

Grid Solutions

HIGH VOLTAGE DIRECT CURRENT SYSTEMS



GE VERNOVA

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 Vernova Advantage

GE Vernova is globally recognized for designing, manufacturing and delivering customized HVDC solutions for utilities worldwide. GE Vernova 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 Vernova offers the complete package including early feasibility studies, project management from network analysis and design, to commissioning. GE Vernova 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 a state-of-the-art valve test facility, one of the largest RTDS(R) laboratories in the industry to perform real-time power system simulation and a new, multi-function Center of Excellence in Stafford, UK where Engineering, Design, Manufacturing and R&D are co-located to support team based execution
- 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 Vernova'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, Elumina™, 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



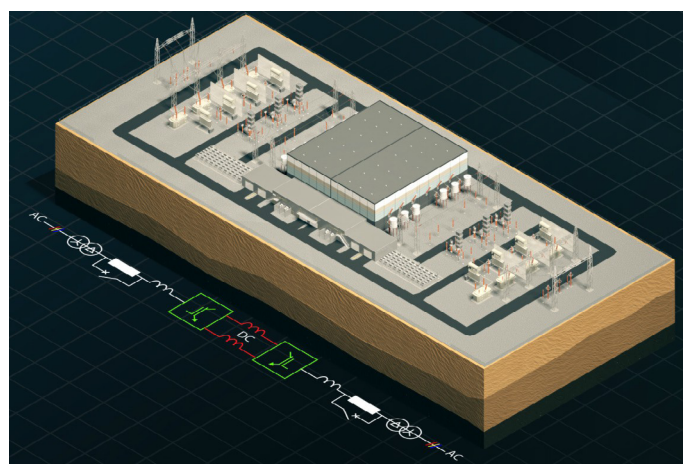
GE Vernova's HVDC Technologies

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.



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

HVDC Schemes

Back to Back Scheme

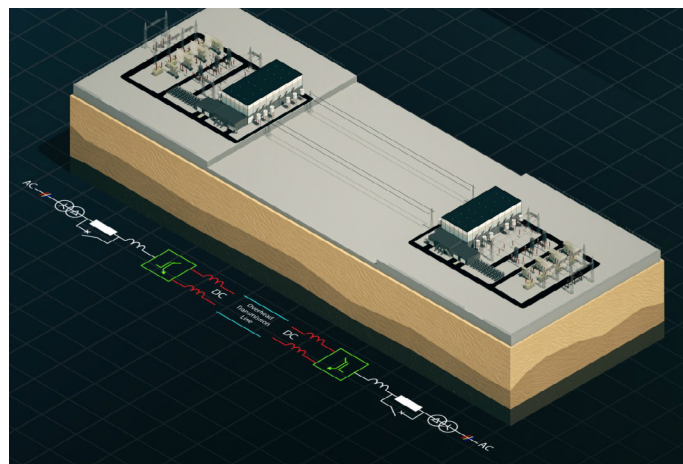
Suitable for frequency changing and asynchronous connections. This scheme provides fast accurate power flow, limiting the spread of cascading faults and provides increased system flexibility relative to new generation requirements. Once interconnected, the two systems' daily and seasonal cost differences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

Point to Point Scheme

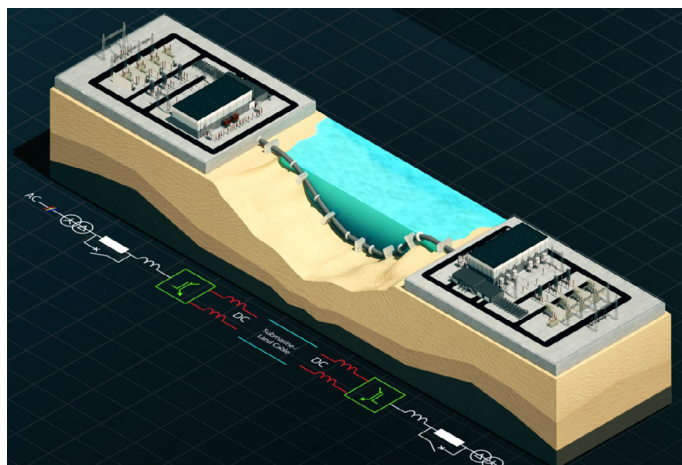
Commonly used for bulk transfer of power applications utilizing overhead lines over long distances providing low cost, fully functional, reliable and environmentally friendly way to transmit power.

