An outstanding track record in HVDC projects

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HVDC milestones

2006
Commissioning of the world’s largest Voltage Source Converter HVDC transmission, Estlink, 350 MW.

2005
Commissioning of the world’s first offshore platform HVDC transmission: Troll HVDC Light (2 x 42 MW), Norway.

2002
The world’s largest HVDC converter, 1,500 MW, 500 kV, commissioned in pole 1 of the Three Gorges Changzhou transmission, China. The world’s longest land cable, the Murraylink HVDC Light transmission (220 MW, 180 km) commissioned in Australia.

2000
The world’s first HVDC project with CCC (Capacitor Commutated Converter) commissioned at Garabi, Brazil, 2 x 550 MW back-to-back.

1999
The world’s first commercial HVDC Light (50 MW) project commissioned in Gotland, Sweden.

1994
New world record for HVDC submarine cables: 450 kV, 600 MW, 250 km for Baltic Cable, Sweden - Germany.

1992
The first multi-terminal HVDC transmission, Quebec – New England (2 x 300 MW, ± 500 kV) commissioned.

1989
New world record for HVDC submarine cables: 400 kV, 500 MW, 200 km for Fenno-Skan.

1987
Itaipu bipole 2 (3,150 MW, ±600 kV) commissioned.

1985
Itaipu bipole 1 (3,150 MW, ±600 kV) commissioned.

The 200 MW Highgate back-to-back station commissioned after a record short delivery time of 17 months.

1982
The world’s first project with 500 kV thyristor valves; Inga-Shaba, Congo, transmission (560 MW) commissioned. (Also the world’s longest line – 1,700 km.)

1979
Contract signed for the world’s largest HVDC transmission: Itaipu, Brazil, 6,300 MW, ±600 kV.

1975
The world’s first HVDC transmission project with 12-pulse converters: pole 1 of the Skagerrak link, 500 MW, Norway – Denmark, commissioned.

1970
ABB’s last mercury-arc valve project commissioned: Pacific Intertie (1,440 MW, ±600 kV), USA.

1985
Mercury-arc valve project commissioned: Konti-Skan (250 MW), Sakuma (300 MW) (image) and New Zealand (800 MW).

Development starts on HVDC valve based on thyristors.

1954
First HVDC project.

Over 50 years in HVDC

Back in the Victorian era, the first power stations in Europe and the USA supplied low-voltage, direct current (DC) electricity, but the transmission systems they used were inefficient. This was because much of the generated power was lost in the cables. Alternating current (AC) offered much better efficiency, since it could easily be transformed to higher voltages, with far less power loss. This set the stage for long-distance high-voltage AC (HVAC) transmission.

As the AC systems grew and power increasingly was being generated far from where most of its consumers lived and worked, long overhead lines were built, over which AC at ever higher voltages flowed. To bridge expanses of water, submarine cable was developed. Neither of these transmission media was without its problems, however. Specifically, problems were caused by the reactive power that oscillates between the capacitances and inductances in the systems.

Power system planners therefore started to look again at DC transmission. What had held up High-Voltage Direct Current (HVDC) transmission in the past was the lack of reliable and economic valves that could convert HVAC into HVDC, and vice versa. However, since the end of the 1920s, when ABB’s forerunner ASEA began making static converters and mercury-arc valves for voltages up to about 1000 V, research focused on developing valves for even higher voltages. It was the work led by Dr Uno Lamm in this area that earned his reputation as ‘the father of HVDC’.

By the 1940s, the time was ripe for HVDC service trials. The first installation was at a test station at Trollhättan. After further successful trials, in 1950 Swedish State Power placed an order for equipment for the world’s first authority HVDC transmission link. This was built between the island of Gotland in the Baltic Sea and the Swedish mainland. The concept for that project proved so successful that it has remained basically unchanged.

In 1954, the Gotland HVDC transmission link, with a rating of 20 MW, 200 A and 100 kV, went into operation. A new era of power transmission had begun.

