Appendix A
HVDC Light® Technical Background

HVDC Light®: Technical Background

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1.0 Introduction

1.0 What is HVDC Light®?

High Voltage Direct Current (HVDC) Light® is an environmentally-benign technology for modern electrical power transmission systems.

HVDC Light® cables are buried underground and underwater so there is no visual impact from the power cables. They do not emit fluctuating electric and magnetic fields (EMFs) so there are no human health related issues. HVDC Light® cables are made using a strong polymeric insulation material, and contain no oil. Overall, the cables provide a minimal impact alternative for large-scale electrical power transmission.

The converter stations use state-of-the-art semiconductor technology to deliver highly flexible, reliable and maintainable electrical power transmission. Virtually all components with the exception of transformers and heat exchangers are enclosed in a building that can be designed to be visually compatible with the local environment.

1.1 Historical background and technology overview

Direct current (DC) was the first type of transmission system used in the very early days of electrical engineering. Although the alternating current (AC) transmission system was developed later, DC continues to play a major role in power transmission: HVDC (high voltage direct current) is the preferred option for long distance bulk power transfer; and HVDC Light® (explained below) is the best alternative when bulk transfer and support of the AC System is desirable, and for applications such as off-shore and windmill installations.

AC and DC systems can be connected together. Alternating current is converted into direct current using "rectifiers." The first high power rectifiers to be used commercially for DC applications were mercury arc valves, first developed in the early 1900's. In 1954, the world's first commercial HVDC link based on mercury arc converters went into operation between the Swedish mainland and the island of Gotland. This was followed by many mercury arc installations, both small and large, around the world. Beginning in the 1960's, mercury arc valves were typically replaced by a second generation of rectifier technology, when semiconductor devices made from silicon, known as thyristors, proved to be lighter, cheaper, more reliable and more efficient than the older mercury arc technology.

The latest technology, introduced to HVDC applications by ABB in the 1990s, uses semiconductor chips that can both rectify and control power more precisely. These chips, called Insulated Gate Bipolar Transistors (IGBTs) lie at the heart of modern HVDC Light® converters.

HVDC Light® is HVDC technology based on another significant technological advance, referred to as voltage source converter (VSC) technology. A voltage source converter transforms DC voltage into AC, or converts an AC signal to DC. HVDC Light® has the capability to keep the voltage and frequency stable, which allows better stability for the overall grid, and allows for better control of power for distribution to customers.

HVDC Light® cables are insulated by extruded polymer. Their strength and flexibility make the HVDC Light® cables well suited for difficult installation conditions both underground as a land cable and as a submarine cable.

2.0 Features

2.1 Underground & underwater: No visual impact

HVDC Light® cables are designed to be direct buried. This results in no visual impact, and also allows for rapid cable burial, which minimizes disruption to nearby residents and stakeholders (see Figure 1).

HVDC Light® cables can also be trenched into the seabed, which minimizes the risk of damage to the cables by third parties (e.g. fishers, undersea research facilities). Aquatic species can quickly recolonize the area once installation is complete.

HVDC Light® cables contain solid insulation, which is an improvement on other types of HVDC and HVAC cables, which use oil or liquid-impregnated paper insulation. The use of solid insulation eliminates the risk of oil leaks and spills in the marine environment, since oil can escape into the environment from liquid-insulated cables.