Submarine/Land Cable Scheme

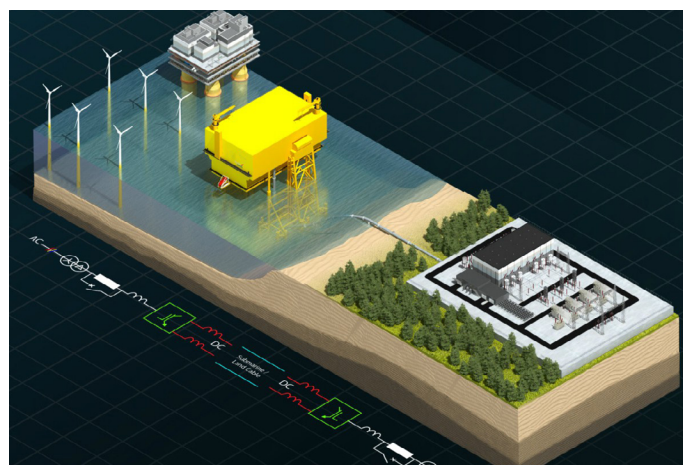
Where the power exchange or transmission crosses water, or an environmentally sensitive region, cables may be the favored method of interconnection between the HVDC Converter Stations. HVDC transmission is particularly attractive and may be the only technically feasible method of transmitting power using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

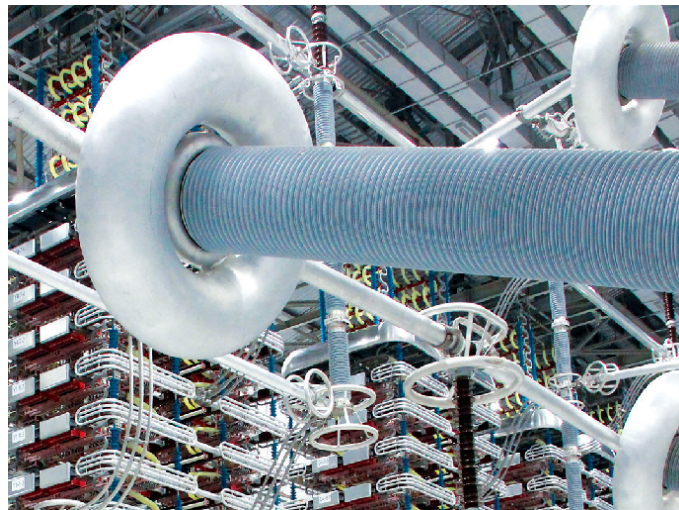
Transfer large amounts of power from distant power sources, such as hydro plants, to a load centre.

GE Vernova's solution

GE Vernova'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

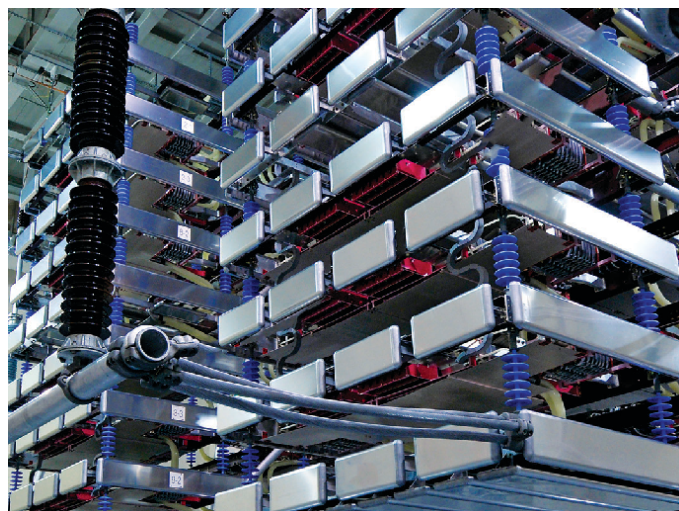
Interconnect asynchronous AC electricity grids to enable energy exchange, which provides dynamic reserve power support, relieve energy bottlenecks and maximize the efficient use of available power.