The company’s second HVDC order, a 160 MW link across the English Channel, followed soon after. The success of these early projects generated considerable worldwide interest and in the 1960s several HVDC links were built: Konti-Skan between Sweden and Denmark, Sakuma in Japan (with 50/60 Hz frequency converters), the New Zealand link between the South and North Islands, the Italy – Sardinia link and the Vancouver Island link in Canada.

The largest mercury-arc valve HVDC transmission link to be built by ABB was the Pacific Intertie in the USA in 1970. Originally commissioned for 1440 MW and later uprated to 1600 MW at ±400 kV, its northern terminal is The Dalles, Oregon, and its southern terminal at Sylmar, in the northern tip of the Los Angeles basin.

In all, eight mercury-arc valve based HVDC systems were installed for a total power rating of 3400 MW. Although many of these projects have since been replaced or upgraded with thyristor valves, some are still in operation today, after nearly 40 years of service.
HVDC stands for High Voltage Direct Current, a well-proven technology used to transmit electricity over long distances by overhead transmission lines or submarine cables. It is also used to interconnect separate power systems, where traditional alternating current (AC) connections cannot be used.

In an HVDC system, electric power is taken from one point in a three-phase AC network, converted to DC in a converter station, transmitted to the receiving point by an overhead line or cable and then converted back to AC in another converter station and injected into the receiving AC network. Typically, an HVDC transmission has a rated power of more than 100 MW and many are in the 1,000 – 3,000 MW range.

With an HVDC system, the power flow can be controlled rapidly and accurately in terms of both power level and direction. This possibility is often used to improve the performance and efficiency of the connected AC networks.

ABB pioneered HVDC technology and is the world leader in the HVDC field. In total, about 70,000 MW HVDC transmission capacity is installed in more than 90 projects worldwide. ABB has delivered more than 55 of these projects with a total transmission capacity of more than 45,000 MW. The largest bipole delivered by ABB to date is 6,300 MW.

There are three different categories of HVDC transmission projects:
- Point-to-point transmission
- Back-to-back stations
- Multi-terminal systems.

The first commercial HVDC scheme, based on mercury arc valves was commissioned in 1954. This was a link between the Swedish mainland and the island of Gotland in the Baltic sea. The power rating was 20 MW and the transmission voltage 100 kV

There was a significant improvement in HVDC technology in 1970 when thyristor valves were introduced in place of the mercury arc valves. This reduced the size and complexity of HVDC converter stations substantially. The use of microcomputer control equipment in today’s projects has also contributed to HVDC’s current success as a powerful alternative to AC power transmission.

In 1995 ABB announced a new concept for HVDC converter stations, HVDC with Capacitor Commutated Converters (CCC), which further improves the performance of HVDC transmissions. And in 1997 a completely new converter and DC cable technology called HVDC Light was introduced.

WHY HVDC?
The reasons for selecting HVDC instead of AC for a specific project are often numerous and complex. The most common arguments in its favour are:

1. Lower investment cost
2. Long distance water crossing
3. Lower losses
4. Asynchronous interconnections
5. Controllability
6. Limited short-circuit currents

In general, the different reasons for using HVDC fall into two main groups, namely:
- HVDC is necessary or desirable from the technical point of view (that is controllability).
- HVDC results in a lower total investment (including lower losses) and/or is environmentally superior.

In many cases, projects are justified by a combination of benefits from the two groups. Environmental aspects are also increasingly important and HVDC has the advantage of a lower environmental impact than AC since the transmission lines are much smaller and need less space for the same power capacity.

One of the most important differences between HVDC and AC is the possibility to accurately control the active power transmitted on a HVDC line. This is in contrast to AC lines, where the power flow cannot be controlled in the same direct way. The controllability of the HVDC power is often used to improve the operating conditions of the AC networks where the converter stations are located.

Another important property of an HVDC transmission is that it is asynchronous. This allows the interconnection of non-synchronous networks.
Success Stories

HVDC delivering success

Three Gorges, China is now the world’s largest HVDC user.

