HVDC PLUS – the decisive step ahead
Stabilized power flows improve transmission grid performance
An ever-increasing demand for energy, a steadily growing share of intermittent renewable resources, and a decrease in conventional power generation are the challenges facing today’s power markets.

**Better grid performance**
Grid operators are faced with ever-increasing requirements when it comes to grid stability, power quality, and reliability. In times of booming renewable power generation and decreasing conventional power generation, they need efficient, innovative solutions to keep the transmission system stable and reliable, and to maintain the safety and security of the supply at all times.

**Improved grid access**
Another challenge is providing grid access, either for remote renewable power generators such as offshore wind farms or for remote load centers like oil rigs. In all cases, transmission capacity is crucial for success, which means providing maximum availability, reliability, and flexibility.

**Lowest CAPEX and OPEX**
At the same time, customers need competitive solutions over the entire lifecycle. Investment budgets are small, and so reduced operating and lifecycle costs are imperative. Compact, adaptable, and maintenance-friendly solutions are also required.
Flexibility and power quality
In today’s power grids, flexibility and power quality are in high demand. HVDC can provide optimum solutions for your specific transmission tasks. This requires:
• Efficient use of HVDC technology with any project-specific adapted voltage rating.
• An HVDC point-to-point transmission system, which can optionally expand into a multi-terminal system with three or more converter stations.

Maintaining the highest standards
An HVDC solution that improves your existing grid infrastructure needs to address the following aspects:
• Maximum availability
• Stabilization of the AC network
• Future-oriented, flexible solutions as a response to varying power market requirements
• Ability to provide grid access of renewable energy sources
• Power exchange between interconnected systems and between asynchronous grids
• Economic, adaptable, and compact solutions
• Maintenance-friendly, safe, and reliable design with comprehensive lifetime services
Siemens has been a pioneer of HVDC technology right from start and continuously driving technology further. HVDC PLUS is our latest development for ensuring economical power transmission and providing controlled power supply to the connected networks.

Versatility at your service
As an innovation leader, Siemens has developed an advanced, universally applicable solution for power transmission with its voltage-sourced converter (VSC) technology HVDC PLUS. The innovative solution offers a controlled power supply in either direction and is ideal as a “firewall” against disturbances developing in highly loaded AC grids. Our HVDC PLUS technology is based on the trendsetting modular multi-level converters (MMC) and offers numerous technical and economical benefits.

Economical and environmental benefits
Environmental constraints play an important role in the development of power systems. HVDC PLUS technology gives top priority to both energy and resource efficiency. For example, the MMCs operate with low switching frequencies, which reduces losses. Due to generation of nearly ideal sinusoidal waveforms on the AC side typically the need for harmonic filtering is eliminated resulting also in less time and costs for planning, engineering, construction, and commissioning. And their compact design means lower space requirements and thus reduced property costs.
The compact footprint can be further reduced e.g. using gas-insulated 320 kV DC compact switchgear. Compared with air insulation, the gas-insulated solution reduces space requirements for the DC switchyard by up to 90 percent.

**Stabilization of AC network**

HVDC PLUS is completely appropriate for steady state and dynamic AC voltage control, independently on each station. Its typical advantages are apparent when weak AC networks are being connected:

- Low dependency on short-circuit power, voltage, and frequency of the AC networks.
- Reactive power can be generated or consumed independent of active power transmission.
- Unbalance control for compensation of large single phase loads.
- During AC transmission network restoration (for example, after a blackout), HVDC PLUS can provide system recovery ancillary service (SRAS).

**Prize-winning health and safety compliance**

We have a clearly defined goal for all our HVDC transmission projects: apply the highest possible safety standard in order to reduce the number of incidents to zero. Our HVDC systems are designed using a risk-based engineering approach to assure a risk-free and safe design, a “safety-first” construction process, and the safe operation of the systems. All projects are executed with the highest health and safety awareness on the part of our management, employees, and partners. Our team on the New Zealand Pole 3 project was recently awarded for outstanding safety achievements.

