle management

HVDC Valve Hall

GE's HVDC Technologies

Line Commutated Converters

Line Commutated Converter is a mature cost effective HVDC technology based on thyristor power semiconductors, which enables the bulk transfer of power of up to 8 GW with low losses and inherent DC fault protection. LCC is available as point to point overhead line and submarine/land cable and is ideally suited for back to back schemes.

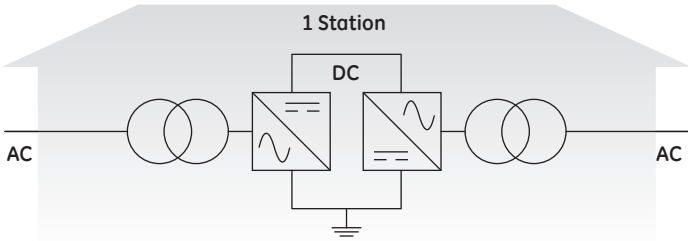
Voltage Source Converters

Voltage Source Converter is a newer technology based on power transistors with a reduced footprint compared to LCC technology. VSC is an ideal technology for submarine/land cable interconnection, integrating renewables, offshore and urban infeed applications. VSC is available as point to point, back to back, submarine/land cable and offshore schemes. VSC has distinct technical advantages over the traditional LCC schemes because it creates an AC waveform that allows the scheme to control real and reactive power independently and transmit real power into a very weak AC network, which is not possible with LCC.

HVDC Schemes

Back to Back Scheme

Suitable for frequency changing and asynchronous connections. This scheme provides fast accurate power flow, limiting the spread of cascading faults and provides increased system flexibility relative to new generation requirements. Once interconnected, the two systems' daily and seasonal cost differences can also be optimized.



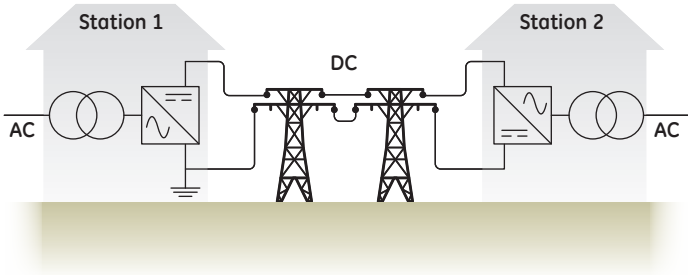
Back to back scheme is suitable for frequency changing and asynchronous connection

Point to Point Scheme

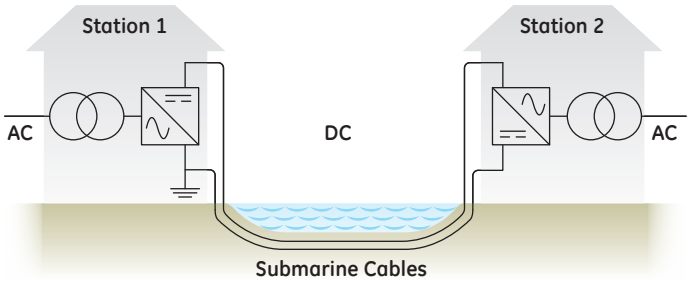
Commonly used for bulk transfer of power applications utilizing overhead lines over long distances providing low cost, fully functional, reliable and environmentally friendly way to transmit power.

Submarine/Land Cable Scheme

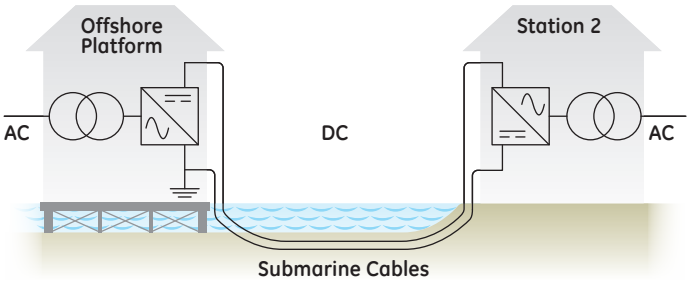
Where the power exchange or transmission crosses water, or an environmentally sensitive region, cables may be the favored method of interconnection between the HVDC Converter Stations. HVDC transmission is particularly attractive and may be the only technically feasible method of transmitting power using cables.



