The power to make a difference

HVDC Light® can deliver 1,100 MW

Björn Jacobson, Marc Jeroense

Our appetite for electric power seems to have no limits and is predicted to double over the next 40 years. This heavy demand for electricity comes at a cost to the environment, both in its generation and in its transmission. An increasing share of new power generation comes from renewable sources, often located in remote areas. Since the mid 1990s, ABB has been developing a new system, called HVDC (high-voltage direct current) Light®, for electric power transmission, with the aim of providing a new transmission alternative, reducing some of the inherent disadvantages of the existing systems. With HVDC Light systems it is possible to transfer DC power over long distances on land by the use of robust and quick-to-install polymeric cable systems. Similarly, submarine cables can be used for sea crossings. HVDC Light converters enrich the electric transmission network with properties like improved black-start capabilities.

Transmission and distribution

In our urbanized world, there are fewer places to erect new power lines. Furthermore, the rise of sustainable energy sources, like solar, wind and remote hydroelectric generators, put greater stress on the power grid. In the remote regions where this power is usually generated, the grid is often weak. Today, renewable energy sources are more commonly used, since they are seen as a solution to the rising CO_2 problem. New climate-protection and energy-trading initiatives have inevitably led to new demands on transmission systems. HVDC Light® technology provides a new alternative for bulding the vital reinforcements required in the grid.

Transmitting bulk power

HVDC allows long-distance electric power transmission with low losses. Classically, HVDC has been used for sea cables or high-power, long-distance transmission. ABB has been at the forefront of this development since the 1930s and has a long record of successful HVDC projects, from the first commercial 12-pulse converters in Gotland in 1954, to today's large-scale systems under construction in China that are capable of transmitting up to 6,400 MW of power 2,000 km from large hydroelectric power plants in western China to southern and eastern China 1.

Power conversion

Electric power is generated as AC in a power station and delivered as AC to the consumer. HVDC transmission needs converters at either end to convert AC to DC (using rectifiers), and DC to AC (using inverters). The conversion is carried out using thyristors in the classic HVDC system and transistors in HVDC Light system.

HVDC Light

ABB is the only supplier with operational experience of more than 10 years for such a voltage-source converter (VSC) transmission system. The first HVDC Light project was the 10 kV trial transmission system in Hällsjön-Grängesberg completed in 1997. Since then, many converter stations have been built and continue to operate successfully in the hands of satisfied customers.

VSC transmission can be connected to very weak networks, and even to networks without additional power sources. It stabilizes voltage by injecting or absorbing reactive power as required, allowing power flow and voltage at the connection point to be controlled simultaneously and independently. In classical HVDC (using thyristor-based converters rather than transistors), such independent control of active power and network voltage is not intrinsic, requiring extra equipment. Furthermore, with VSC transmission, the flow of power can be reversed without changing the polarity of the voltage, a facility not possible with classic HVDC. Instead, the power reversal is achieved by reversing the current direction. Such a property is of great benefit, since polarity reversal might cause high electric-field stresses in the cable system.

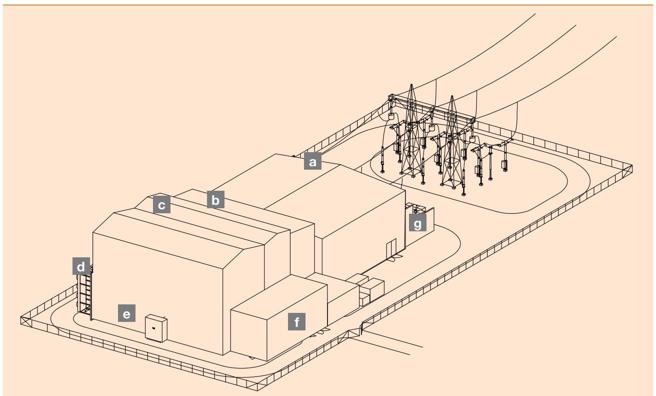
ABB is the only supplier with operational experience of more than 10 years for such a voltage-source converter (VSC) transmission system.

