ENERGY TRANSITION

Evolution of HVDC Light®

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ABB has been pioneering the voltage source converter (VSC) for high-voltage direct current (HVDC) applications since the first installation of HVDC Light. After more than 20 projects commissioned and the uptake of commercial operation, it is now time to take the next step in power transmission capabilities, using HVDC Light with improved current capacity, compactness and controllability.

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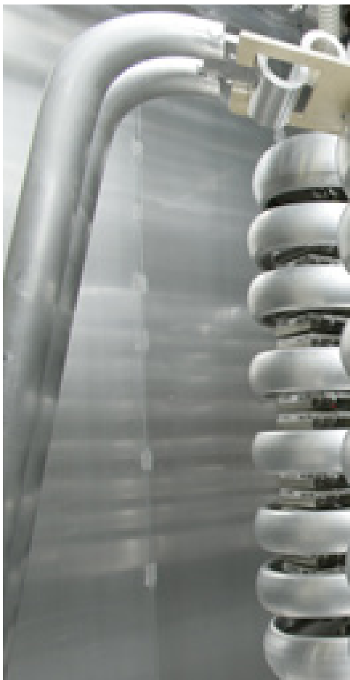
ABB's predecessor company, ASEA, started work on HVDC transmission in 1929 with the development of the Classic HVDC product, also known as the line-commutated converter (LCC). In 1954, ASEA constructed the world's first commercial HVDC link – to the island of Gotland, in the Baltic Sea. This pioneering heritage was later expanded to VSCs and, in 1997, ABB laid the ground for the world's first VSC-HVDC demonstration project, in Hällsjön, Sweden, thus introducing HVDC Light. This groundbreaking event marked the advent of transistors as power semiconductors for HVDC transmission, which allows voltage and frequency to be controlled by the converter. Since the introduction of HVDC Light, well over 20 projects have been completed or are under construction.

Since HVDC Light can easily adapt to required grid codes, fast delivery time and additional auxiliary services such as black start and AC voltage support are possible.

HVDC Light technology is being successfully deployed in an increasing number of applications, thanks to the parallel development of higher converter voltage and power ratings, improved semiconductors based on insulated-gate bipolar transistors (IGBTs) and advances in extruded cables with solid-polymer insulation →1. By embedding HVDC Light functionalities into an AC network, voltage support, reactive power compensation, black start and the performance of existing grid assets can be reinforced.



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01 Skagerrak 500 kV HVDC Light Hybrid bipole, converter building.

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02 HVDC Light converter valve in a power-from-shore application.

HVDC Light evolution
The evolution of HVDC Light started in the mid-1990s with the idea being to bring the excellent dynamic performance of VSC that had existed in train drive systems and variable-speed drives over to transmission systems. At this time, vital supporting technologies – such as high-voltage semiconductors and digital control systems – were also rapidly evolving. HVDC Light was launched in 1997 with the Hällsjön pilot after three years of intense research and development dedicated to solving, for example, the problem of how IGBTs could be controlled in series connection, thus enabling a high-voltage IGBT setup that could operate in the kHz range. Technology areas such as system design, valve design, control and protection design and plant design were adopted for the voltage source technology from ABB's knowledge of classic HVDC in order to create HVDC Light.

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For remote offshore wind generation, HVDC Light enables connection distances above 100 km – a difficult proposition for conventional AC solutions.