Point to point overhead line is suitable for bulk transmission overland



Point to point submarine cable bulk transmission underwater or underground



Submarine scheme provides bulk transmission from offshore platform to shore

HVDC Applications

Transferring Bulk Power Over Long distances

Challenge

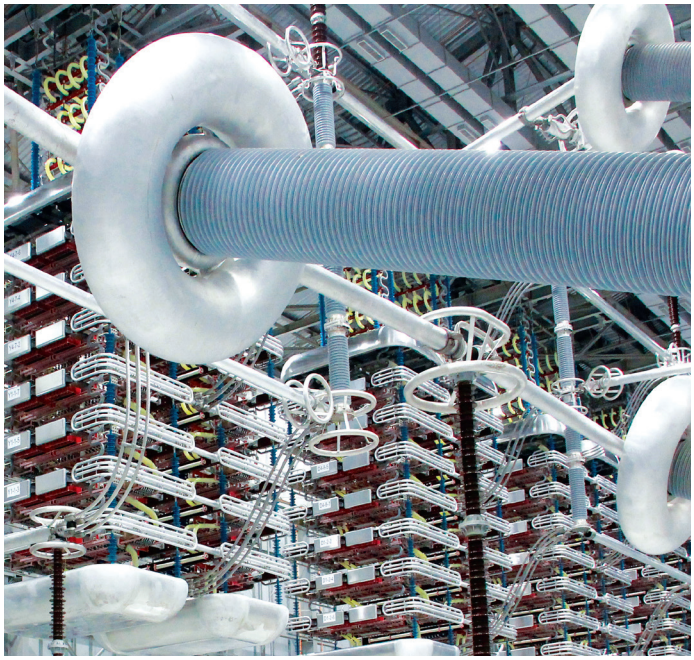
Transfer large amounts of power from distant power sources, such as hydro plants, to a load centre.

GE's solution

GE's HVDC LCC point to point scheme is ideal for the bulk transfer of power utilizing overhead lines over long distances providing a fully flexible, controllable and environmentally friendly solution for transmit power.

Benefits include

- Maximizing transmission of substantial power utilizing UHVDC up to 800kV
- Improves environment impact as a result of the smaller towers and right of way requirements
- Increasing power capacity up to 3 times more than AC circuits



Interconnecting Grids

Challenge

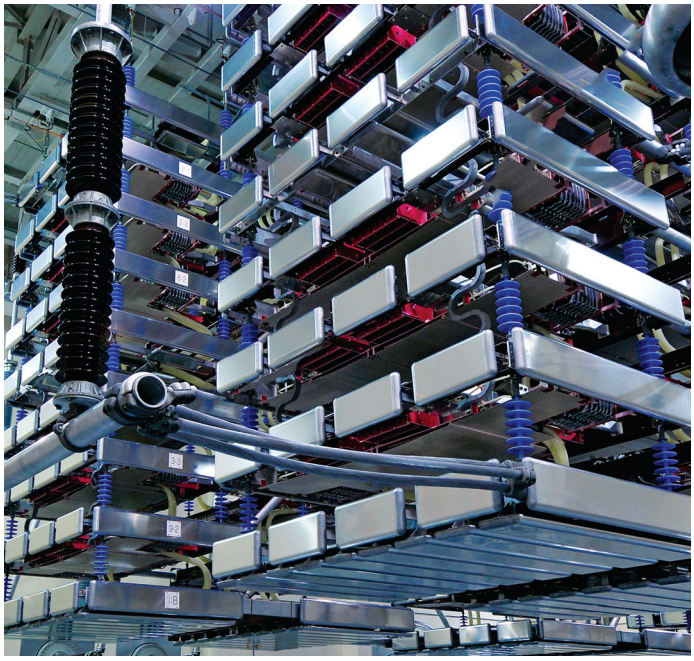
Interconnect asynchronous AC electricity grids to enable energy exchange, which provides dynamic reserve power support, relieve energy bottlenecks and maximize the efficient use of available power.

GE's solution

GE's HVDC back to back schemes are ideal for interconnecting grids operating at different frequencies, not synchronized, operating at high power and in extreme temperatures up to +55° C.

Benefits include

- Exchanges energy between two unsynchronized AC systems
- Provides fully controllable and flexible dynamic reserve power support
- Manages fault propagation providing a power "firewall" between the interconnected networks



HVDC Applications

Connecting Offshore Wind

Challenge

Bring power from distant wind farms to the onshore grid.