China’s Three Gorges Hydroelectric Power Plant will be the largest of its kind in the world, with a generating capacity of over 22 GW by 2009. Power from this plant will be sent to East China by three HVDC lines and to South China by one HVDC line. The East China System and the South China System are asynchronous with the Central China System, so the HVDC links also connect the large AC systems asynchronously.

The total capacity of this HVDC transmission system will be 7,200 MW. It will consist of the 1,200 MW HVDC line Gezhouba – Shanghai commissioned in 1989 by ABB and two 3,000 MW lines. The first of these lines, Three Gorges – Changzhou, was commissioned by ABB in 2003. In 2004 ABB was awarded the contract for converter stations for the second 3,000 MW HVDC transmission to Shanghai, which goes into operation in 2007.

The two 3,000 MW HVDC lines were compared with five 500 kV AC lines and the HVDC option was found to be the most advantageous, considering investments and losses as well as land use.

The transmission to the South China System is another 3,000 MW line, Three Gorges – Guangdong, which is 940 km long. This was commissioned in 2004 to support rapid load growth in the south. HVDC was chosen primarily because of the length of the transmission and also because the two systems are asynchronous.

RAPID CITY TIE

In 2003 ABB installed a back-to-back HVDC transmission system link, interconnecting the eastern and western power grids of the United States. The HVDC system, called the ‘Rapid City Tie’ because it passes close to Rapid City, South Dakota, carries 200 MW of power. ABB completed the contract in only 19 months – six months faster than the industry standard.

The HVDC system provides voltage and frequency support in case of disturbances in either of the grids. ABB designed, manufactured and installed the HVDC system as part of the joint project between Basin Electric Power Cooperative of North Dakota, and Black Hills Power of South Dakota.

CROSS SOUND CABLE INTERCONNECTOR

The Cross Sound Cable Interconnector is a 330 MW, 40 km HVDC Light buried submarine cable system that connects the electric transmission grids of New England and Long Island, New York. The Cross Sound Cable Interconnector provides additional power transfer capability between New Haven, Connecticut and Shoreham, Long Island, in either direction. The purpose of the Cross Sound link is to improve the reliability of power supply in the Connecticut and New England power grids and allow increased sharing of power plant capacity, so reducing the amount of power plant capacity each must have for a particular winter or summer. The connection was also designed to promote competition in the New York and New England electricity markets by enabling electricity to be traded among power generators and customers in both regions.

After the huge black-out in August 2003, a federal order allowed the first use of the Cross Sound Cable Interconnector. The cable interconnection played a great part in getting Long Island out of the dark, and restoring power to hundreds of thousands of customers across Long Island.
ESTLINK – MORE POWER TO THE BALTIC

Estlink, based on ABB’s HVDC Light technology, went live at the end of 2006. It is the first interconnection between the Baltic states and the Nordic countries, and is an important step towards greater energy efficiency in Europe. Linking these two key grids will improve grid reliability and help to avoid future black-outs, as well as contribute to industrial competitiveness and improve supply to consumers.

The 100km cable link, two-thirds of which runs beneath the Gulf of Finland, is oil-free and has no magnetic field – important environmental considerations. An estimated 2TWh of electricity will be transmitted through the cable, which is rated at 350MW with a low ambient overload capacity of 365MW. The two HVDC converter stations at each end of the link will be capable of generating/consuming up to 125Mvars of reactive power independently of each other and independently of the active power transfer.

Estlink is just one of a number of existing and planned projects connecting mainland Europe and the Baltic countries with Scandinavia and the Nordic region.

On land, a 93mm diameter XLPE cable was installed. The submarine cable is also XLPE, with a 96mm diameter and steel armouring.

TROLL A – THE FIRST LAND-POWERED OFFSHORE PLATFORM

In 2005, ABB successfully commissioned an HVDC Light project on behalf of Statoil that made the Troll A platform the first on the Norwegian continental shelf to be powered by electricity generated on land. The project comprised a double circuit, 2 x 40MW subsea cable installation from Kollsnes on land, to Troll A, 67km offshore, to feed two large compressors.

