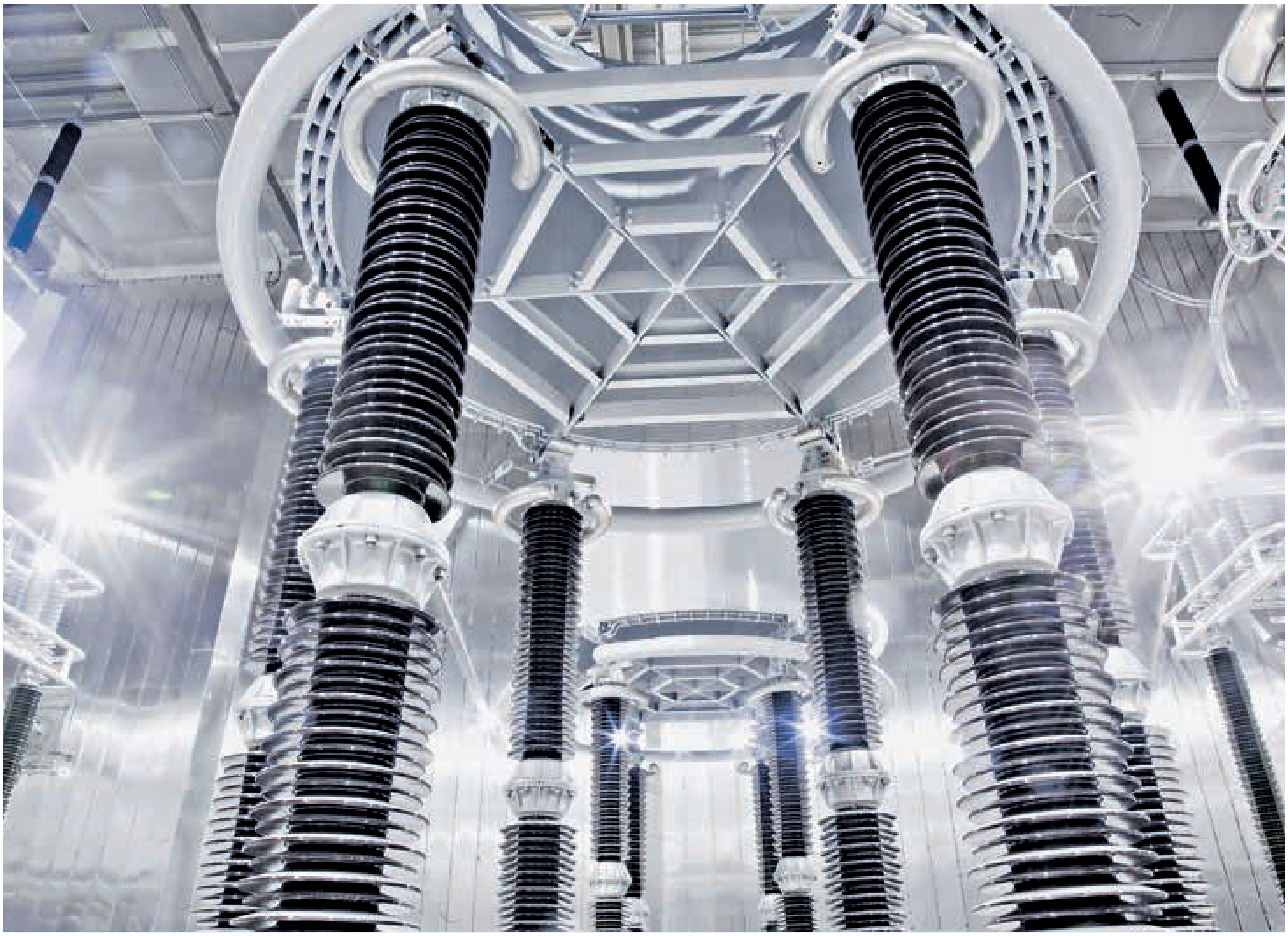
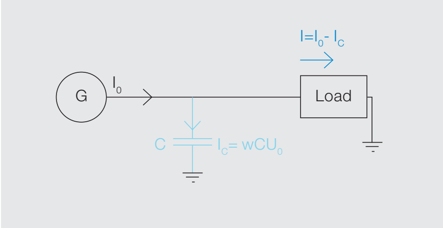