GE's solution

GE's HVDC VSC technology is the most economical and feasible solution for connecting submarine cable applications, such as offshore wind farms. GE's solution gives full control and flexibility in managing the intermittent and variable generation.

Benefits include

- Provides a low loss solution, with the most efficient method of transmission technology
- Enables the controllability of intermittent power
- Optimizes the use of submarine cables

Infeed Urban Areas

Challenge

To get power into congested cities to address increasing demand, lack of power highways and difficulties with establishing rights of way for a new grid.

GE's solution

GE's VSC HVDC technology is ideally suited to provide controllable and efficient power into congested areas where small footprint and environmentally acceptable solutions are essential.

Benefits include

- Minimizes the visual impact of the power infeed on the local landscape
- Provides high levels of power injected directly to where it is needed
- Manages fault propagation providing a power "firewall" between the interconnected networks
- Provides lowest loss solution, with the most efficient method of transmission technology

Connecting Renewable Generation

Challenge

Bring power from remote renewable sources to load centres

GE's solution

GE's HVDC LCC and VSC are amongst the most economical and feasible solutions for connecting renewable generation applications, such as wind, hydro and solar power. GE's solution gives full control and flexibility in managing the power flow from the intermittent and variable generation to the load.

Benefits include

- Provides a low loss solution, with the most efficient method of transmission technology
- Enables the controllability of intermittent power
- Improves environment impact as a result of the smaller towers and right of way requirements
- Increasing power capabilities up to 3 times more than AC circuits

Multi-terminal HVDC systems and DC Grids

Challenge

Interconnect three or more regions and power systems to facilitate power exchange and trading, and to provide added system security, efficiency and flexibility to the benefit of the overall grid.

GE's solution

GE's HVDC enables the interconnection of multiple HVDC converters providing controllability of power flow and facilitates the future expansion into HVDC grids.

Benefits include

- Better management and integration of renewable energy generation
- Increases grid security
- Enables cross border energy trading
- Provides more efficient network by reducing reliance on thermal generation

GE's HVDC References

GE has designed, delivered and supports an installed HVDC capacity of more than 35 GW globally in a broad range of applications and environments. The below details are a selected representation of HVDC projects, a complete reference list is available upon request.

1. **Canada**
   Project: McNeill
   Scheme: Back to Back
   Rating: 150MW
   Status: Ongoing
2. **Canada**
   Project: Nelson River
   Scheme: Overhead Line
   Rating & Year: Bipole1-1.6GW, 1973/93
   Rating & Year: Bipole2-2GW, 1978/85
3. **Canada**
   Scheme: De-icer+SVC
   Rating & Year: 250MW, 2008
4. **Canada**
   Project: Lower Churchill
   Scheme: Cable & Overhead Line
   Rating: 900MW Bipole
5. **Brazil**
   Project: Rio Madeira
   Scheme: Overhead Line, 2375 km
   Rating: 3150MW, 600kV
   Status: Ongoing
6. **Brazil-Uruguay**
   Project: Rivera
   Scheme: Back to Back
   Rating & Year: 70MW, 2000
7. **Brazil-Uruguay**
   Project: Melo
   Scheme: Back to Back
   Rating & Year: 500MW, 2016
8. **Sweden**
   Project: Konti-Skan 1
   Scheme: Cable & Overhead Line
   Rating & Year: 380MW, 2006
9. **Sweden**
   Project: South-West Link
   Scheme: 3-Terminal Cable & Overhead Line
   Rating & Scheme: 2 x 720MW (VSC)
   Status: Ongoing
10. **UK-France**
    Scheme: Cable
    Rating & Year: 2000MW, 1986/2012
11. **Germany**
    Project: DolWin3
    Scheme: Offshore
    Rating: 900MW (VSC)
    Status: Ongoing
12. **France-Italy**
    Project: France Italy Link
    Scheme: Cable
    Rating: 2 x 600MW (VSC)
    Status: Ongoing
13. **Sardinia-Corsica-Italy**
    Project: SACOI
    Scheme: Cable & Overhead Line
    Rating & Year: 380MW, 3-Term, 1967/85/93
14. **Saudi Arabia**
    Project: GCCIA
    Scheme: Back to Back
    Rating & Year: 3 x 600MW, 2009
15. **South Africa-Mozambique**
    Project: Cahora Bassa
    Scheme: Overhead Line
    Rating & Year: 1920MW, 1978
16. **India**
    Project: Chandrapur
    Scheme: Back to Back
    Rating & Year: 2 x 500MW, 1997
17. **India**
    Project: Champa-Kurukshetra I/2
    Scheme: Overhead Line 1305 km
    Rating: 2 x 3000MW/800kV
    Status: Ongoing
18. **India**
    Project: Vizag
    Scheme: Back to Back
    Rating & Year: 500MW, 1999
19. **India**
    Project: Sasaram
    Scheme: Back to Back
    Rating & Year: 500MW, 2001
20. **China**
    Project: Lingbao 2
    Scheme: Back to Back
    Rating & Year: 750MW, 2009
21. **China**
    Project: 3G-Shanghai 2
    Scheme: Overhead Line 970 km
    Rating & Year: 3000MW/500kV, 2010
22. **China**
    Project: Nindong-Shandong
    Scheme : Overhead Line 1355km
    Rating & Year: 4000MW/660kV, 2011
23. **South Korea**
    Project: Buk-Dangjin-Godeok
    Scheme: Cable 34 km
    Rating: 1500MW/500kV
24. **South Korea**
    Project: Jeju-Jindo
    Scheme: 122 km Cable
    Rating & Year: 400MW/250kV, 2013
25. **South Korea**
    Project: Jeju-Haenam
    Scheme:100km Cable
    Rating & Year: 300MW/180kV, 1999
26. **China-Russia**
    Scheme: Back to Back
    Rating & Year: 750MW, 2009