Statoil’s decision to take power from the mainland rather than install generators on the platform was taken for economic and environmental reasons. Conventional platform-based generation, with gas turbines or diesel generators, usually achieves just 25 per cent efficiency compared with land-based combined-cycle generation of 75–80 per cent.

On-platform power generation produces large amounts of CO₂. In the case of Troll A it would result in an estimated 230,000 tons of CO₂ and 230 tons of NOₓ and potentially substantial climate tax liabilities.

MURRAY LINK - AUSTRALIA

The Murraylink 220 MW interconnector between the Riverland in South Australia and Sunraysia in Victoria is a 180 km underground high-voltage power link that is believed to be the world’s longest underground transmission system.

ABB provided a complete HVDC Light transmission system, comprising XLPE cables and converter stations. The order was placed by Murraylink Transmission Company Pty (TransÉnergie Australia) a subsidiary of TransÉnergie, the transmission division of Hydro-Québec, Canada.

Murraylink benefits both South Australia and Victoria by enabling electricity trading in Australia’s deregulated power market. From its near tri-state border site, it can deliver power from South Australia, Victoria, New South Wales and the Snowy River generation in either South Australia or Victoria. Murraylink used existing corridors and required no private easements, nor use of private land.

HVDC CONTROL SYSTEMS MODERNISED IN RECORD TIME

The 1970s and 1980s generations of HVDC links are approaching the age of 30. Their analog control systems – although still in perfect working order – are in need of modernization to prevent unforeseen outages from occurring.

Recently, ABB has replaced the control systems of two HVDC links in the USA – the CU and Square Butte – with its MACH 2™ control and protection system to secure availability, add new functionality and ensure another 30 years or more of trouble-free performance. The projects set industry benchmarks for rapid project completion and minimal transmission disruption.

Images (clockwise from left): Estlink Cable, Cross Sound Station converter station, Murray Link Cable laying, Square Butte control system upgrade.
HVDC Light® is ABB’s own patented, state-of-the-art, power system designed to transmit power underground and under water, as well as over long distances. It offers numerous environmental benefits, including ‘invisible’ power lines, neutral electromagnetic fields, oil-free cables and compact converter stations.

HVDC Light® is HVDC technology based on voltage source converters (VSCs). With extruded DC cables, power ratings from a few tens of MW up to several hundreds of MW are available.

HVDC Light® cables have extruded polymer insulation (XLPE). Their strength and flexibility make the HVDC Light® cables well suited for severe installation conditions both underground as a land cable and as a submarine cable.

The converter station design is based on VSCs employing state of the art turn-on/turn-off IGBT power semiconductors that operate with high frequency pulse width modulation.

HVDC Light® has the capability to rapidly control both active and reactive power independently of each other, to keep the voltage and frequency stable. This gives total flexibility in location of the converters in the AC system since the requirements of short-circuit capacity of the connected AC network is low (SCR down to zero).

**CONVERTER STATIONS**
The HVDC Light® converter station design is based on a modular concept. For DC voltages up to ±150 kV, most of the equipment is installed in enclosures at the factory. For the highest DC voltages the equipment is installed in buildings. The converter stations have a very small installation footprint on site, while all equipment except the power transformers is indoors. Well-proven and tested equipment at the factory makes installation and commissioning quick and efficient.

The stations are designed to be unmanned. They can be operated remotely or could even be automatic, based on the needs of the interconnected AC networks. Maintenance requirements are determined mainly by conventional equipment such as the AC breakers and cooling system.

**CABLE SYSTEM**
The cable system comprises cables, accessories and installation services. The cables are operated in bipolar mode, one cable with positive polarity and one with negative polarity. The strength and flexibility of the HVDC Light® cables makes them perfect for severe installation conditions:
- The submarine cables can be laid in deeper waters and on rough seabed terrain.
- Ploughing makes installation of land cables very cost effective.