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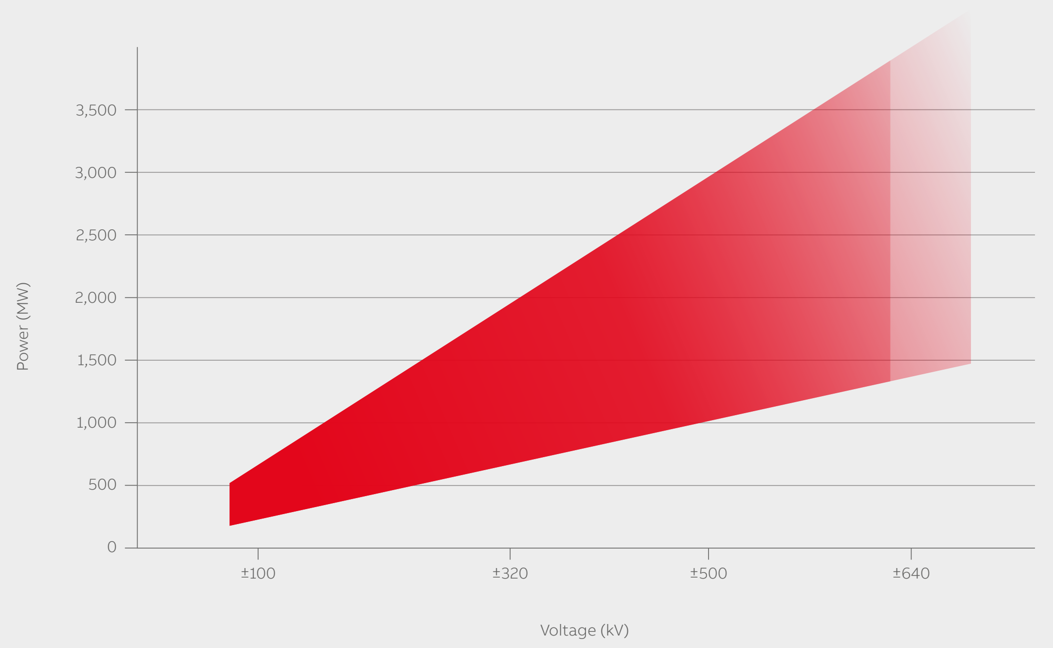

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The first commercial HVDC Light link, on Gotland, was to support the integration of renewable wind power into a fairly weak island grid. The project was a showcase for how HVDC Light can support grid resilience through active and reactive power control with high dynamic performance. The power level was a modest 55 MW at 80 kV.

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The increase to 1,400 MW at 500 kV DC has enabled cable interconnectors with lengths of 300 to 700 km to reach the power limit allowed in some European grids.

The next evolutionary step was to introduce HVDC Light as an interconnector between asynchronous grids. Since HVDC Light can easily adapt to required grid codes without any negative effect on existing grid infrastructure, fast delivery time and additional auxiliary services such as black start and AC voltage support are possible. Interconnector projects were installed in Australia, North America and Europe.

HVDC Light has always targeted environmental challenges, resulting in the development of power-from-shore applications for the oil and gas industry as well as for the connection of remote offshore wind generation →**2**.

For the latter, HVDC Light enables connection distances above 100 km – a difficult proposition for conventional AC solutions. In fact, voltage-source HVDC has been a fundamental enabler for remote offshore wind farms. Further, projects in Norway have proven HVDC Light's ability to provide a solution with small physical footprint and weight, and with a performance and availability superior to gas turbine technology.

HVDC Light was originally always combined with high-voltage, extruded XLPE DC cables, which give a high power density with a narrow right of way. Solutions with a mix of overhead lines and cables or only overhead lines have also been deployed. In the Caprivi Link project between Namibia and Zambia, for example, two weak grids are connected by a long HVDC Light overhead line. The Caprivi Link can be expanded from an asymmetrical monopole to a bipole scheme in a later stage – which is possible thanks to HVDC Light's controllability, where control parameter adjustment enables easy adaption to different grid conditions.

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03 Possible power range for HVDC Light systems.

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04 The new BIGT structure.

The increase of the HVDC Light power level to 1,400 MW at 525 kV DC has enabled cable interconnectors with lengths of 300 to 700 km to reach the power limit allowed in some European transmission grids. 3,000 MW at 500 kV is the next step foreseen, which would enable HVDC Light to be employed in many new point-to-point or multi-terminal systems, thus solving many transmission challenges, especially in remote generation applications →3. The combination of modern power semiconductors, the MACH control and protection system, and the system knowledge collected in the ABB HVDC Light experience database will serve the industry well and is a good base for the next step in the evolution of HVDC Light.

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Compact converter designs that reduce valve hall size and deliver efficient valve control, reduced losses and increased reliability are criteria that have driven valve development.

Development of converter valves, systems and plants
Having started with small-scale monopoles and DC cables, VSC systems based on modular multilevel converters now extend HVDC to the whole range of possible applications and configurations, eg, high-power, multi-terminal bipolar transmission with overhead lines, high-power offshore wind farm grids, and system synchronization and stabilization installations.

Advanced control features like black-start capability, islanding, power system stabilization and harmonic suppression have been implemented. System control and protection developments, including hybrid DC breakers, make HVDC Light applications compatible with the HVDC grids of the future.