Energy Consulting

GE has a dedicated staff of consultants that provide engineering, technical support and expertise to the electrical power industry to support HVDC projects worldwide. Below are details of the support and services GE provides its customers.

Transmission network planning and operational studies

GE's technical subject matter experts, contribute towards advancements in the electric power industry through supporting the following activities:

- Long-term scenario based planning for bulk power transmission investments
- Mid-term investment planning for regional transmission adequacy and security
- Short-term operational planning for maintenance and construction related congestion planning
- Near real-time or real-time system security analysis for congestion and transmission capability analysis

Post-disturbance analysis (model validation studies)

- Establish an understanding of the performance of the power system and its components under stressed and/or extreme conditions
- Consequently validate the models that are applied for design, planning and operation of transmission network and its equipment

Pre-specification studies of new or refurbished equipment

- Analysis and studies on the refurbishment of existing controls and valves to support equipment replacement
- Technical and economic studies to evaluate and support building of new HVDC systems

Converter Transformers

Advanced Manufacturing and Testing

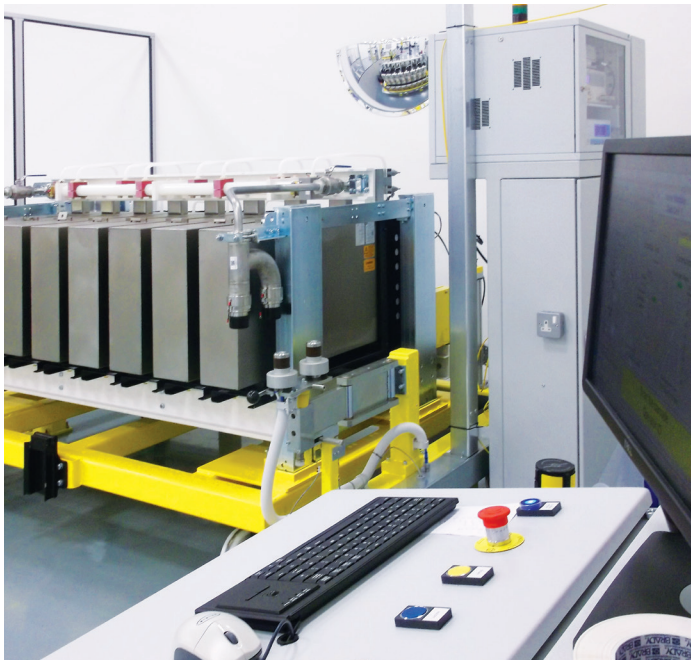
GE's Manufacturing Facility

GE designs, manufactures and tests to the high industry standards at its state-of-the-art manufacturing facilities. GE has an excellent track record in safety and is dedicated to the research, application and development of an extensive range of technology solutions for customers in the utility and energy industries