**Operational advantages**

- A very high level of system reliability, and redundancy for all key components of the converter control.
- Standard control and protection system; hardware and software in hot standby and proven in practice.
- Minimized maintenance and service requirements.
- Compact station design with little high-voltage equipment and typically no harmonic filters.
- Black-start capability to improve speed of recovery of interconnected grids.
HVDC PLUS is a technological breakthrough for highly efficient power transmission. Available applications thus include long-distance transmission via overhead lines and cables as well as network interconnectors and grid access solutions.

**HVDC PLUS interconnectors**

HVDC PLUS interconnectors connect independent national and/or regional grids regardless of their frequency. By converting the AC power into DC and from DC back to AC, the superior features of our HVDC PLUS converters help to stabilize and improve the grid operation and all grid code requirements can be met. One example is a back-to-back interconnector where both converters are at the same location.

**HVDC long-distance transmission**

For covering long distances, HVDC power transmission is often the most efficient and economic solution. In such cases HVDC PLUS is the preferred solution where its superior features are beneficial for the overall project. A variety of media can be used for power transmission: cables, compact transmission lines (CTL), or even existing overhead lines. There are numerous technical solutions that are best discussed with our experts to find the most appropriate configuration for your individual needs.
Grid Access
Siemens offers perfect solutions for HVDC offshore applications. HVDC PLUS is the ideal space-saving solution to provide grid access to offshore wind farms with its dynamic fast control. This helps to make regenerative energy sources fit for the grid, and to connect them according to the conditions of each particular Grid Code by providing the required voltage quality at the grid coupling point.

Our DC Compact Switchgear offers additional space-savings on the platform.

HVDC PLUS provides also power for connecting remote loads:
- from shore to offshore oil and gas platforms and
- for mines

### Multi-terminal connections and future DC grids
In addition to the most commonly applied point-to-point connections HVDC PLUS facilitate expansion to multi-terminal systems and further develop to DC grids in the future to back up existing AC grids.

Due to its operation principle to keep the DC Voltage constant in one polarity and to change direction of power transfer by reversing the current, HVDC PLUS ideally suitable for multiterminal applications.

This enables to develop HVDC transmission solutions stagewise and provides high flexibility to expand existing schemes in case of future changes in power grids or load flow scenarios.

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<td>Converter transformers</td>
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<td>Cooling</td>
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<td>AC switchyard</td>
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<td>4</td>
<td>Control and protection</td>
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<td>5</td>
<td>DC compact switchgear</td>
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<td>6</td>
<td>DC yard</td>
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<td>7</td>
<td>Converter hall</td>
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The next generation of power modules for more than 2 kA

The highly efficient HVDC PLUS half-bridge topology is used for most HVDC PLUS applications today. It has also been used for connecting offshore wind parks in the North Sea to the German national grid.

Further, the technology has proven its supremacy in the INELFE project linking France and Spain as the world’s most powerful VSC link at 2 x 1,000 MW.

This technology also features our latest innovation, the new half-bridge module based on cutting-edge IGBT technology with a DC current capability of more than 2 kA, which fits to the new development in XLPE cable technology. Its high power density results from its 6.5 kV voltage class, and means that a reduced converter hall size can be used. By a smaller number of submodule levels, losses are lowered even more.

Half-bridge type MMC:
The power capacitor can be connected in one polarity to the terminals.
For HVDC overhead line configurations, MMC in full-bridge topology is the right choice, as this allows for selective clearing of line faults. The graph shows a typical HVDC PLUS full-bridge topology design.

The power capacitors can be connected to the terminals at either polarity. This means that the DC voltage is independent of the AC voltage and can be controlled to zero or even be entirely reversed to maintain current control on the AC and DC sides and also under short-circuit conditions. The DC voltage can also be controlled over a wide range, including both polarities. HVDC PLUS technology from Siemens is based on strategies proven in a wide range of industrial applications of VSC technology, and offers the following advantages:

- Immediate initiation of fault clearing by reversing the line voltage polarity for a short period of time in order to extinguish and de-ionize the electric arc followed by the possibility of multiple restart attempts
- Flexibly controllable DC voltage provides a voltage ramp-up characteristic, which takes into consideration project-specific AC conditions
- Flexible operation at a reduced voltage as a precautionary measure in adverse weather conditions and increased air pollution
- Minimized fault clearance time for multi-terminal systems, when combined with selective fault detection
Optimized support from an experienced partner

Siemens is not only the inventor of HVDC PLUS, we are also the most experienced partner on the market today. And it shows – not just in our leading technology but also in comprehensive lifecycle support and individual services tailored to your needs.