Powering the world

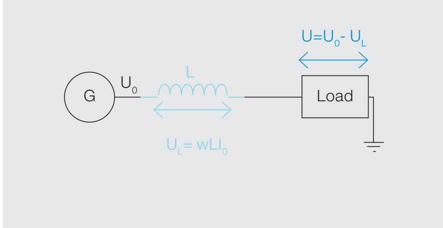
ABB is the global leader in HVDC transmission

MAGNUS CALLAVIK, MATS LARSSON, SARAH STOETER – The installation of the world's first commercial high-voltage direct current subsea power link, Gotland 1, in 1954 was the beginning of ABB's lifetime commitment to HVDC. Since then, generations of ABB engineers have, together with ABB's customers, pushed the envelope of HVDC technology, resulting in more powerful links at greater distances. Today, as much as 8,000 MW can be transmitted – the 2,210 km, ± 800 kV Hami-Zhengzhou UHVDC link commissioned in early 2014 is one example. ABB has had many other firsts over the years, not least of which is the groundbreaking development of the world's first hybrid HVDC breaker, resolving the largest roadblock in the development of an HVDC grid. As more electricity is generated from renewable sources in remote areas and requires long-distance transmission, there is a greater push toward DC power. ABB, the only supplier to offer the complete range of products for an HVDC system, remains committed to HVDC.