Assembly and Automated Production Testing

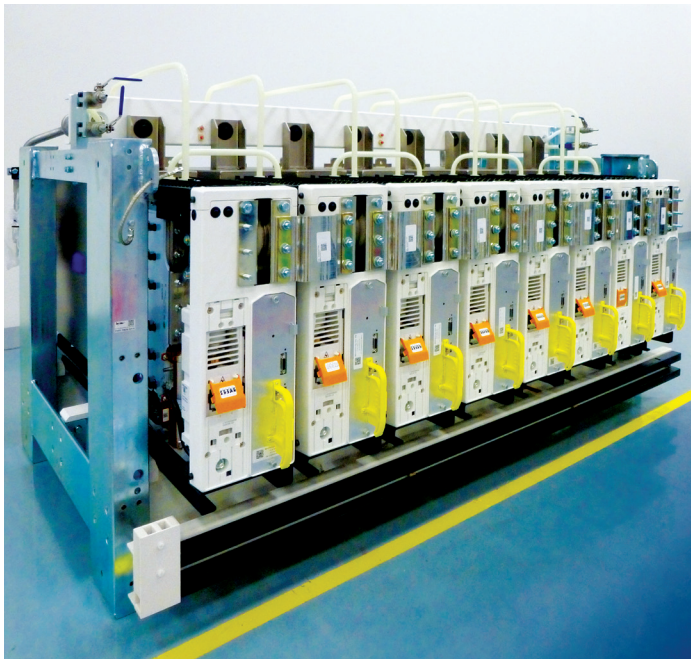
GE's manufacturing processes and tools have been designed to be applied as a "flow" production line, from initial assembly to final product testing. This results in increased quality, decreased cycle times and improved safety. The product testing has been designed and developed as functional test applications that are applied to every project to confirm 100% adherence to electrical, mechanical and cooling requirements.