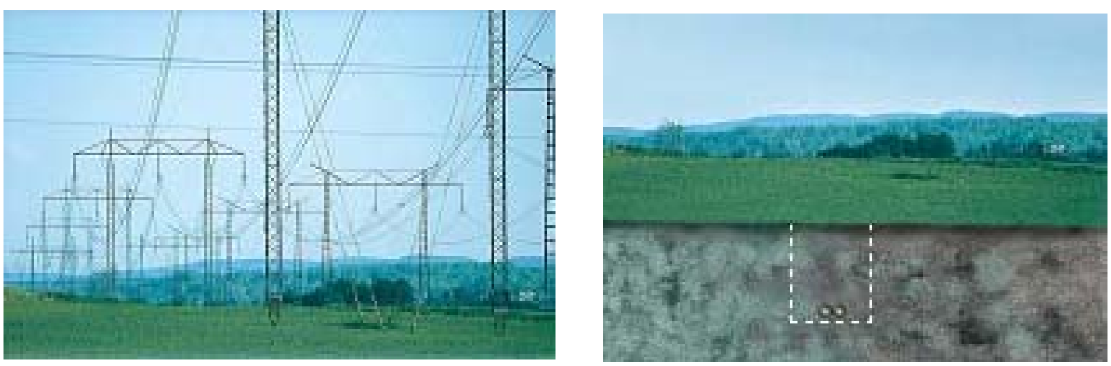


Figure 1: Overhead AC lines (left); Underground DC cables (right)

2.3 No electromagnetic fields

HVDC Light® cables do not have the same health concerns as AC power lines because they emit no varying electromagnetic fields. The only field present is an extremely low static magnetic field in close proximity to the cables which is similar to the natural background field of the Earth. The cables and converter stations are shielded, which results in no electric fields.

2.2 Low magnetic field

HVDC Light® cables are laid in pairs, usually close together. As they carry the same current levels in opposite directions, the static magnetic fields from the cables largely cancel each other out. Figure 2 demonstrates a bipolar DC system in which currents are flowing in opposite directions. Cancellation occurs where the magnetic fields (as denoted by the blue and red arrows) overlap. The resulting magnetic field decreases rapidly toward zero with distance from the cables.

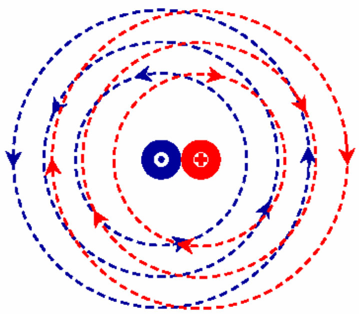


Figure 2: Diagram of a bipolar DC system.

The resulting static magnetic field is similar in magnitude and character to the Earth's natural magnetic field. Static fields, by definition, do not fluctuate (unlike the fields associated with AC transmission lines) and do not induce currents in nearby objects as fluctuating magnetic fields are known to do.

2.4 Low acoustic noise

HVDC Light® cables do not make noise as do AC transmission lines. Noise within the converter stations is mitigated through containment of equipment within the converter station building and through properly designed acoustic properties of the walls and roof. The layout of the converter station also can be designed to minimize noise and to meet local noise requirements.

2.5 Low overall environmental impact

Buried cables, the absence of electromagnetic fields, the freedom from concern relating to oil leakage into the environment, the elimination of the need for wide swaths of clear-cut right of ways, and the low visual impact of converter station structures designed to blend in with the surrounding community, all combine to provide substantially lower overall environmental impacts than the AC transmission alternatives.

3.0 Examples of HVDC Light® Installations

ABB has delivered more than 55 HVDC projects around the world providing more than 45000 MW of capacity. ABB has also completed a number of HVDC Light® projects, with more than 400km of HVDC Light® cables installed. An additional 400km of cable is scheduled to be installed in 2006 alone.

Sample Installed HVDC Light® projects include:

Project	Date	Capacity	Length	Purpose
Gotland, Sweden	1999	50 MW ± 80 kV	2 x 70km cables	Connects wind farm to load centre
DirectLink, Australia	2002	3 x 60 MW ± 80 kV	6 x 65km	Connects two regional electricity markets.
Cross Sound Cable, U.S.	2002	330 MW ± 150 kV	2 x 42km	Power transmission to Long Island.
MurrayLink, Australia	2002	200 MW ± 150 kV	2 x 180 km	Connects two regional electricity markets and controls power flow.
Troll A, Norway	2005	2 x 40 MW ± 60 kV	4 x 68km	Powers compressors to increase natural gas production on oil platform. The Troll A oil platform provides 10% of Europe's oil needs.
Estlink, Estonia-Finland	2006	350 MW ±150 kV	2 x 105 km	Improved security of the electricity supply in the Baltic States and Finland.

