Application of HVDC Light to Power System Enhancement

Gunnar Asplund
ABB Power Systems ABB
SE-771 80 Ludvika, Sweden

1. INTRODUCTION

HVDC Light is the most recent HVDC technology based on Voltage Source Converters (VSC) and extruded DC cables with power units up to 200 MW. HVDC Light converters include Insulated Gate Bipolar Transistors (IGBT's) and operate with high frequency Pulse Width Modulation (PWM) in order to get high speed control of both active and reactive power. HVDC Light cable is a cable with insulation of extruded polymer and specifically adapted for direct voltage.

On March 10, 1997 power was transmitted on the worlds first Voltage Source HVDC transmission between Hellsjön and Grängesberg in central Sweden. Two and a half years of excellent operation experience has shown, that the technology is mature.

Four commercial transmissions are under design, manufacturing and commissioning.

Especially in cases, where AC transmission is difficult from environmental, technical or economical point of view HVDC Light offers an environmentally friendly solution which makes the permission process simpler.

2. TECHNOLOGY

With the appearance of high switching frequency components, such as IGBT's it becomes advantageous to build VSC using PWM Technology. The AC-voltage is created by switching very fast between two fixed voltages. The desired fundamental frequency voltage is created through low pass filtering of the high frequency pulse modulated voltage. See Fig.1and 2.

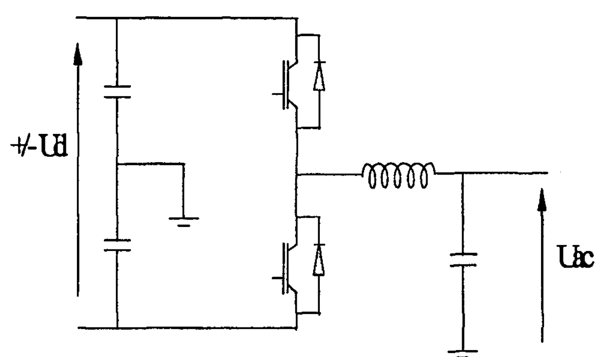


Fig. 1 shows one phase of a VSC converter using PWM.

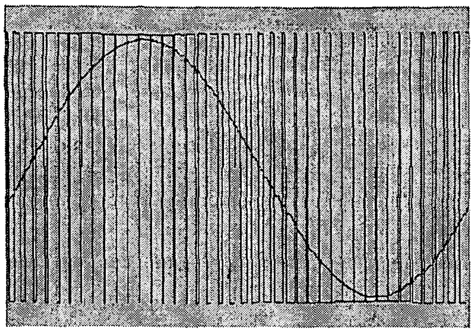


Fig. 2 shows the PWM pattern and the fundamental frequency voltage in a Voltage Source Converter.

With PWM it is possible to create any phase angle or amplitude (up to a certain limit) by changing the PWM pattern, which can be done almost instantaneous. Hereby PWM offers the possibility to control both active and reactive power independently.

This makes the Pulse Width Modulated Voltage Source Converter a close to ideal component in the transmission network. From a system point of view it acts as a motor or generator without mass that can control active and reactive power almost instantaneously. Furthermore, it does not contribute to the short circuit power as the AC current can be controlled.

2.1 The VSC converter

The converter consists of an IGBT valve bridge, the converter control, the converter reactor, DC capacitor, and an AC-filter.

The bridge is in its basic form a two-level, three-phase topology with six valves and series connected IGBT's in each valve. Every IGBT is provided with an antiparallel diode. Turn on/off of each single IGBT is ordered via an optical link from the control equipment on ground potential. The semiconductors are cooled with deionized water.

The fundamental frequency voltage across the converter reactor defines the power flow between the and DC sides. The active power flow between the converter and the network is controlled by changing the phase angle (δ) between the fundamental frequency voltage generated by the converter (Ug) and the voltage on the bus. The reactive power flow is determined by the amplitude of Ug which is controlled by the width of the pulses from the converter bridge.

2.2 HVDC Light Cable technology

The new HVDC Light cables have insulation of extruded polymer. The insulation is triple extruded together with the conductor screen and the insulation screen.

In HVAC there has been a change of technology going from paper insulated cables to extruded cables, mostly XLPE. The preference of extruded cables also for applications in HVDC has been obvious for a long time. Several reports have been published where XLPE has been tested for HVDC applications but without success. One reason has been the existence of space charges in the insulation leading to uncontrolled local high electric fields causing dielectric breakdowns. Another reason has been uneven stress distribution due to temperature dependent resistivity causing overstress in the outer part of the insulation. This HVDC Light cable development work with the objective to type test an extruded HVDC cable, was initiated a couple of years ago. It has now resulted in an extruded cable for HVDC that is an important part of the HVDC Light concept and opens new opportunities for future power transmission and distribution.

2.2.1 Life time of HVDC Light Cable

It is a general consensus that insulation materials have less ageing when exposed to DC voltage compared to AC-voltage. The first HVDC submarine cable, 100 km long and installed in 1954 between the Swedish mainland and Gotland, showed no ageing after 32 years of operation.