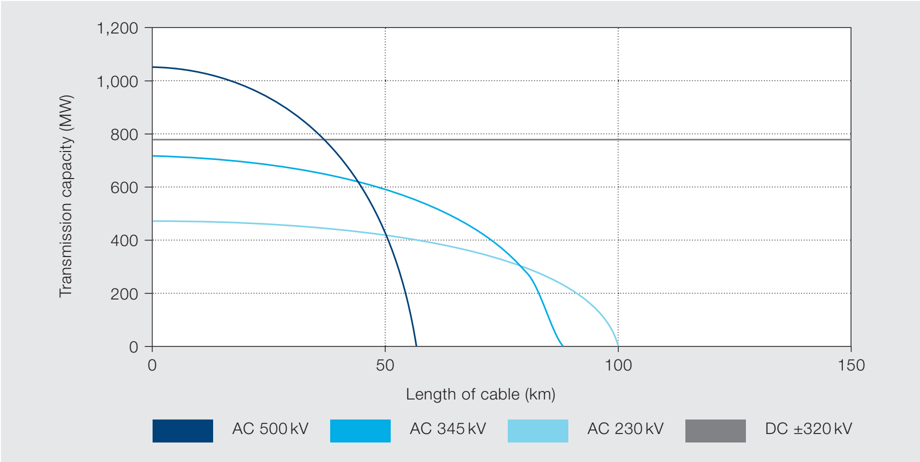
1 The limitations of AC transmission



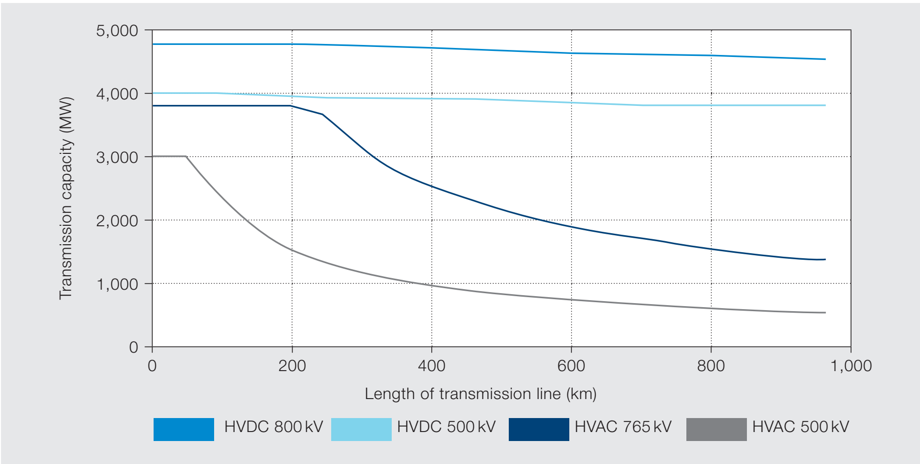
1a Underground cable



1b Overhead line



1c Transmission capacity of AC and DC with cables



1d Transmission capacity of AC and DC with overhead lines

Back in the early days of electricity supply, AC (alternating current) was adopted for power transmission because it could be stepped up or down as needed by transformers, and because it could be interrupted more easily than DC (direct current). High-voltage AC grids evolved as an efficient way to connect existing islands of distribution grids and large generation units with industrial and residential loads. It was not until some decades later that the technology for high-voltage DC (HVDC) power advanced sufficiently for the first commercial HVDC link to be established. The pioneering work by Uno Lamm at one of ABB's predecessor companies, ASEA, began in 1929 and resulted in the first subsea HVDC link using mercury-arc converter valves in 1954. Now, 60 years later, ABB has supplied, or has been a subsupplier to, more than 90 HVDC connections. The company has helped transform HVDC from being a relatively specialized application to a key technology enabling both low-loss, high-power connections between power markets and remote renewable generation.

Why HVDC?

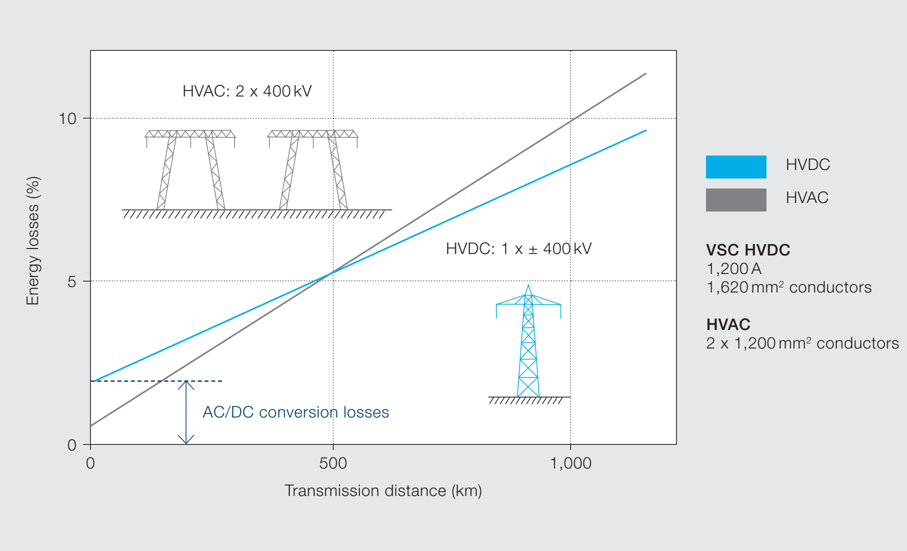
In DC, as opposed to AC, electrons flow through the circuit in one direction only, and, as a result, do not generate reactive power. AC cables have primarily capacitive characteristics → 1a, whereas overhead lines have primarily inductive characteristics → 1b. Long AC cables generate a lot more reactive power than they consume, and require a large reactive current to charge and discharge the cable as the grid voltage changes polarity 50 or 60 times per second. This current is added to the active current needed to transport the energy from one end of the cable to the other.

Both active and reactive current use the thermal capacity of the cable. Due to the generation of reactive power, high-voltage AC cable transmission links have a maximum practical length of about 50 to 100 km → 1. In underground cables longer than 50 km, most of the AC current is required to charge and discharge the capacitance (*C*) of the cable → 1a. In

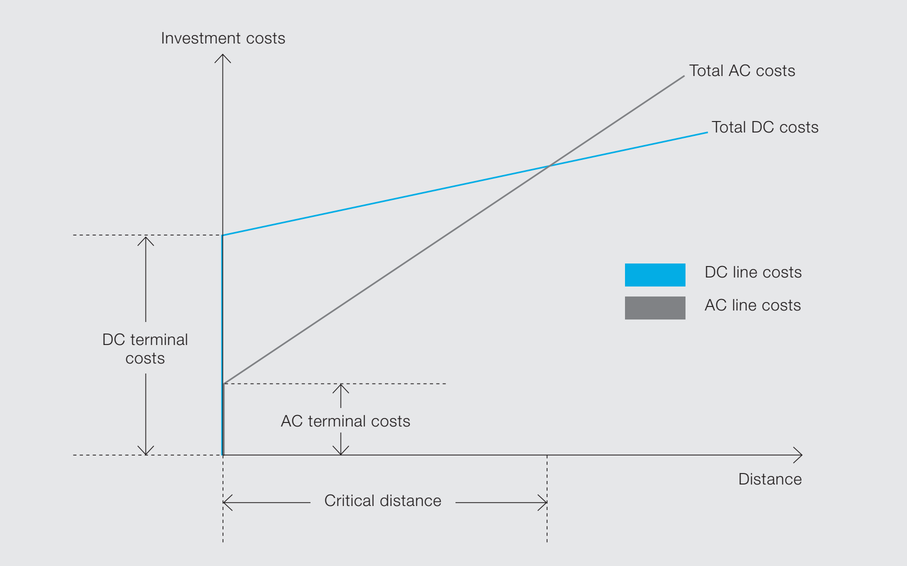
Title picture
The new HVDC Light technology is increasingly being used as the power range increases and losses decrease. Shown here is the reactor hall for an HVDC Light installation at 320 kV.