4.0 Benefits to the AC system

4.1 Independent power transfer and power quality control

The HVDC Light® system contributes to grid stability and controllability by allowing independent control of both the active and the reactive power flow within the operating range of the HVDC Light® system.

Power in an AC system can be considered to consist of two types: active power (also referred to as 'real power'), and reactive power. Active power is the component of transmitted AC electrical power that can be utilized by consumers and residents to do usable work. Reactive power is the portion of power flow that represents the energy alternately stored and released by the inductance and/or capacitance in the system and is used to control voltage on the transmission network. Reactive power is measured in 'volt-amperes reactive' (VARs).

In HVDC Light® systems, the active power can be continuously controlled from full power export to full power import. Each of the HVDC Light® stations also can control its reactive power flow independently of the other station. However, the flow of active power to the DC network must be balanced, which means that the active power leaving the DC network must be equal to the active power coming into the DC network, minus the losses in the HVDC Light® system. To attain this power balance, one of the stations controls the DC voltage, while the other station adjusts the transmitted power within the power capability limits for the HVDC Light® system.

4.2 Increased transfer capacity in the existing system

The fast and accurate voltage control capability of the HVDC Light® converter makes it possible to operate the grid closer to its full capacity. The higher voltage level at which the HVDC Light® converter allows a transmission system to operate allows more power to be transferred through the AC lines.

In traditional AC power transmission systems, one of the major limiting factors for power transfer is voltage stability. If the grid is exposed to an imminent voltage collapse, which can interrupt power supply. HVDC Light® can support the grid with the reactive power necessary to minimize disruption to the grid and electricity customers.

4.3 Fast restoration after blackouts

HVDC Light® can efficiently aid grid restoration after a blackout. The voltage support, frequency support and fast time response provided by HVDC Light® are much needed during such conditions. For example, in August 2003, when the north-east USA experienced a blackout, the Cross Sound Cable Project (which interconnects Connecticut and Long Island) provided voltage and frequency support, and thereby played a major role in the restoration of power to the grid.

Black-start capability, the support provided to the AC grid by the converter stations, is also an important feature. Black-start allows for an HVDC Light® system to greatly decrease the time for AC grid restoration, and works as follows: The HVDC Light® converter station normally follows the AC voltage of the connected grid. The voltage magnitude and frequency are determined by the control systems of the generating stations. If there is a voltage collapse, or a blackout, the HVDC Light® converter can instantaneously switch to its own internal voltage and frequency and disconnect itself from the grid. The converter can then operate as an idling “static” generator, ready to be connected to a “black” network to provide the first electricity to important loads. The only requirement is that the other converter for the DC system is unaffected by the black-out.

HVDC Light® is particularly beneficial in reducing the costs associated with the grid restoration process. Energy costs during the period of instability can be considerably higher than normal. By speeding the restoration process, costs are reduced.