**ENVIRONMENTAL BENEFITS:**
- Magnetic fields are reduced substantially since HVDC Light® cables are laid in pairs with DC currents in opposite directions.
- Risk of oil spill, as in paper-oil-insulated cables, is eliminated.
- The cable insulation is PE based and not dangerous.
- The cable metals can be reused.

**APPLICATIONS**
HVDC Light® is an alternative to conventional AC transmission or local generation in many situations. Possible applications include:
- Connecting wind farms to grids
- Underground power links
- Powering islands
- Oil & gas offshore platforms; power from shore
- Asynchronous grid connection
- City centre in-feed

HVDC Light® was introduced in 1997. A number of underground transmissions up to 350 MW are in commercial operation and more are being built.
Major black-outs in recent years have shown how relatively minor malfunctions in interconnected grids can have repercussions over wide areas. As one link overloads it is tripped, increasing the strain on neighboring links which in turn disconnect, cascading black-outs over vast areas and causing huge productivity losses for the economy.

The solution is a ‘firewall’ permitting the interchange of power but preventing the spread of disturbances. This can be accomplished using an HVDC link since it can fully control transmission but does not overload or propagate fault currents.

**PERFORMANCE UNDER AC SYSTEM FAULTS**

When a temporary fault occurs in the AC system connected to the rectifier (AC to DC), the HVDC transmission may suffer a power loss. Even in the case of close single-phase faults, the link may transmit up to 30 per cent of the pre-fault power. As soon as the fault is cleared, power is restored to the pre-fault value.

When a temporary fault occurs in the AC system connected to the inverter (DC to AC), a commutation failure can occur interrupting power flow. Power is restored as soon as the fault is cleared. A distant fault with little effect on the converter station voltage (less than around 10 per cent) does not normally lead to a commutation failure. A CCC (Capacitor Commutated Converter) HVDC converter can tolerate about twice this voltage drop before there is a risk of commutation failure. HVDC Light® is even more fault-tolerant. Since the converter can control the reactive power and the filters are small, the loss of active power has no impact on the AC voltage.

Another advantage of both HVDC and HVDC Light® transmissions is that they do not contribute to the fault current: the impact on the fault-free side of the DC transmission is smaller, and on the side with the fault, the fault current is lower than it would be with an AC link. The fault-free network experiences an interruption of power flow in the DC transmission but no fault current.

**HOW HVDC CAN HELP DURING CONTINGENCIES**

The main reason why a fault condition spreads to a wide area is often that AC transmission links become overloaded. This leads to their disconnection which in turn overloads other lines and so on.

An HVDC transmission link is easily engineered to take specific remedial actions in case of a disturbance. Furthermore, such actions are often smooth and continuous – in contrast to the hard switching of AC links. The most important feature of HVDC is that it can never become overloaded.

**EMERGENCY POWER CONTROL**

When HVDC transmission connects two asynchronous networks and there is a sudden outage of generation in one of the networks leading to an abnormal frequency and/or voltage, the link can be made to automatically adapt its power flow to support the troubled grid. The power flow is limited so as not to jeopardize the integrity of the sending network.

When HVDC transmission is connected inside an AC grid with AC lines parallel to the DC link, the power in these lines can be monitored and the DC power can be automatically adapted to protect the AC lines from being overloaded.

**VOLTAGE CONTROL**

In a disturbed network, voltage depressions or oscillations often occur. In many cases the reactive power capability of a classic HVDC station can help reduce this by modulating its reactive power consumption. An HVDC Light® converter has an even greater ability to generate or consume reactive power within a wide range.

**DEPENDENCE ON SHORT CIRCUIT POWER FROM THE CONNECTED AC GRID**

Classic, thyristor-based HVDC depends on the correct functioning of the AC system. The AC/DC converter requires a minimum short circuit power from the connected AC grid. HVDC Light® does not rely on short circuit power to function because the inverter does not require the help of external generators. It can thus energize a ‘dead’ network with its ‘black start’ capability.