Plant design focuses on compact solutions – ideal for both for onshore and offshore – that place great emphasis on space, weight, EMC (electromagnetic compatibility) and noise requirements. Footprint has reduced by a factor of two every five years.

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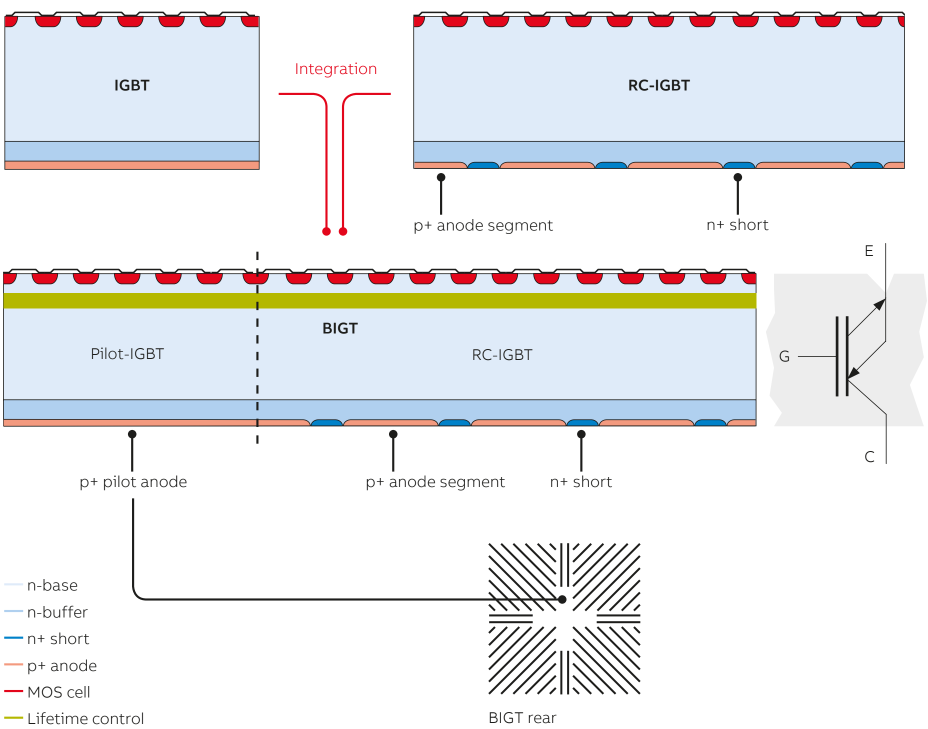

Simple layout and corresponding plant design
Compact converter designs that reduce valve hall size and deliver efficient valve control, reduced losses and increased reliability are criteria that have driven valve development.

Today's HVDC Light converters scale from 80 kV to 800 kV and 100 MW to 4,600 MW, with rated DC currents up to 3,000 A. The use of BIGTs (bi-mode insulated-gate transistors) and advanced switching algorithms allow for increased current density and low converter losses.

Station losses are now under 1 percent per station and in the range of HVDC Classic (LCC-HVDC used for ultrahigh-power transmission).

State-of-the-art test capabilities
With larger HVDC Light converter power ratings, test demands increase. Operational testing, for example, is performed to verify the performance of converter valves under worst repetitive stress (voltage, current and temperature) conditions and to verify the interactions between the valve electronics and power circuits.

A new 2,900 m^2 test facility was recently constructed to verify converter valves with current ratings of 3,000 A and above. In the test setup, power circulates between two single-phase systems representing independent converter stations. Only converter losses are fed into the test circuit. Each valve arm consists of six cells. The equivalent three-phase power of this setup is 31 MW.

5,200 V/3,000 A BIGT Stakpak Modules
Over the past few decades, advances in high-voltage semiconductor devices have led to tremendous improvements in terms of higher power handling capabilities and lower losses. For VSC topologies, a prime development goal was full integration of the active power semiconductor switch and the antiparallel freewheeling diode.

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This led to a focus on an IGBT and diode integration solution – referred to as the reverse conducting IGBT (RC-IGBT). The main aim was to obtain higher power densities and more compact systems while improving the diode performance when compared to modern IGBT/diode solutions.