HVDC Light cables are configured as a basic bipolar pair – one cable with positive polarity, the other with negative polarity. By operating the cables with anti-parallel currents, the overall magnetic field of the cables is nearly eliminated, which is another positive aspect of HVDC Light technology. Through the coordinated development of converters, insulated-gate bipolar transistors (IGBTs) and HVDC Light cable systems, VSC transmission can produce a synchronized voltage for an entire wind turbine park and can now provide an alternative to high-voltage (400 kV and 500 kV AC) power lines. The design philosophy used to improve HVDC Light voltage levels has been one of cautious extension to existing voltage levels 2. Stringent tests have been carried out according to

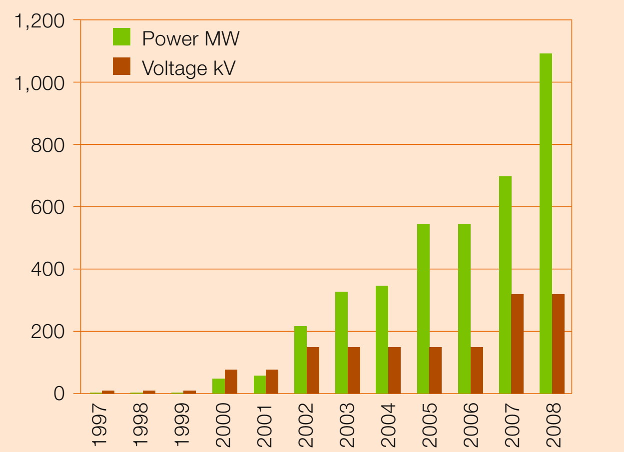
Footnote

[1] Cigré is a non-governmental organization established in 1921 to provide guidelines related to the planning and operation of power systems.

1 1,100 MW converter station: The station layout in this example covers 160 m x 70 m to the fence.



2 Historical development of higher HVDC voltage levels



Cigré recommendations.[1] Prototype tests, high-voltage insulation tests and component tests have been performed at ABB and at third-party laboratories. Critical components have been tested in a specially built, unique high-voltage switching circuit. Calculations, simulations and operational tests at full power per component have then been verified by measurements in the field. In fact, with more than 1,500 km of HVDC Light cables installed and more than 28,000 IGBTs operating in 29 converters (or 22 converter stations), ABB has earned a reputation for effective and reliable power transmission through HVDC Light technology Factbox.

Specialized transistors

ABB produces all IGBTs for HVDC Light, the largest of which has a maximum turnoff current of 4,000 A in normal operation and can withstand about 18 kA during short-circuit conditions 3. These data translate to a DC capability of around 1,800 A, when safety margins have been added.

Control system

The MACH2™ control system is computerized and fast. The cycle time for the internal control loops is 100 µs. The system keeps track of the state of the converters and the attached equipment and protects it from current or voltage overloading. The control includes fast internal valve current and DC voltage regulation. The fastest protection circuits act within 10 µs to protect the valves.

The main functions of MACH2 include power and voltage control. Frequency control and reactive-power control can be used alternatively to control the system. The active power can be controlled by setting it to a certain level, or by letting the network frequency determine the power need (so-called automated mode). Likewise, the reactive power can be set or allowed to vary as a function of the network voltage (so-called voltage control mode).

Different types of damping functions are available on request, for instance damping of sub-synchronous torsional interaction between the grid and generators. HVDC Light can help to dampen these oscillations, thereby protecting generators from potentially harmful vibrations.

The MACH2™ control system keeps track of the converters and attached equipment, protecting them from current or voltage overloads.

New possibilities with HVDC Light

With the introduction of HVDC Light stations and extruded polymeric cables, the traditional market for HVDC cable interconnections, ie, long submarine links, is expanding and new market-driven opportunities are developing. These include offshore applications, such as mainland-grid power supply to oil platforms and the transmission of offshore-generated power from wind farms. Since HVDC Light cables have no alternating magnetic and external electric fields and the cables can be buried underground, acceptance of new power transmission systems using HVDC Light technology is high. Reduced visibility together with fast, relatively unobtrusive installation, all contribute to shortened approval processes, and a short project realization time. The small dimensions of the cable system and the simplified installation procedure with a reduced number of joints per kilometer, together with the durability of the underground cabling, make installation and maintenance highly cost effective. In an HVDC Light transmission system, a significant part of the cost is in the conversion equipment. Further, the transmission capacity, unlike an AC line, is not reduced with increasing distance. This makes the HVDC Light system more cost effective with increasing transmission distance. Local conditions vary a great deal but in the cases studied it has been shown that for distances above 200 km HVDC Light can be an attractive alternative to overhead lines of comparable capacity, even from a financial point of view.

Extruded versus mass-impregnated cable

Cables insulated with mass-impregnated (MI) paper can also be used with HVDC Light, as was the case in the Valhall project. Both polymer and MI cables can and have been used in the sea, but MI cables are at the moment preferred for the highest voltages (400 to 500 kV DC). Polymer cables are preferred on land because they are fast and easy to join and install 4.