A long-term test on HVDC Light Cable with terminations has been successfully running for 365 days. This qualifies the cable for a rated voltage of 123 kV DC. The test voltage is – 210 kV DC which is 1.7 times the intended operating voltage. The cable is subjected to loading cycles consisting of 8 hours heating to 70 degrees. Centigrade followed by 16 hours cooling. The average electrical stress is 38 kV/mm.

The first commercial order, the Gotland HVDC Light Project, includes 140 km of 80 kV HVDC Light underground cable.

2.3 Advantages of combining VSC and Extruded DC Cable

HVDC cables are particularly well suited for long distance power transmissions. The cables are operated in bipolar mode, one cable with positive polarity and one cable with negative polarity. HVDC Light single core cables are installed close in bipolar pairs with antiparallel currents and thus eliminating the magnetic fields.

3. PROJECTS

Although HVDC Light is a recently developed technology a number of commercial projects already exists.

3.1 The Gotland HVDC Light Transmission

During the past years, there has been a considerable increase in wind power production on the Swedish island of Gotland. The infrastructure built for existing consumption cannot receive the increasing production. Wind power production does not conform to consumption.

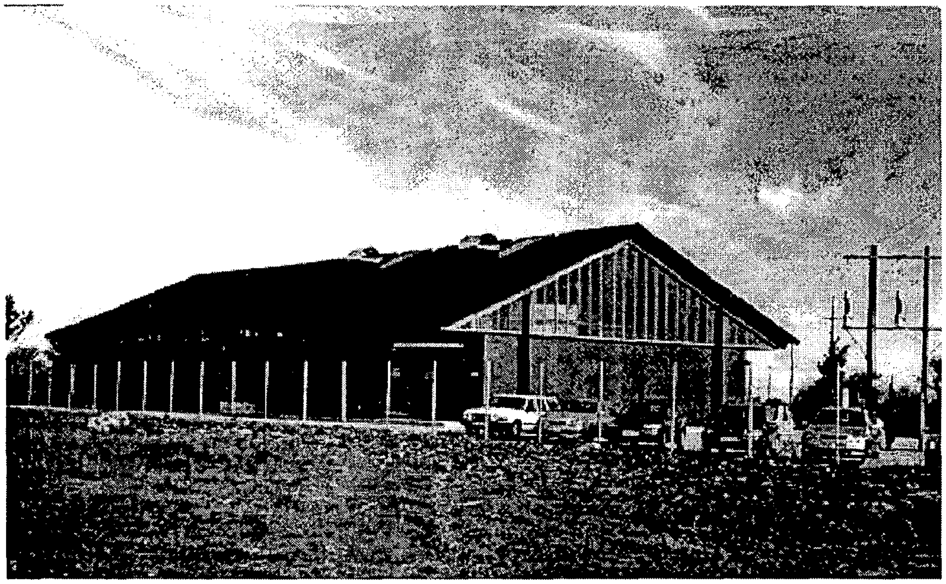
Being the best technical alternative, HVDC Light has been chosen for the project. Power transmission, as well as electrical quality demands on the connecting network, will be with common station equipment. DC transmission parallel with the existing network will also contribute to improving the dynamic stability of the entire AC-network. Simulation tests have shown that such a plant will also help to maintain electrical quality for the northern part of the island.

With the Gotland HVDC Light transmission, the reactive power capabilities are used to control the AC-voltages of the networks connected to the converter stations. The voltage control of a station constitutes an outer feedback loop and gives the reactive current order in such a way that the set voltage on the network bus will be retained.

The speed of response time for a change in voltage is 50 ms, which means that for a step order change in the bus voltage, it takes 50 ms to reach the new setting. With this speed of response, the AC-voltage control will be able to control transients and flicker up to around 3 Hz, as well as other disturbances, and keep the AC bus voltage constant. It is thus capable of relieving a considerable part of the wind power generated flicker from the AC bus.

Permits for the cable installation. Applying for permits from authorities (including associated environmental permits) is normally a time consuming process and is often slowed by doubts and questions. With underground DC cables, this process has taken very little time, primarily due to the limited number of questions raised (primarily related to magnetic fields). One hundred and eighty-five property owners accepted within a few weeks. Another contributing factor to rapid approval was that 50 km of the total 70 km run is on the existing 70 kV line right of way. Due to this, lightning overvoltages may have an effect on the insulation of the cable screen. While not considered critical, the phenomenon should be taken into consideration in similar projects.

The method of using two underground cables for opposite polarities lying closely together provides the environmental advantages of a magnetic field of a static nature and reduced to low values.



The Gotland HVDC Light Converter Station.

3.2 The Tjæreborg HVDC Light Project

The Tjæreborg Wind Farm is in the western part of Denmark, on the West Coast. A DC feeder rated 8 MW will be installed in parallel with the AC- feeder. Disconnected from the net the windfarm may be operated at frequencies varying between 35 Hz and 52 Hz. Within this frequency band, frequencies that could cause mechanical resonance will be avoided.