**REACTIVE POWER**

A great advantage of HVDC is that it does not transmit reactive power. The classic HVDC converter consumes reactive power; it is therefore common practice to include a reactive power supply in the converter station. This is normally done in harmonic filters and shunt capacitor banks. The CCC HVDC converter consumes less reactive power as the converter includes a series capacitor. A classic thyristor-based HVDC station can help to stabilize the AC voltage by modulating its reactive power consumption.

An HVDC Light® converter has the ability to generate or consume reactive power within a wide range and can therefore take an even more prominent roll in stabilizing the AC voltage.
Current projects

BORKUM 2
In September 2007 E.ON Netz awarded ABB the contract to supply a 400 MW HVDC Light® transmission system that will integrate the world’s largest offshore wind farm into the German grid.

The Borkum 2 wind farm will be developed by BARD Engineering GmbH. It will consist of 80 x 5 MW wind generators located about 130 km from the coast in the North Sea. The generators will feed power into a 36 kV AC cable system which will be transformed to 154 kV for the HVDC Light® offshore station. The receiving station will be located at Dilele, 75 km from the coast where the power will be injected into the German 380 kV grid.

ABB is responsible for system engineering including design, supply and installation of the offshore converter, underwater and underground cable systems and the onshore converter.

SHARYLAND
Sharyland Utilities has awarded ABB the contract for a 150 MW back-to-back HVDC tie at Mission, Texas on the border with Mexico.

The tie will enable power exchange with the Comisión Federal de Electricidad (CFE) in Mexico and also increase reliability of power in the Rio Grande Valley. It will be the first large-scale open-access asynchronous interconnection suitable for commercial purposes between the ERCOT system in the USA and CFE. (The 36 MW Eagle Pass / Piedras Negras HVDC Light link can also allow power exchange between ERCOT and CFE.)

OUTAOUAIS
Hydro-Québec TransÉnergie and Hydro One Networks are constructing a new interconnection between the 315 kV grid in Ontario and the 315 kV grid in Quebec. ABB is delivering a back-to-back HVDC converter station, Outaouais, which will add 1,250 MW of transmission capacity between the two Canadian provinces by 2009. In addition to improving grid reliability in both provinces, Ontario will benefit by having substantially more access to emission-free hydroelectric power from Quebec that replaces fossil fuel sources.

SAPEI
The SAPEI link will be the second link from Sardinia to the Italian mainland. Terna - Rete Elettrica Nazionale SpA, awarded the contract for two HVDC converter stations - one in Fiume Santo, Sardinia and the other in Latina, on the Italian mainland - to ABB in 2006. The HVDC system, a bipole of a total of 1,000 MW, will be an important strategic link to deliver surplus power from the island of Sardinia to the Italian mainland, and help strengthen Italy’s power grid near Rome.

NORNED
When it is commissioned at the end of 2007, the 580 km NorNed link, a 700 MW interconnection between Norway and the Netherlands, will be the world’s longest underwater high-voltage cable.

ABB is carrying out the project on behalf of two state-owned power grid companies, TenneT in the Netherlands and Statnett in Norway. The interconnection will lead to power trading between the two countries and increase the reliability of electricity supply. Traditional AC transmission systems with underwater cables cannot be longer than about 60 to 100 km. Beyond this, the losses are prohibitive. The NorNed cable, operating at +/- 450kV and laid in water as deep as 420 m in some places, will have losses of only around four per cent.

VALHALL
BP is relying on ABB’s HVDC Light Technology to supply power for the entire offshore AC system for the redevelopment of its Valhall North Sea oil and gas field – its ‘flagship for the field of the future’. The offshore gas turbines will be decommissioned, and all the field’s 78 MW of power will be delivered over a distance of 300 km from the Norwegian coast.

CONTROL SYSTEM UPGRADES
ABB is carrying out three contracts to upgrade control systems at the Skagerrak 1&2 HVDC interconnector between Denmark and Norway, the Cahora Bassa HVDC link between Mozambique and South Africa, and the Blackwater back-to-back station in New Mexico which interconnects the Western and Texas power grids in the United States.

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