ABB has supplied more than half of the world's HVDC connections.

2 DC power has lower losses on longer distances.



3 There is a critical distance at which DC becomes more cost effective.



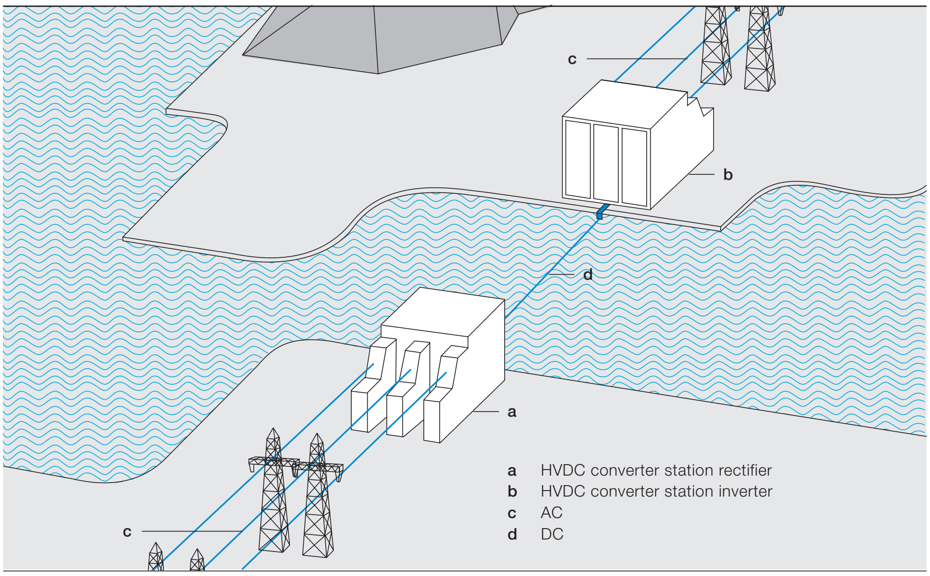
overhead lines longer than 200 km, most of the AC voltage is needed to overcome the voltage drop and phase shift due to the inductance (*L*) of the line → 1b. *C* and *L* can be compensated for using reactors/capacitors or FACTS (flexible alternating current transmission systems), or by the use of DC power.

HVDC is the most efficient method of transmitting power over substantial distances by cables → 2. HVDC has a higher initial cost – the converter stations – but because the overhead lines and cables are less expensive, there is a critical distance above which DC is more cost effective → 3. Furthermore, transmitting DC power over long distances with overhead lines is more efficient than AC transmission and is a cost-effective method of connecting two grids operating at different frequencies (asynchronous grids). This can be done via a power line between two converter stations or in a back-to-back arrangement with both converters in the same location.

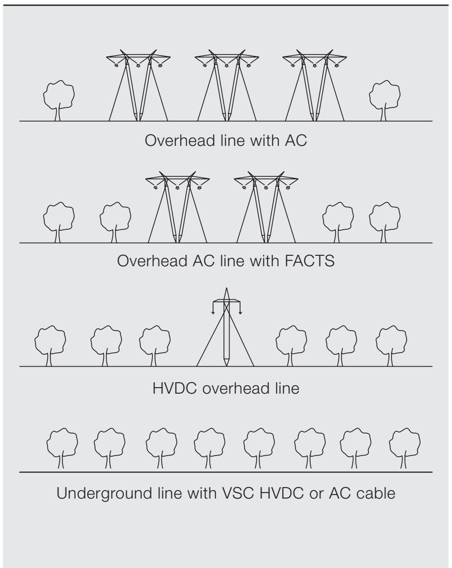
An HVDC system takes electrical power from an AC network via a transformer, converts it to DC at a converter station and transmits it to the receiving point by overhead lines or underground cables, where it is turned back into AC using another converter → 4.