Factbox Abundant experience in HVDC Light and static var (Volt-Amps-reactive) compensation (SVC) installations.

Project	Number of converters	Year in operation
1 Hällsjön	2	1997
2 Hagfors (SVC)	1	1999
3 Gotland	2	1999
4 Directlink	6	2000
5 Tjæreborg	2	2002
6 Eagle Pass	2	2000
7 Moselstahlwerke (SVC)	1	2000
8 Cross Sound Cable	2	2002
9 Murraylink	2	2002
10 Polarit (SVC)	1	2002
11 Evron (SVC)	1	2003
12 Troll A	4	2005
13 Holly (SVC)	1	2004
14 Estlink	2	2006
15 Ameristeel (SVC)	1	2006
16 ZPSS (SVC)	1	2006
17 Mesnay (SVC)	1	2008
18 BorWin 1 (Nord E.ON 1)	2	2009
19 Martham (SVC)	1	2009
20 Liepajas (SVC)	1	2009
21 Siam Yamato (SVC)	1	2009
22 Caprivi Link	2	2010
23 Valhall	2	2010
24 Liepajas Metalurgs (SVC)	1	2010
25 Danieli – GHC2 (SVC)	1	2011
26 Danieli – UNI Steel (SVC)	1	2011
27 EWIP	2	2012

Projects 1–18 have been installed; 19–23 have been ordered and are in production, but not yet commissioned.

3 IGBT valves – the heart of the converter

Cables and overhead lines

Cables are not always a real alternative, for example in mountainous terrain, where it is difficult for diggers and trucks to gain access. In certain environments overhead lines result in substantially lower costs. In these situations, HVDC Light can be used with overhead lines. One example is the Caprivi Link in Nambia, which is under construction with overhead lines that cover 970 km of rugged terrain, expected to be operational in late 2009. When using HVDC overhead lines, the power per line can be higher than the corresponding AC line, particularly for long lines; this means fewer transmission lines are necessary to carry the required power and, therefore, fewer right-of-way issues need to be resolved. It is even possible to combine overhead lines with cables. Here, since the line is open to the atmosphere, the cable has to be protected from lightning overvoltage with surge arresters and electronic protection.

4 The cables for HVDC Light are extruded polymeric cables.

a Aluminum conductor
b Resistive polymer
c Insulating polymer
d Outer resistive polymer
e Sheath
f Moisture barrier
g Mechanical protection

ABB's HVDC Light, with its powerful IGBTs and high-tech cables, can now deliver 1,100 MW of power.

AC is not suitable for long high-power cable transmission

AC oscillates with 50 or 60 cycles per second (50/60 Hz power frequency) regardless of whether it is extra-high voltage, high voltage, medium voltage or low voltage. For each cycle, the AC cable is charged and discharged to the system voltage. This charging current increases with cable length. At a certain length, the charging current of the cable become so large that nothing remains for useful power. Of course, long before this happens, the AC cable is no longer economical. The problem gets larger with higher applied voltage. This limits length and power ratings for AC cables. For short distances, they may be very useful, but not for long high-power transmission. DC cable, on the other hand, has no corresponding charging current. In the DC cable all current is useable.

HVDC Light transmission comes of age

With ABB's powerful IGBTs and sleek high-tech cable systems, HVDC Light technology is now in a position where it can be used as an integral and important part in transmission systems of the world. The term "Light" now applies only to the ease of application, not to any lack of muscle. With a wealth of experience from many field installations, its reliability is proven and assured.

ABB engineers keep extending the boundaries of the technology. Voltage, current, power, footprint and efficiency are some of the key parameters that are being continuously improved. In the long run, one also may envisage a DC grid overlain on the AC grid to increase capacity without losing stability and without requiring more overhead lines. There are still a number of issues to be solved for a DC grid, in particular breaking DC currents; however, a DC grid could be the best solution to bring in and distribute sustainable energy from sun, wind and water, thereby reducing CO_2 emissions. In general, key items under continuous development include IGBTs, cable systems and control system hardware and software.

Changing power

HVDC Light has reached an important milestone and is now available at a power level of 1,100 MW. This creates a new transmission alternative with underground DC cables, transmitting power over large distances. New possibilities are also offered – for instance, grid reinforcement in the existing networks, feeding isolated loads like offshore installations and bringing electric power from remote sustainable sources to where people live and work.

Björn Jacobson
ABB Power Systems
Ludvika, Sweden
bjorn.jacobson@se.abb.com

Marc Jeroense
ABB Power Systems
Karlskrona, Sweden
marc.jeroense@se.abb.com