GE Vernova's solution

GE Vernova'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

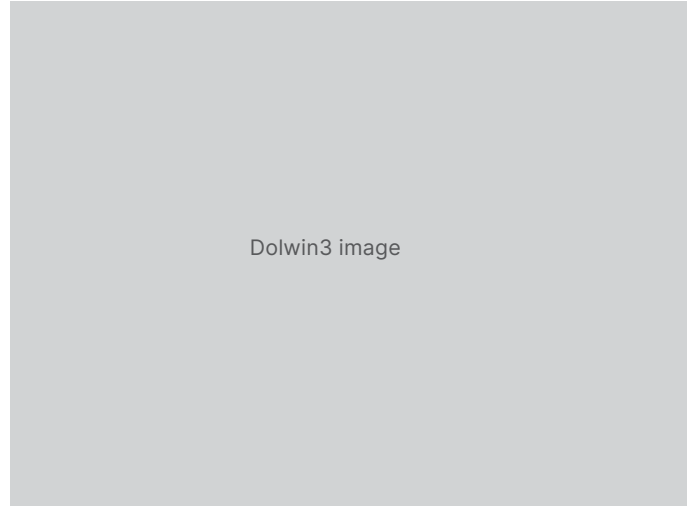
Bring power from distant wind farms to the onshore grid.

GE Vernova's solution

GE Vernova's HVDC VSC technology is the most economical and feasible solution for connecting submarine cable applications, such as offshore wind farms. GE Vernova'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



Urban Area Infeed

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 Vernova's solution

GE Vernova'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
- Additional functions in VSC offer dynamic, local response to events, limiting the impact of faults and disturbances.
- 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 Vernova's solution

GE Vernova'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 Vernova'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 Vernova's solution

GE Vernova'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 Vernova's HVDC References

GE Vernova 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
- 2. Canada**
Project: Nelson River
Scheme: Overhead Line
Rating & Year: Bipole1-1.6GW, 1973/93
Rating & Year: Bipole2-2GW, 1978/85
- 3. Canada**
Project: Levis De-icer
Scheme: World's 1st HVDC De-icer + SVC
Rating & Year: 250MW, 2008
- 4. Canada**
Project: Labrador Island Link (LIL)
Scheme: Cable & Overhead Line
Rating: 900MW Bipole
- 5. Brazil**
Project: Rio Madeira
Scheme: Longest scheme in the world when built, 2375 km
Rating: 3150MW, 600kV
- 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: World's 1st VSC hybrid Cable & Overhead Line
Rating: 2 × 720MW (VSC)
- 10. UK-France**
Project: IFA2000
Scheme: World's Highest Power Submarine Cable / Most Utilized Interconnector When Built
Rating & Year: 2000MW, 1986/2012
- 11. Germany**
Project: DoWin3
Offshore Wind
Scheme: 80 km Submarine Cable
Rating: 900MW (VSC)
- 12. France-Italy**
Project: France Italy Link
Scheme: Cable
Rating: 2 × 600MW (VSC)
- 13. Sardinia-Corsica-Italy**
Project: SACOI
Scheme: World's 1st 3-terminal HVDC Link
Rating & Year: 380MW, 3-Term, 1967/85/93
- 14. Saudi Arabia**
Project: GCCIA
Scheme: Back to Back
Rating & Year: 3 × 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 × 500MW, 1997
- 17. India**
Project: Champa-Kurukshetra 1/2
Scheme: Overhead Line 1305 km
Rating: 2 × 3000MW/800kV
- 18. India**
Project: Visakhapatnam (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 - Highest Rated 12-Pulse Bridge in the World, 2011
- 23. South Korea**
Project: Buk-Dangjin-Godeok
Scheme: Cable 34 km
Rating: 3000MW/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, World's 1st LCC with Black Start Capability
Rating & Year: 300MW/180kV, 1999
- 26. China-Russia**
Project: Sino Russia
Scheme: Back to Back
Rating & Year: 750MW, 2009
- 27. United Kingdom**
Project: Sofia Offshore Wind
Scheme: 220 km Submarine Cable
Rating: 900MW (VSC)
- 28. South Korea**
Project: East Power 1
Scheme: xxxx
Rating: xxx