5.0 Descriptions & Illustrations

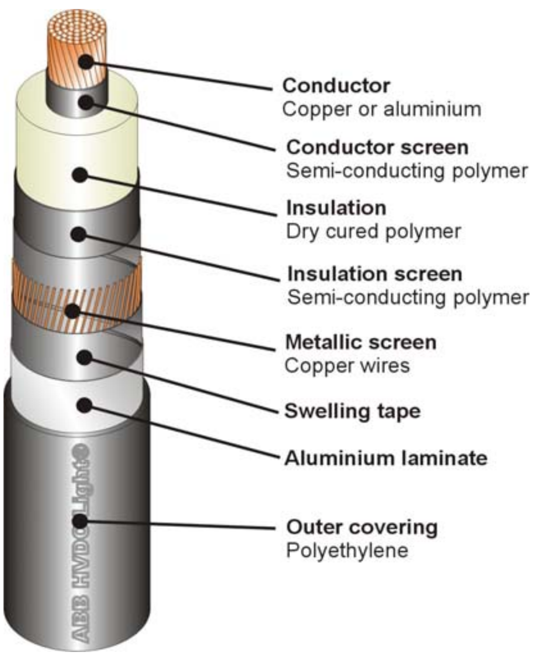
5.1 Cables

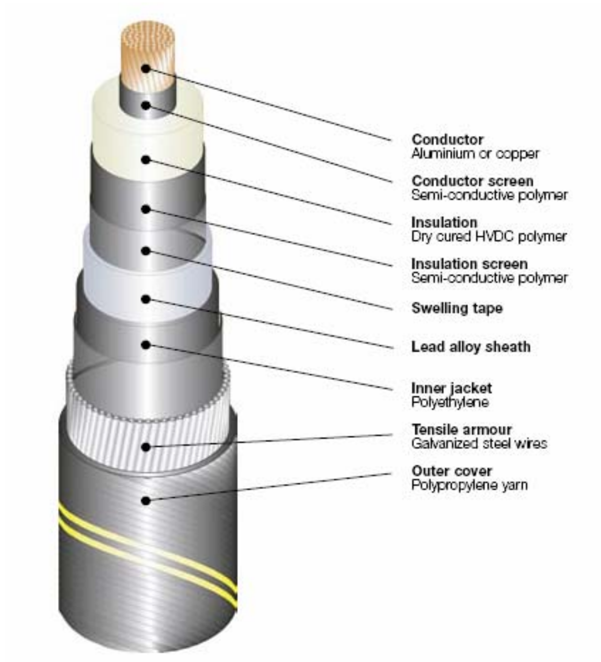
HVDC Light® cables are protected with armour and are insulated by a non-polluting, recyclable solid material, known as XLPE (Cross-linked Polyethylene). The construction of HVDC Light® XLPE cables is shown in Figure 3. The conductor is round in cross-section and consists of compacted stranded round wires (either copper or aluminum). A metal-polyethylene laminate is also sometimes used to surround the insulation. The laminate is bonded to the polyethylene, which helps to ensure the physical integrity of the cable.

For submarine cables, a lead alloy metallic sheath covers the conductor and a polyethylene sheath is extruded over the lead sheath. The polyethylene sheath provides mechanic and corrosion protection for the lead sheath. The marine cable is protected by tensile armour, which consists of galvanized round steel wires close to each other twisted round the cable. The tensile armour is flooded with bitumen in order provide protection against corrosion. The tensile armour also provides mechanical protection against impacts and abrasion if a cable becomes unburied, or is not buried to safe depth in the seabed. The outer surface for submarine cables consists of two layers of polypropylene yarn, the inner one impregnated with bitumen. The polypropylene yarn is a semi-wet covering.

HVDC Light® cables are designed to meet the current and voltage ratings for the specified power transmission capacity and for the specified installation conditions. The inherent lifetime of insulating materials is better for HVDC than for AC.

HVDC Light® cables do not contain oil, which could leak into the environment, and have many other advantages compared to other cable types. For example, HVDC Light® cables have a smaller bending radius compared to paper insulated cables. This makes it possible to use smaller cable drums for transportation. The smaller bending radius also makes it possible to go around obstacles such as rocks, etc. Also, as previously noted, HVDC Light cables have no associated varying EMFs.





Diagrams courtesy of ABB Inc.

Figure 3: HVDC Light® terrestrial (left) and marine (right) cable

5.2 Valves

The type of semiconductor used in HVDC Light® valves is called the StakPak™ IGBT from ABB Semiconductors. As a conducting device, the IGBT is used for handling high currents.

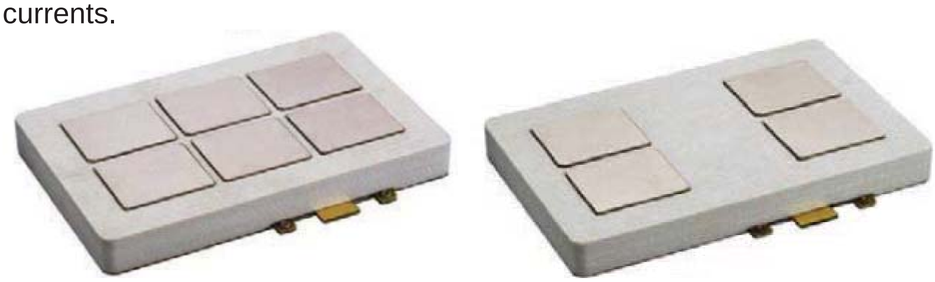


Figure 4: StakPak™ IGBTs with six and four sub-modules.