Initially, such a concept was only realized for RC-IGBTs with a lower voltage rating (< 1,200 V), suitable for soft switching applications that have low demand on the diode-mode switching performance. However, despite major challenges with respect to the design and performance trade-offs for a hard switching RC-IGBT, ABB became the first to develop a high-voltage RC-IGBT with voltage ratings up to 6,500 V for mainstream VSC applications such as HVDC Light.

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05 The 3,000 A BIGT StakPak.

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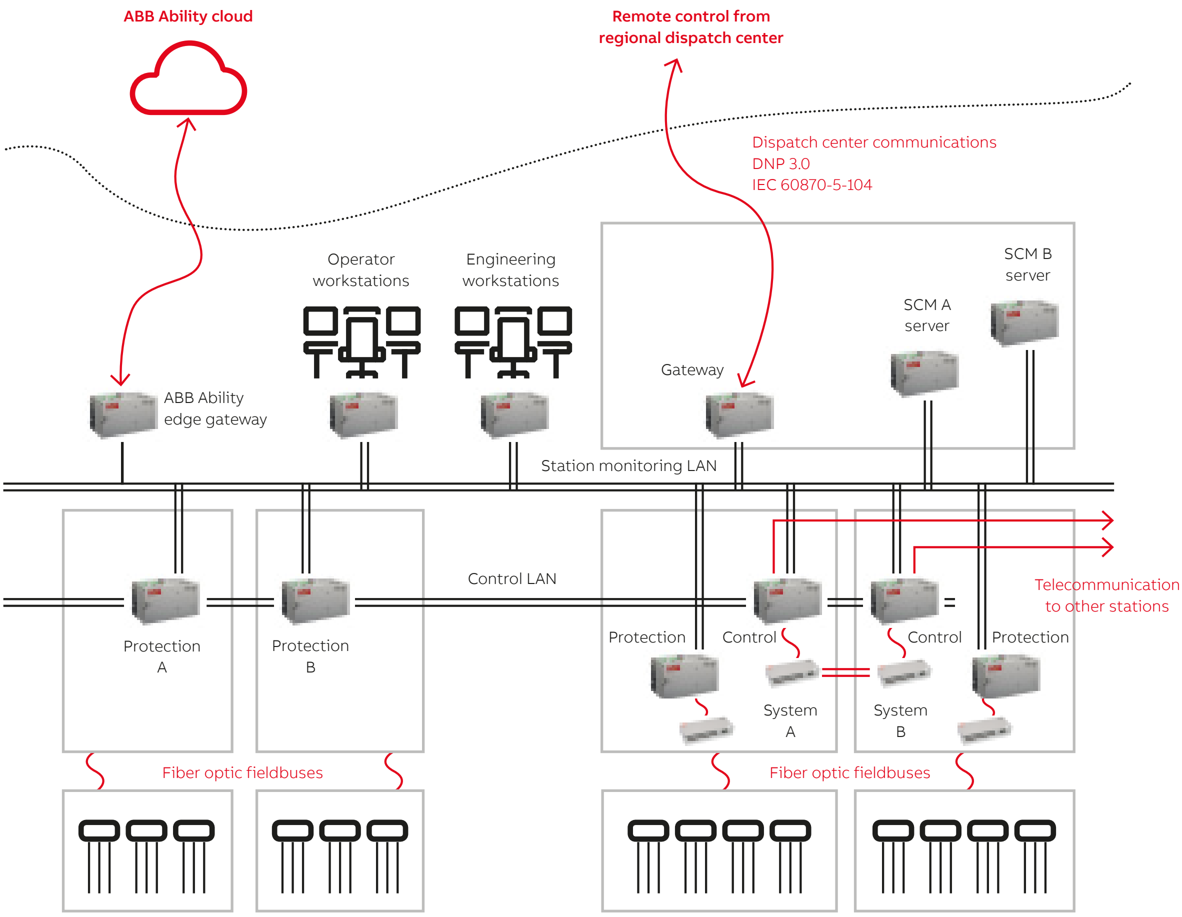
06 Structure of the HVDC MACH 3 control system for one pole.