VSC sub module end of line production test



VSC module end of line production test

VSC Sub Module

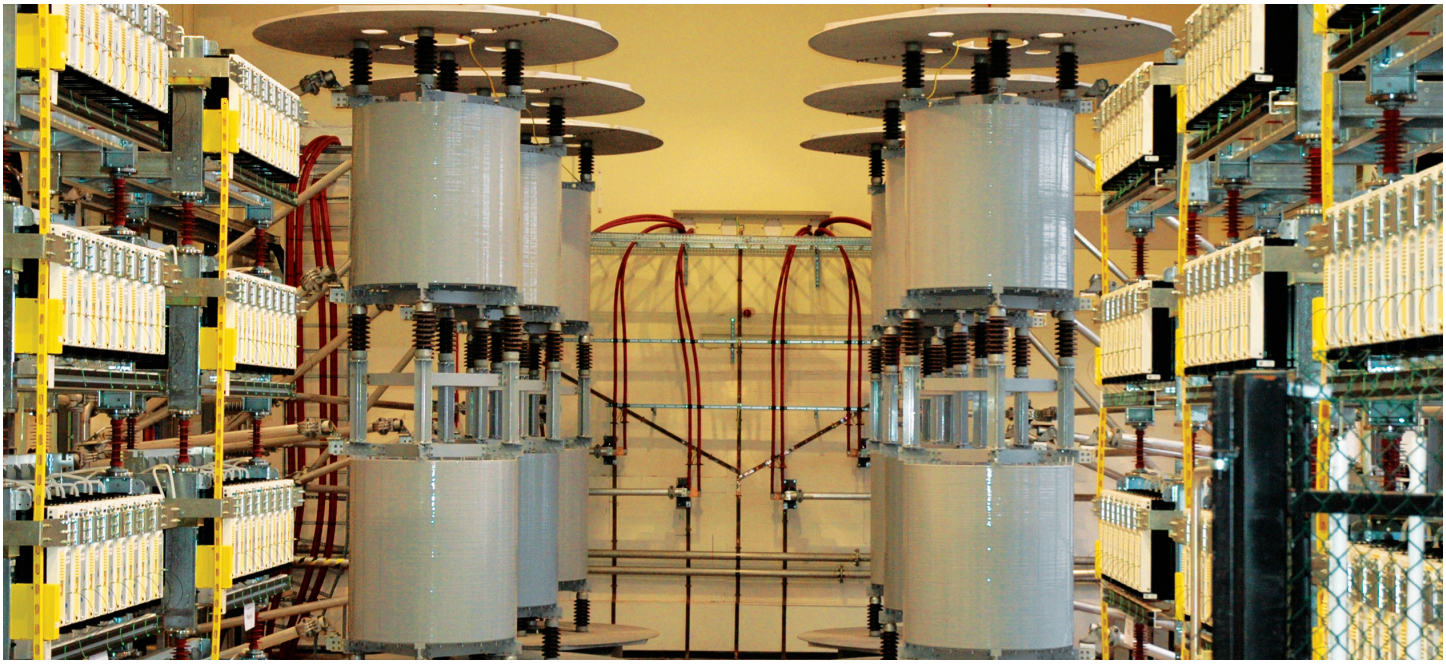


VSC module

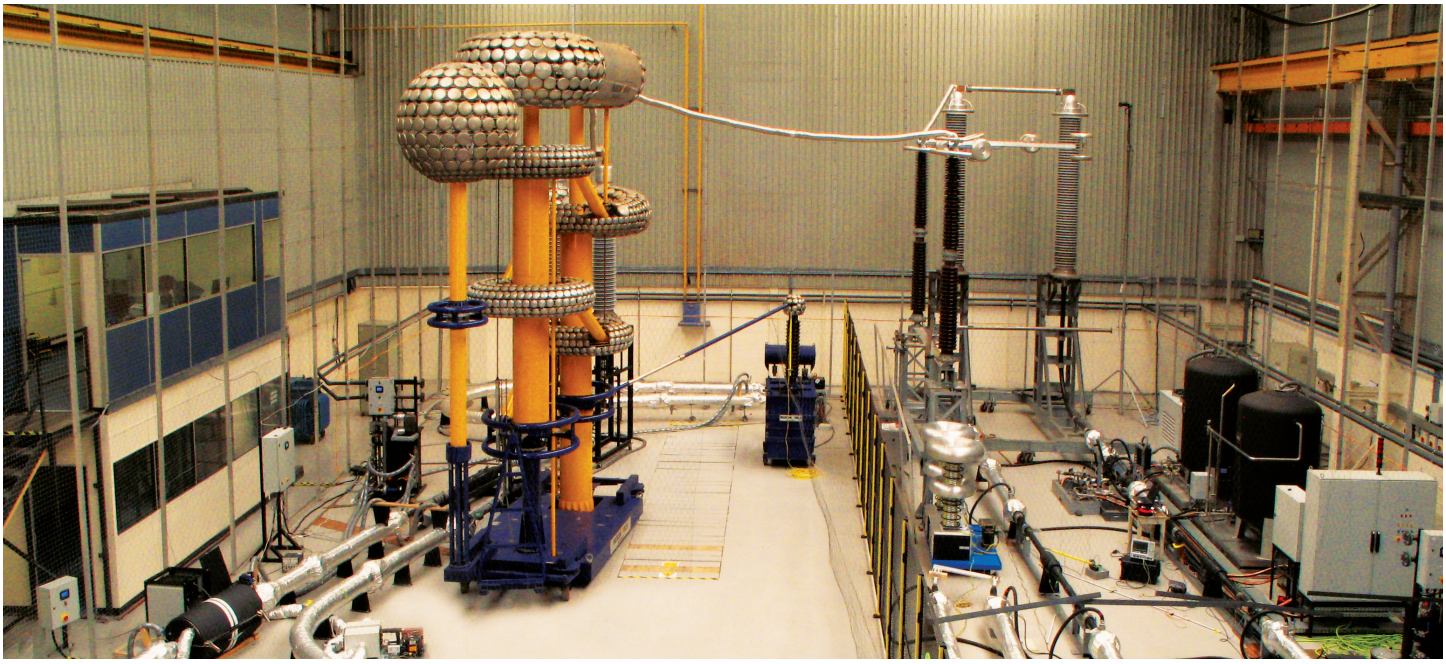
Advanced HVDC System Testing Capability

GE has made significant investment to develop industry leading HVDC system testing capability. GE has a history of many "1st" in HVDC technology development, including innovative ways to test and validate the technology. GE was the 1st to introduce the concept of a synthetic test circuit, which has now been widely adopted by all of the manufacturers of HVDC systems. Similar innovation and investment have been made in the following areas as well:

- One of the largest VSC HVDC demonstration laboratories in the world
- State-of-the-art valve test facility
- One of the only HVDC cable ageing laboratories in the industry
- The industries only model-based control system, validated in GE's world-class RTDS laboratory



VSC Demonstrator



Cable Ageing Laboratory

For more information about
GE's HVDC Systems visit

GEGridSolutions.com/HVDC

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