Energy Consulting

GE Vernova 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 Vernova provides its customers.

Transmission network planning and operational studies

GE Vernova'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 Vernova's Manufacturing Facility

GE Vernova designs, manufactures and tests to the highest industry standards at its state-of-the-art manufacturing facilities. GE Vernova 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



VSC sub module end of line production test



VSC sub module

Assembly and Automated Production Testing

GE Vernova'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 module end of line production test



VSC module

Advanced HVDC Valve Testing Facility

GE Vernova has a long history in developing what ultimately became adopted by the industry as the premier method of testing HVDC valves. In 2019, GE Vernova has again set a new standard in both LCC and VSC valve testing with the introduction of the state-of-the-art Valve Test Facility in Stafford, UK

Testing of HVDC Valves

Type tests for HVDC valves are defined in IEC 60700-1 (for LCC valves) and IEC 62501 (for VSC valves). These standards define several categories of testing; however, the most challenging category of test is the “operational tests” that demonstrate the ability of the valve to withstand the repetitive voltage and current stresses occurring alternately during normal operation. With currents of several kiloamperes and off-state voltages of hundreds of kilovolts for the valve as a whole, such circuits are challenging to design and build without requiring very powerful test supplies.

GE Vernova introduces a new and novel approach to HVDC valve testing, utilizing full-bridge MMC valves at the heart of the solution.

Introduction to the New Test Facility

The MMC topology has transformed the HVDC industry, allowing the flexibility of VSC to be achieved with power ratings and efficiency that are now starting to challenge those of LCC technology. Accordingly, when the need was identified to build a new, purpose-built HVDC Valve Test Facility (VTF), it was fitting that MMC valves should be at the heart of the new test circuit.

The new VTF makes use of the fact that MMC valves are effectively “controllable voltage sources”. It therefore stands to reason that if a sufficiently large and powerful MMC valve is used (and provided with a source of energy to make up the losses in the circuit) then it

can be used as a current or voltage “arbitrary waveform generator” and take the place of both the high-current and high-voltage parts of the older synthetic test circuit. This allows the test circuit to be made considerably simpler than the classic synthetic test circuit.

The programmable waveform generator is constructed from four series arrays of Full-Bridge MMC submodules, with 48 submodules in each array. By using this number of submodules, the test circuit is capable of producing a repetitive test voltage far in excess of what is required by the International Standards, with a test current in LCC mode of up to 6000A.

In series with each of the four arrays of Full-bridge submodules is a multiple-tapped reactor, which allows the effective commutating reactance for the project to be adjusted to accurately represent the conditions for the valve under test. This is particularly important for testing LCC valves.

The circuit also includes an impulse generator which can be used to apply carefully-timed impulses of various different front-times to the valve during the recovery interval, which is an essential requirement of the type tests for an LCC valve operated under inverter conditions. For the slower front times, such as 100µs, the Full-Bridge valves of the main operational test circuit can be used as the impulse generator.

In addition, provisions are made to perform the IGBT turn-off tests and diode overcurrent tests required for the testing of VSC valves.

GE Vernova has now built a new, purpose-built test facility which allows the testing of HVDC valves to be taken to new levels of waveform fidelity. The test plant is located in Stafford, UK, near GE Vernova's HVDC Centre of Excellence and is capable of testing both LCC and VSC valves to voltage and current levels higher than are required today or in the foreseeable future.



For more information, visit
gevernova.com/grid-solutions

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