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The advanced RC-IGBT concept is the BIGT referred to above. The BIGT was designed in accordance with the latest IGBT design concepts while fully incorporating an optimized integrated antiparallel diode in the same structure [1] [2] →**4.**

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A 5.2 kV BIGT chip was implemented in a new generation of ABB's press-pack module. This new module is based on the already well-known StakPak™ platform that has proved its outstanding reliability and ruggedness by serving for many years as the principle switching device in ABB HVDC Light applications. The newly designed 5.2 kV Stakpak employs the BIGT chip technology but maintains the same packaging features that made the previous generations successful →**5.**

The new Stakpak module is the first commercially available high-voltage module equipped with BIGT chips [3].

The new module keeps the concept of individual chip contacts through strong press pins, which allow for a better cooling capacity and enable a relaxation of the flatness tolerance on the stacking cooler. All the Stakpak modules consist of a number of standard rectangular submodules; switch power is determined by the number of submodules in the frame. Since the BIGT is an integrated structure, the requirements of different IGBT/diode ratios is no longer an issue and much higher current ratings for the same given footprint can be achieved. The six-submodule version shown in →**5** can be rated up to 3,000 A – making it the most powerful IGBT-type package developed to date as it is capable of both IGBT- and diode-mode operation.

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MACHTM 3 – the control and protection brain
HVDC transmissions have always been different from AC transmissions in that the power flow on an AC line is solely determined by the voltage and phase angle difference between the endpoints, whereas the power transfer of an HVDC system is fully controllable and the power flow is determined by the control system. This property is what provides many of the outstanding system features of an HVDC system, but it also requires a very fast and reliable control system.

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Since the first commercial installation of HVDC Light, power capacity has increased by more than 60 times while equipment has become more compact and converter losses are four times lower.

With the introduction of HVDC Light (VSC) converters in the mid-1990s, the controllability of the HVDC converters took a quantum leap forward, as not just the active power but also the reactive power became fully controllable. The high-performance MACH 2 control and protection system was introduced together with HVDC Light, which allowed the first generation of VSC converters to achieve their outstanding performance.

It is therefore very timely that the evolution of ABB's HVDC Light technology, with higher power handling capacity, higher reliability and even further controllability coincides with the introduction of the latest generation of control and protection systems from ABB, the MACH 3 →**6.**

MACH 3 is based on high-performance 64-bit multicore general purpose processors, eight-core floating point digital signal processors (DSPs) and the latest generation of large FPGAs (field-programmable gate arrays). The DSP alone is capable of an astounding 160 Gflops (160 x 10^9 floating point operations per second) →**7-8.**

MACH 3 also provides high-speed communication links between the units and to and from the distributed I/O units. Optical fiber cabling eliminates almost all control and protection copper wiring and thus substantially increases reliability and safety in the station.

With its outstanding communication capabilities, MACH 3 is the ideal platform to implement a fully digitalized HVDC station. All time-tagged events and alarms together with all important measured values are immediately available to the control and protection computers – from where they can

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07 PS700, the latest main computer for MACH.

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08 MACH PS935 Digital signal processing unit.

be made available to the range of ABB Ability™ services presently being introduced.

Future improvements – introducing ABB Ability MACH 3

Since the first commercial installation of HVDC Light, power capacity has increased by more than 60 times while equipment has become more compact and converter losses are four times lower. This rapid development, combined with unprecedented controllability, underpins the rapid growth of VSC-HVDC worldwide. Further improvements in performance and compactness during the next decade are foreseen.

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ABB became the first to develop a high-voltage RC-IGBT with voltage ratings up to 6,500 V for mainstream VSC applications.

In parallel to the development of HVDC Light, ABB is taking the next step in connectivity with ABB Ability. ABB Ability is a unified, cross-industry digital capability – extending from device to edge to cloud – with devices, systems, solutions, services and a platform that enable more knowledge of the system, more capabilities and improved performance delivered by connectivity of the grid equipment.

For HVDC, this can be exemplified by improved remote support, enhanced cyber security protection, dedicated support functions and facilities, and asset health systems. Developments and experience of collaboration in large automated systems in other industrial segments suggest coming rapid development in these areas. After all, HVDC stations, or plants, have been digitized for decades and represent some of the most vital grid assets. Digitization will come as a natural next step in the increased use of HVDC in the future grid [4]. ●

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References

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[2] M. T. Rahimo, et al., "The Two in One Chip, The BiMode Insulated-Gate Transistor BIGT," ABB Review, 2/2013. pp 19-23.

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