The conversion is carried out using high-power semiconductor valves. Because HVDC transmits only active (real) power, no line capacity is wasted on transmitting reactive power. Therefore, the same power can be transmitted over fewer transmission lines than would be required

4 Overview of an HVDC system



5 Different transmission technologies



6 Comparison of HVDC Light and HVDC Classic

HVDC Light (power from 50 to 2,500 MW)	HVDC Classic (power up to 8,000 MW)
– Each terminal is an HVDC converter, which can support the AC network as a Statcom (SVC Light)	– Most economical way to transmit power over long distances
– Suitable for both submarine and land cable connections	– Long submarine cable connections
– Advanced system features to enhance the performance of the AC network	– Around three times more power in a right-of-way than overhead AC
– Footprint (eg, 1,200 MW): 100 x 150 x 20 m	– Footprint (eg, 600 MW): 200 x 120 x 22 m

using AC, so less land is needed to accommodate the lines. HVDC induces minimal magnetic fields, so the power lines may be safely built closer to human habitation ➔ 5. Upgrading an AC transmission line to carry DC can substantially increase its loadability and provide controllability that can be used to protect the power networks against blackouts.

HVDC Classic

HVDC Classic is one of two HVDC technologies used today ➔ 6. Based on thyristor power semiconductors, it is used primarily for bulk electrical transmission over long distances and for interconnecting separate power grids where conventional AC methods are not suitable. HVDC Classic transmission typically has a power rating between 100 and 8,000 MW. It uses overhead lines (for distances over 600 km) or subsea cables (for distances of 50 to 100 km), or a combination of cables and lines. Thyristor power semiconductors are line commutated, meaning that the turn-off signal is controlled by the AC line voltage reversal.

HVDC Light®

HVDC Light, introduced by ABB in 1997, is used to transmit electricity where the power involved exceeds 50 MW. It uses IGBTs (integrated-gate bipolar transistors), which, unlike thyristors, offer fully controllable power semiconductor switching. The link with the highest power rating in operation to date is the 500 MW / ±200 kV East-West interconnector between Ireland and the United Kingdom. Major advances in switching loss reduction have been accomplished – from an initial 3.7 percent to less than 1 percent – while HVDC Light technology has expanded the operating power ranges up to about 2 GW based on present voltage and current capability. HVDC Light can be used for grid interconnections, offshore links to wind farms, strengthening power networks, and powering oil and gas platforms. Thanks to the superior reactive power control capability of an HVDC Light terminal, it can increase the transfer capacity of the AC network surrounding the terminal.

ABB's HVDC Light features oil-free polymer-insulated extruded cables or mass-impregnated cables. The lighter, extruded cables, used together with prefabricated joints, enable long underground transmission. Because HVDC Light uses the IGBT as the power electronics device for the conversion, superior independent controllability can be achieved. HVDC Light offers the same benefits as traditional HVDC systems, but also provides more secure power control and quick power restoration in the event of a blackout. Because of its ability to stabilize AC voltage at the terminals, it is the ideal technology for wind parks, where the relative compactness of HVDC Light converter stations compared with HVDC Classic converter stations is a key enabler for remote offshore wind power generation.

Converter stations and transformers

Electricity generated in a power station must first be stepped up to the appropriate voltage and converted from AC to DC for long-distance transmission, and then stepped down and converted back to AC for distribution to consumers. The stepping up and down is performed by transformers. ABB is one of the world's leading suppliers of transformers and transformer components – including insulation materi-

In 2012, ABB announced a major breakthrough in the development of the DC grid – the hybrid HVDC circuit breaker.