Turnkey solutions – the key to successful projects
If you are planning an HVDC connection, you can rely on our unique expertise. All key components are manufactured in our own facilities, and we have the necessary expertise and worldwide project experience to create turnkey solutions that make for successful projects. This includes our continuous work to further advance the technology. As a result, we were the first to offer HVDC in MMC technology, the first and only supplier of 2 x 1,000 MW with VSC technology, and the first to upgrade an existing HVDC PLUS with black-start capability. This means that we can assume responsibility for the entire lifecycle of your project, from the first analysis through creation of an optimized solution to commissioning – including after-sales services from operation to the reliable supply of spares and more.

Our services span the entire lifecycle
As a partner of industry, Siemens offers the whole spectrum of HVDC after-sales services to help customers get the most out of their HVDC assets. Our services range from standard preventive maintenance services to cyber security and asset management consulting. Retrofit and refurbishment services help customers extend the lifetime of their HVDC assets.
HVDC after-sales services
Siemens is an established service provider that helps you obtain top performance and availability from your HVDC system. This includes minimizing unplanned downtime through preventive and predictive maintenance. We provide a full range of valuable and reliable services.

To increase transparency of your assets:
- On-site condition assessments (“health checks”)
- Condition monitoring and diagnostics
- Remote services
- Asset management and advisory services

To ensure high asset availability:
- Preventive maintenance
- Field service and repair
- Spare parts
- 24/7 expert hotline and technical support
- Obsolescence management

To optimize asset performance:
- Refurbishment
- Upgrade and uprate

To support you in operation management:
- Asset operation
- Spare parts management
- Customer qualification and training
- Cyber security services
In December 2010, RTE and REE as the INELFE joint-venture ordered both stations, which use HVDC PLUS voltage-source converters in a modular multi-level converter arrangement (VSC-MMC) with a transmission voltage of ±320 kV DC. A rated power capacity of 2 x 1,000 MW in both directions makes Baixas-Santa Llogaia the most powerful HVDC VSC transmission system in the world. Power reversal is possible in 150 milliseconds – and the 64.5 km link transmits power via underground cables in trenches and an 8.5 km tunnel through the Pyrenees. The inter-European turnkey project successfully began operations in 2015.

Pioneering converter technology
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Black-start function
The project illustrates the unique capability of the VSC technology to provide an independent exchange of reactive power for each network as well as black-start capability. The latter enables the HVDC system to restart a collapsed network. In preparation for the on-site tests, the black-start sequence was systematically simulated using a generic AC grid representation. During commissioning it was successfully tested on a meshed AC network for the Baixas-Santa Llogaia project by, for example, performing black-start tests in both directions, with resynchronization with either REE’s or RTE’s AC network.

The Baixas-Santa Llogaia interconnection HVDC transmission link between France and Spain is an important component of the trans-European electricity network. The interconnection doubles the capacity for exchanging electrical power between both countries, boosting supply reliability and ensuring that more renewable energy sources can be integrated without endangering the stability of the grid.

HVDC PLUS linking France and Spain: a milestone for Europe’s energy market
Flexible operation of HVDC link
during changing AC system configurations

Three individual active power control modes of operation are available:

• Power set-point control regulates the HVDC according to the utilities’ dispatched active power set points. This control mode is typically required during asynchronous network operation, where all parallel AC lines are out of service or unavailable.

• External power control regulates the HVDC’s ordered active power as a percentage of the interconnected AC power. It is only possible during synchronous network operation, when one or more parallel AC lines are in service.

• AC line emulation is an innovative solution and unique feature of the Baixas-Santa Llogaia project. It has been the preferred mode of control since the start of commercial operation. It regulates the HVDC’s ordered active power as a function of the phase angle over the parallel AC interconnection. No direct operator active power set-point dispatch of the HVDC is needed, but it can be entered if required.