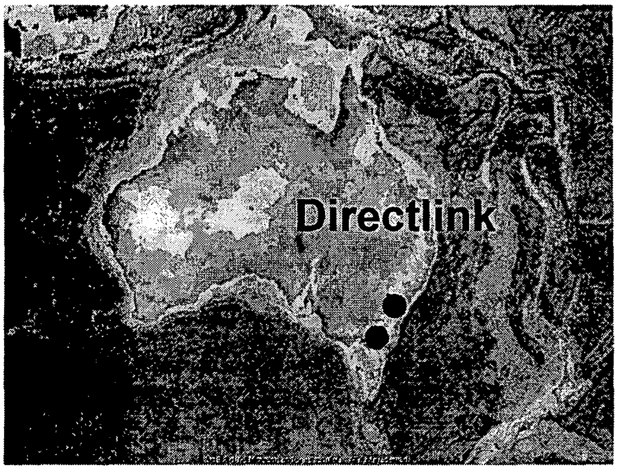
The preliminary studies and simulations of a DC feeder for the Tjæreborg wind farm have indicated that the concept is very promising. Several problems—e.g., voltage collapse, critical cable lengths, and wind power control that may be crucial for large offshore wind farms can be solved. Additionally, application of DC feeders may improve the power quality from wind farms and may contribute significantly to improvement of overall system stability even with a high degree of installed wind power.

That is, the use of VSC HVDC will make it possible to control the power production from wind farms and contribute to system frequency regulation.

3.3 Directlink HVDC Light Project

Directlink project is a transmission in Australia. This is an ITP (Independent Transmission Project) developed by the Hydro-Quebec group and North Power. The so-called Directlink is rated at

180 MVA, cable length is 65 km and it interconnects the Queensland and New South Wales networks. The extruded HVDC Light cable will be used along an existing rights-of-way. The driving forces behind this project are a capacity shortage in Queensland combined with surplus capacity in New South Wales. HVDC Light was the preferred choice due to the short delivery time, just 12 months, and the ease of cable installation. Here, the customer utilises an existing rights-of-way along a railway, where the extruded HVDC Light cable is ploughed into the ground for a large part of the transmission route.



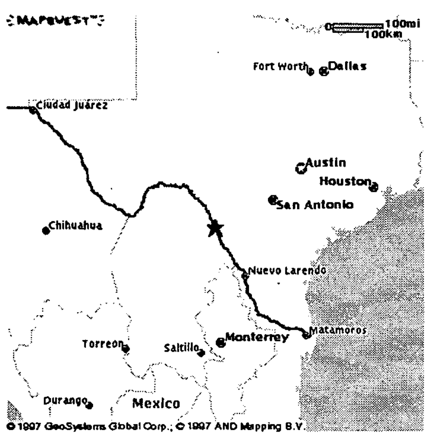
Map showing the Directlink project.

3.3 Eagle Pass

Central and South West Corporation (CSW) (NYSE: CSR) and Commission Federal de Electricidad (CFE) will install an asynchronous electrical tie using HVDC Light technology. The electric tie will link the transmission system of CSW's Central Power and Light Company (CPL) subsidiary with the Mexican transmission system owned and operated by CFE. CSW is working with EPRI, the utility industry's collaborative science and technology organization, to develop, install and test the tie, which is expected to be operational by June 2000.

The 36-megawatt HVDC tie, a Back-to-Back voltage source converter (BTBVSC) will be installed at CPL's Eagle Pass substation and will allow energy exchange to occur across the existing 138-kilovolt tie-line between Piedras Negras and Eagle Pass. The existing line is currently used only in emergency situations.

Eagle Pass substation is located in the western part of the CPL system in Texas and is served by two 138 kV transmission lines load is transferred over the border if conditions are such that the load can not be supported on its own grid. The primary function for the HVDC Light Back-to-Back in the near future will be to exchange power between the two asynchronous grids at low short circuit ratios.



Map showing the Eagle Pass project.

4. HVDC LIGHT IN THE DEREGULATED MARKET

The present ongoing deregulation makes interconnections more interesting. As in all trade the driving force is differences in prices. In the case of an deregulated electricity market trade will take place as soon as there is a price difference between two places if there is a transmission capacity available. In reality, the lack of transmission capability is one major force that creates price differences.

This fact makes it increasingly interesting to interconnect networks that are not synchronous or have bottlenecks.

In both these cases HVDC Light is very suitable as there are no problems created in the connected networks by the dc link. On the contrary, the power quality will be improved as the HVDC Light terminals can control reactive power in each station in excess of the active power transfer between stations.

As have been demonstrated earlier there is also much higher probability to get the necessary permissions for laying cables than to get permissions for overhead lines, thereby reducing the project risks.

5. CONCLUSIONS

The new electric transmission system, HVDC Light, is utilising state of the art semiconductors, control and cable insulation and can offer many new transmission opportunities as has been demonstrated by actual projects above. It offers a lot of possibilities to enhance the power systems. Wind power, even big parks, can easily be connected to the grid. In many cases HVDC Light can give new opportunities to trade electric energy in the new deregulated markets. As HVDC Light has been developed to minimise environmental impact and impact on the connecting grids, the licence procedure is generally more favourable than more traditional solutions. As experience is gained a lot of new applications will be realised such as feeding islands and far away located communities as well as city infeed and multiterminal applications.