7 HVDC cable technology

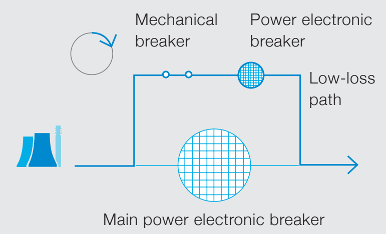
- XLPE plastic insulation
- Lightweight land cable at 10 kg/m
- Low number of joints for land installations
- Prefabricated joints
- Flexible, allowing coiling and installation from a barge (over 200 barges available)
- Flexible production (ie, AC and DC cables in the same production line)
- Maximum cable voltage of 320 kV

7a Extruded polymer HVDC cables

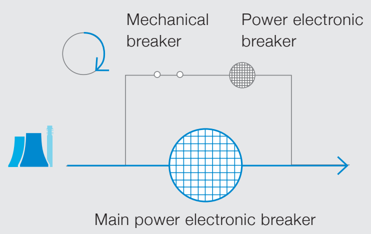
- Oil-impregnated insulation
- Heavyweight land cable at 25 kg/m
- High number of joints for land installations
- Tailored joints
- Requires special ship for installation (three such ships available globally)
- Dedicated production line for DC cables
- Maximum cable voltage of 500 kV

7b Mass-impregnated HVDC cables

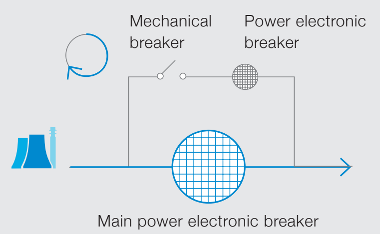
8 ABB's hybrid HVDC breaker



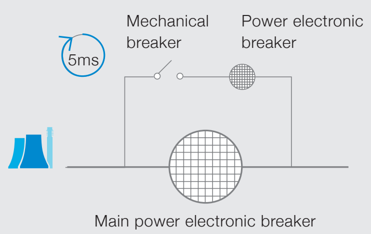
8a Normal operation: Power flow in path with least resistance (results in lower losses)



8b Power electronic breaker blocks upper current path to direct the flow into lower path



8c Mechanical breaker opens to block upper path



8d Main electronic breaker block in lower path

als and kits, tap changers, bushings and electronic control equipment – as well as service for transformers.

The core element of an HVDC system is the power converter, which serves as the interface to the AC system. The conversion from AC to DC and vice versa is carried out in a converter station using valves, which can carry current in one direction only. This feature is needed for both rectification and inversion.