The current rating of the IGBT is determined by the number of modules. A StakPak™ IGBT has two, four or six sub-modules (Figure 4).

5.3 Converter stations

Converter stations are designed to blend into the surrounding architectural environment. Figure 5 shows a schematic of a typical HVDC Light® converter station. The converter station has a compact layout, with the majority of equipment housed in a typical warehouse-style building. The buildings are made of steel sheets and contain doors, stairs and catwalks. The IGBT's valves are installed in steel enclosures (Figure 6). The control and cooling equipment is normally also installed in enclosures.

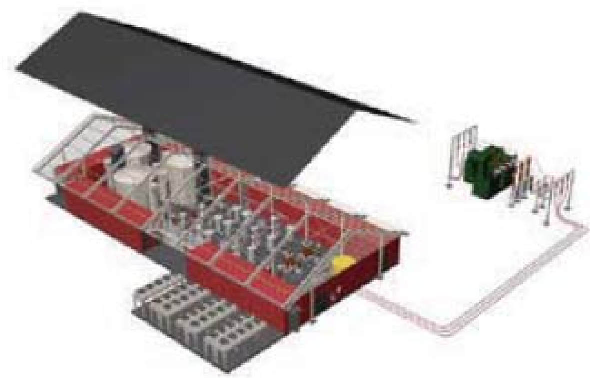


Figure 5: Schematic of a typical HVDC Light® converter station.

The main functions of the building are high frequency shielding, noise reduction, and weather protection. The wall cladding of the building is normally metal sheeting, which can be insulated with sound barriers to reduce noise levels. Power transformers and located outside the building and are placed on solid foundations. The transformers are connected to the indoor AC filter by AC cables.

The HVDC Light® converter station consists of four parts:

1. The DC yard, with DC filtering and switches;
2. The converter, with the IGBT valves and the converter reactors;
3. AC filter yard;
4. The grid interface, with power transformer and switches.

The different parts are interconnected with high voltage cables, which facilitates physical separation the parts, so as to fit them into available sites.

Figure 6: Valve enclosure

6.0 Reliability and Quality

6.1 Availability

One of the main design objectives of ABB for the HVDC Light® transmission system is to minimize the number of forced outages and the duration of scheduled maintenance.

To assure high reliability and availability, the HVDC Light® design principles include:

- Simple station design;
- Use of components with proven high reliability;
- Automatic supervision; and
- Use of redundant and/or back-up control systems and equipment such as measurements, pumps, etc.

Readily available spare units are also provided. The design allows for maintenance activities to be performed with minimum curtailment to the system operation. Maintainability is increased by the introduction of redundancy, or back-up, to an economically reasonable level achieved by having no single point of failure interrupt the system operation.

6.2 Maintainability

Unavailability due to scheduled maintenance depends both on the design of the HVDC Light® transmission system and on the organization of the maintenance work. The modern design, which incorporates extensive redundancies for essential systems such as cooling systems, duplicated control systems and station service power, allows most of the maintenance work to be done with no interruption of operation. This work requires 200-400 man-hours per year, depending on the size of the transmission system.

6.3 Quality Assurance/Standards

ABB has developed an effective and efficient quality assurance program complying with ISO 9001 and other applicable standards and an environmental management system complying with ISO 14000. The knowledge from significant experience with different HVDC projects, solid technical resources, and closely developed relations to key sub-suppliers, ensures reliable products that comply with exact specifications. The quality assurance program provides a means to ensure that the installation during different phases is carried out in a predictable manner, in line with applicable standards.