Control system replicas

A replica of the control system was set up to improve future projects, enable network studies, and optimize maintenance. The replicas help to:

• Develop skills and knowledge of HVDC systems
• Investigate interaction phenomena related to HVDC and FACTS devices
• Train engineers and support maintenance activities
• Improve specification and optimize system performance
• Validate future REE and RTE’s project controls modifications
• Study and test multi-vendors and multi-infeed systems

Technical data

<table>
<thead>
<tr>
<th>Customer</th>
<th>INELFE (RTE and REE)</th>
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<tbody>
<tr>
<td>Project name</td>
<td>Interconnection Baixas-Santa Llogaia</td>
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<tr>
<td>Location</td>
<td>Baixas, France – Santa Llogaia, Spain</td>
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<tr>
<td>Power rating</td>
<td>2 x 1,000 MW, symmetrical monopole</td>
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<tr>
<td>Type of plant</td>
<td>HVDC PLUS converters for 64.5 km underground cable power transmission</td>
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<tr>
<td>Voltage levels</td>
<td>± 320 kV DC, 400 kV AC, 50 Hz</td>
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<tr>
<td>Type of converter</td>
<td>MMC in half-bridge topology</td>
</tr>
<tr>
<td>Siemens services</td>
<td>Maintenance technician on site, 24/7 hotline and support</td>
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</tbody>
</table>
Project references

First HVDC PLUS with modular multi-level converter (MMC) technology –

Trans Bay Cable

World’s most powerful HVDC PLUS offshore transmission platform with self-sustaining living quarters in commercial operation –

SylWin 1

World’s first HVDC PLUS with full-bridge converter –

ULTRANET
<table>
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<tr>
<th>Customer:</th>
<th>Trans Bay Cable, LLC</th>
<th>Operational highlights:</th>
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<tbody>
<tr>
<td>Location:</td>
<td>Pittsburg (California) – San Francisco (California), USA</td>
<td>HVDC PLUS enhances the performance of the transmission grid, improves reliability, and reduces maintenance costs. HVDC PLUS is the preferred solution in space-constrained urban environments like San Francisco. After successful commissioning in November 2010, the Trans Bay Cable Project met the California Independent System Operator’s (ISO) planning and reliability standards. The system was upgraded to black-start capability in 2016.</td>
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<tr>
<td>Type of plant:</td>
<td>HVDC PLUS in half-bridge topology connected via an 86 km submarine cable</td>
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<td>Power rating:</td>
<td>400 MW, symmetrical monopole</td>
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<td>Voltage levels:</td>
<td>± 200 kV DC, 230 kV/115 kV AC, 60 Hz</td>
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<tr>
<td>Location:</td>
<td>70 km west of Sylt island near the Dan Tysk wind farm, North Sea – Büttel, Germany</td>
<td>Compact DC solution for low-loss offshore-onshore power transmission and grid connection according to grid code. While grid fluctuations must always be taken into account in wind-based power generation, grid stability and reliability are significantly enhanced thanks to the Siemens HVDC PLUS technology.</td>
</tr>
<tr>
<td>Type of plant:</td>
<td>HVDC PLUS offshore and onshore converters in half-bridge topology connected via 205 km on/offshore cable</td>
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<tr>
<td>Power rating:</td>
<td>864 MW, symmetrical monopole</td>
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<td>Voltage levels:</td>
<td>± 320 kV DC, 155/300/380 kV AC, 50 Hz</td>
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<tr>
<th>Customer:</th>
<th>Amprion GmbH and TransnetBW GmbH</th>
<th>Operational highlights:</th>
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<tbody>
<tr>
<td>Location:</td>
<td>Osterath – Philippsburg, Germany</td>
<td>With its stabilizing functions, high availability for overhead line transmission, black-start capability, and full-bridge topology to clear faults in the DC sections quickly and flexibly, the bipolar ULTRANET HVDC PLUS system delivers high reliability. ULTRANET will be the first link with DC lines placed on existing AC pylons, which will be provided by Amprion GmbH and TransnetBW GmbH.</td>
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<tr>
<td>Type of plant:</td>
<td>HVDC PLUS converters in full-bridge topology connected via 340 km overhead line</td>
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<td>Power rating:</td>
<td>2,000 MW, bipolar</td>
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