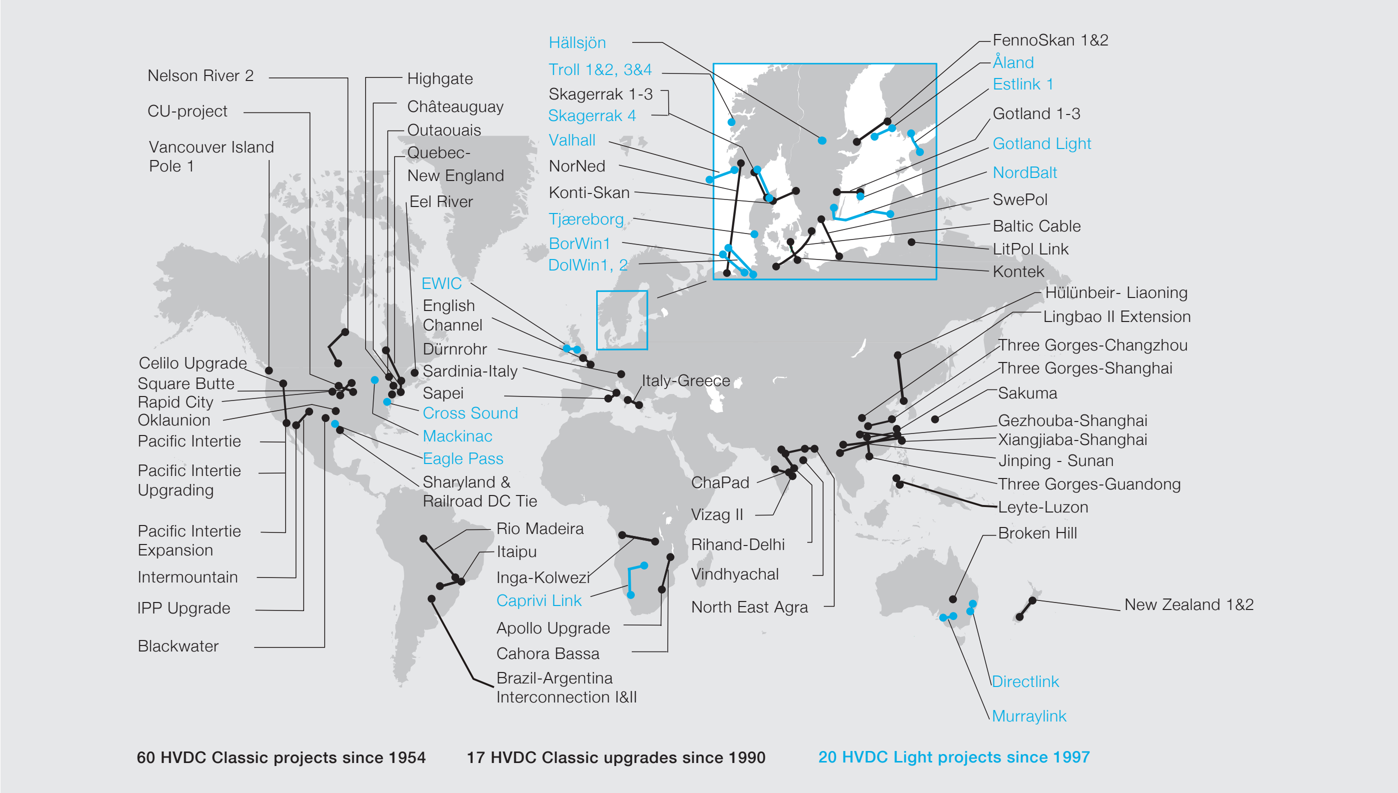
Cables

HVDC makes it possible to stretch the transmission distance for subsea or underground cables → 7, as has been shown by two world-record installations – the world's longest subsea cable, NorNed, which connects Norway to Holland via a 580 km mass-impregnated cable, and the world's longest underground cable, the Murray link, which uses two 180 km long extruded cables to connect the Riverland region in South Australia and Sunraysia region in Victoria.

Mass-impregnated submarine cables

Mass-impregnated cables have been in use since 1895. ABB has delivered more than 1,700 km of such HVDC cables all over the world. The 580 km long, 700 MW / 450 kV cable link between Norway and the Netherlands represents a milestone in both power and length for this cable type.

9 ABB has supplied more than half of the world's 170 HVDC projects.



Extruded polymer land and subsea cables (HVDC Light)

New HVDC Light cables have insulation consisting of extruded cross-linked polyethylene polymer. The insulation is triple extruded together with the conductor screen and the insulation screen.

The extruded DC cables are an important part of the HVDC Light concept. Typically, a link will have two cables, with one carrying voltage of positive polarity and the other negative. The strength and flexibility of HVDC Light cables make them suitable for submarine use as well.

Control and protection system

ABB has its own powerful, flexible and reliable control and protection system, which uses state-of-the-art computers, microcontrollers and digital signal processors connected by high-performance industrial standard buses and fiber-optic communication links. The system is called MACH (Modular Advanced Control for HVDC and SVC) and is designed specifically for converters in power applications. All critical parts of the system have inherent parallel redundancy and use the same switchover principles that have been used by ABB for HVDC applications since the 1980s.

Service and upgrades

As the installed base of HVDC links grows older, the number of upgrades to the system components increases. After about 20 years of operation it is common to upgrade valves and control systems. Often, after another 20 years, the whole link or station is upgraded or replaced with new HVDC solutions. To date no commercial HVDC link has been shut down, which demonstrates the reliability and long lifetime of the equipment and the market relevance of these links. Requests for service are growing, and ABB is commonly chosen as a turnkey service supplier.

The hybrid DC breaker

One of the major disadvantages of HVDC and one of the main reasons today's grid is primarily an AC grid, is the inability to to interrupt the flow of power and DC fault currents. The lack of ultra-fast DC breakers has been a huge roadblock to using HVDC beyond point-to-point links. That is, however, until very recently.

In 2012, ABB announced a major breakthrough in the development of the DC grid – the hybrid HVDC circuit breaker → 8. This breaker combines mechanical and power electronic switching that enables it to interrupt power flows of up to 1 GW – equivalent to the output of a large power station – in less than 5 ms. This innovation is paving the way for a more efficient and reliable electricity supply system.

Since the introduction of the first commercial subsea HVDC link, ABB has become – and remains – a leader in HVDC technologies, and is the world's leading supplier of HVDC projects to date → 9.

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