A direct link

Efficient power transfer with HVDC Light®

JAN R. SVENSSON – Modern day ABB HVDC activity can be traced back to a 1993 study by Gunnar Asplund, HVDC research manager, on utilizing VSCs for HVDC. In the intervening years, ever-larger and more sophisticated HVDC links have been installed around the world and HVDC has turned into a billion-dollar business for ABB.

On the basis of the positive results of Asplund's study, ABB initiated, in August 1994, a large project to further explore the VSC approach.

The IGBT was the workhorse of the new technology. IGBTs are metal-oxide semiconductor (MOS) devices in which the power needed for the control of the component is very low and can be taken from the snubber circuit connected in parallel. Therefore, no auxiliary power from ground level is needed to power the gate unit (GU). Moreover, both the turn-on and turn-off switching of the IGBT can be controlled precisely by the GU, which makes it possible to connect the IGBTs in series.

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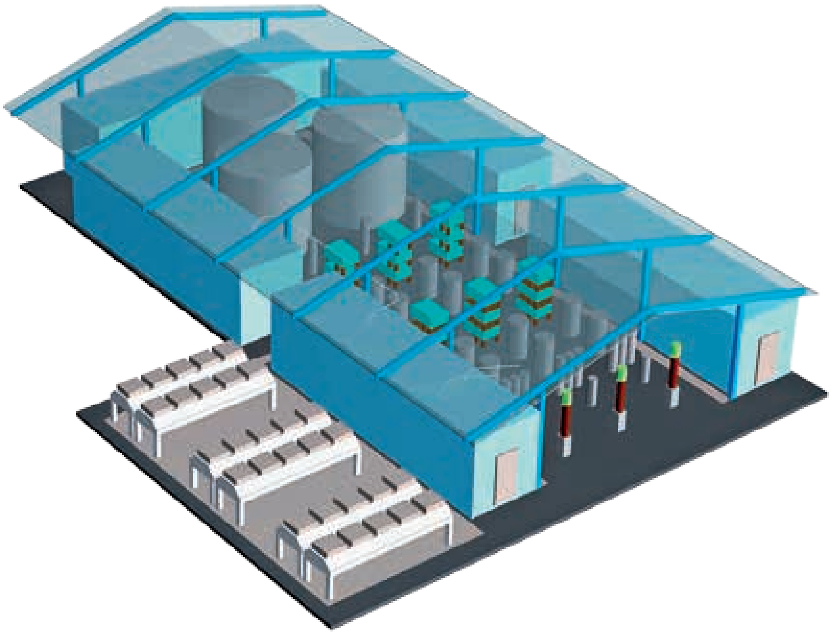
The key technology developed by ABB was the series connection of IGBT press-packs to handle high voltages, together with the development of a short-circuit failure mode (SCFM) concept and appropriate testing regime.

To successfully handle series-connected IGBTs, they all need to be switched (on or off) at the same time so each IGBT experiences the same voltage stress. For a VSC HVDC station, this means hundreds of IGBTs have to be switched individually in a fraction of a microsecond.

A complete series-connection concept was developed, including design, manufacturing and tuning of the GUs together with the snubber circuits and the power supply. Finally, the concept was verified by building an H-bridge prototype with four series-connected IGBTs per valve.

The feasibility of the VSC HVDC concept was shown in 1997 by a demonstrator installed between Hällsjön and Grängesberg, in central Sweden, on a 10 km, temporarily decommissioned 50 kV AC line. The demonstrator specifications were:
– Rating of 3 MW / ±10 kV, switching frequency 1,950 Hz
– Two stations utilizing two-level, three-phase VSCs

1 Gotland HVDC Light project.



- 2.5 kV/250 A press-pack IGBT
- IGBTs cooled with deionized water
- Mix of overhead line and cable
- DC breaker and DC chopper utilizing series-connected IGBTs

On March 10, 1997, power was transmitted on the world's first VSC HVDC. An extensive test program followed, showing that the concept fulfilled all the expectations.

Introduction of HVDC Light

In May 1997, ABB launched HVDC Light and customers were invited to Sweden for seminars and a study visit to the demonstrator. The HVDC Light design was based on a modular concept with a number of standardized sizes in the range of 10 to 100 MW. The design had two-level converters up to around ± 80 kV.

HVDC Light was launched as an environmentally friendly product: Since power is transmitted via a pair of underground cables there is no visual impact. The balanced voltage to ground eliminates the need for an electrode so there is no ground current and no electromagnetic field emanates from the cable pair.

The stations are designed to be unmanned and are, in principle, maintenance-free. Operations can be carried out remotely. The first pilot installation of HVDC Light started operation in November 1999 on the Swedish island of Gotland with two extruded 80 kV cables with a total length of 140 km connecting the terminal stations ➔ 1.

Applications

As a synchronous generator, the VSC creates its own phase voltages. A cascaded controller achieves fast control of the active and reactive currents independently of each other in an inner controller, while the outer, slower, controller tracks either the active power reference or the DC link voltage reference, utilizing the active current. The reactive current is used to control the AC voltage or inject/consume reactive power. The cascaded controller together with outer control loops allow a wide variety of application areas to be served, for example:
- Interconnecting grids.
- The connection of generation assets remote from the consumer – eg, offshore wind – and supply of remote loads, eg, power from shore to oil and gas platforms.
- DC links in AC grids enhance the AC grid performance. HVDC Light removes bottlenecks in existing AC grids and eases right-of-way for cable lines. Moreover, HVDC Light improves

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2 Troll A platform. The HVDC Light station is the gray box between the cranes.

AC grid stability and reliability levels and increases power quality.
- City-center infeed. HVDC Light has a small footprint and its cable technology eases right-of-way on existing routes.

Higher voltages and powers

To meet customer demand for higher powers and lower losses, HVDC power semiconductors and their packaging have undergone continuous development. This has enabled optimization of converter topologies and control algorithms, including pulse-width modulation (PWM) strategies.

HVDC Light: 2002 – 2005

A new generation of extruded polymer insulated cable was created to enable a DC link voltage of ± 150 kV. A converter station using a three-level active neutral point clamped VSC was also developed. These were utilized in two projects: the 330 MW Cross Sound Cable Project and the 220 MW Murray Link. The station separation in the latter is 180 km.

HVDC Light: 2005 – 2007

In a further development, a new generation of semiconductors made it possible to go back to the two-level converter topology by using an optimized PWM algorithm. A number of projects were delivered, including the 300 MW Caprivi link, which was the first HVDC Light with an overhead link to connect the northeastern and central parts of Namibia (950 km).

HVDC Light: 2007 –

The latest HVDC Light delivers increased power at lower losses by utilizing a modular multilevel converter (MMC) topology with half-bridge converter cells. This technical advance has enabled projects such as the 800 MW DolWin1, which is the first HVDC Light project that uses 320 kV extruded cables; and the 1,400 MW North Sea Link, which is a bipolar HVDC Light connection between Norway and the United Kingdom (730 km). It will be commissioned in 2021.

Drive systems using HVDC Light on an offshore platform

Many offshore applications are ideal candidates for HVDC. The Troll A gas platform in the North Sea, for example, uses compressors to boost gas pressure in the pipelines, which deliver gas to the mainland, 70 km away. Usually, the platform generator required to power compressors is bulky and not particularly efficient. However, ABB had been working on very-high-voltage (VHV) electrical motors based on stator windings that exploit extruded AC cables with polymer insulation. A VHV motor can be connected directly to HVDC Light without using a transformer. Utilizing power from the mainland via VHV motor and HVDC Light confers many advantages:
- Electricity from the mainland is generated with less greenhouse gas emission
- Higher efficiency and less maintenance than gas turbines or diesel engines
- Reduced weight and space requirements on the platform

In 2005, two parallel systems were installed in Troll A – ±60 kV with a VHV motor of 44 MW/56 kV AC. Two further systems were completed in 2015 with a VHV 50 MW motor power and voltage of 66 kV AC → 2.

The future is HVDC Light

In just 19 years, the visionary 3 MW demonstrator has multiplied to 25 HVDC Light installations that transfer over 10 GW and a worldwide billion-dollar ABB business has grown. The rapid development of HVDC Light will continue due to drivers such as climate change, the addition of renewables to the grid, demand for better power quality and the close integration of energy markets with the power infrastructure.

The attractiveness of HVDC Light will continue to grow as technology pushes powers ever higher and losses lower with the introduction of new semiconductors, new materials for cables and new high-voltage converters.

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