Trend lines

The first high-voltage direct current (HVDC) pioneers started work in the early 1920s, but it was not until 1954 that ASEA, a predecessor of ABB, was able to develop and commission the first commercial subsea HVDC link, to the island of Gotland, in Sweden. Since then, HVDC technology has been characterized by rapid and continuous advances driven by new and demanding customer needs. Despite the maturity of the technology, the last few years have seen a steady stream of world-record-breaking achievements in both the classic line-commutated converter (LCC) and in the more recent voltage source converter (VSC) areas. HVDC progress has, to a large extent, been made possible by the evolution of a particular set of key technologies and products and it is likely that these will continue to drive the field for the foreseeable future.

Future directions in HVDC transmission

Technologies for bulk power transmission are evolving fast

1 HVDC is the technology of choice for bringing distant offshore wind power to shore.

PER SKYTT – Advances in HVDC technology in recent years have been breathtaking: Bulk transmission for extremely long distances has reached levels of 8 GW using ± 800 kV ultrahigh-voltage DC and ratings above 10 GW are envisioned within a few years; world-record subsea transmission cable projects have opened the door to the further expansion of the global power cable network; and new VSC technology will simplify the job of connecting weak AC networks as well as making it easier to transfer power from offshore wind generators and other remote renewables → 1.

In addition, HVDC makes it more straightforward to interconnect asynchronous AC networks and it can effectively be used in very long subsea cables that connect AC systems. HVDC is also ideal for powering offshore oil and gas installations with clean electricity from shore. Further, embedding HVDC in AC systems is an effective way to reinforce bulk transfer and strengthen the AC system operation.

Customer values

As in many technology areas, one of the most important aspects of the product is a continuous reduction of cost for the user during its entire life cycle – which in HVDC can span decades. The initial investment, driven by equipment and plant size, and engineering and commissioning efforts, can be considerable and improved technology and processes can contribute significantly to cost reduction here. HVDC also saves cost during operation because total electrical system losses, a major factor for many operators, are lower than in other solutions.

Other aspects are important too: As HVDC is a part of critical national electrical infrastructure, reliability and

2 HVDC lines in Brazil. HVDC meets many criteria for bulk electrical power transport.

3 Evolution of HVDC Classic power and voltage ratings

Valve type	Year	Voltage (kV)	Power (MW)
Mercury arc	1954	100	20
Mercury arc	1968	533	1,440
Thyristor	1970	50	10
Thyristor	1977	250	500
Thyristor	1978	500	560
Thyristor	1979	400	1,000
Thyristor	1985	500	2,000
Thyristor	1987	600	3,150
Thyristor	2003	500	3,000
Thyristor	2010	800	6,400
Thyristor	2013	800	7,200
Thyristor	2014	1,100	10,000

availability become essential considerations. In addition, less-easily definable requirements often come into play, such as an efficient approval process for the system, the supplier's experience, simplicity of updates and upgrades, and project execution time → 2.

Performance improvements

Even though HVDC technology has reached a point at which many vital and demanding applications can be satisfied, there is a need for further enhancement in capabilities and performance:

- Increased power ratings and lower losses for bulk transfer using LCCs
- Increased power ratings for VSCs – enabling connections to remote renewable generators or the interconnection of weak AC networks
- Further reduction in HVDC station size – allowing applications offshore and in constrained urban areas

These enhancements will come about by developments in key enabling-technology areas → 3.

Enabling technologies

The advances in HVDC have, to a large extent, been made possible by the evolution of a particular set of key technologies and products. These same technologies and products provide the arena in which future decisive steps will be taken. The improvements being made to individual components and the way they are used within HVDC systems suggest that HVDC transmission systems will continue to gain in functionality and capacity for the foreseeable future.

> Breaking DC currents has been a major challenge when applying HVDC on a large scale. However, ABB's new hybrid HVDC breaker has changed this.

Power semiconductors

The core of an HVDC system is a silicon-based power semiconductor device: a thyristor in an HVDC Classic system, or a more controllable transistor device, an IGBT (insulated-gate bipolar transistor), for HVDC Light → 4–5. This technology benefits from the astonishing progress that has been made in the mainstream semiconductor business – where fabrication processes for microprocessors and computer memory have pushed material and processing limits beyond what many thought possible. The industry has gone from 4-inch to 5-inch and now 6-inch thyristors, increasing current ratings. Voltage ratings have been increased by many kilovolts purely with enhanced processing ability and material quality. The IGBT has seen an even more drastic development in the past few years that has enabled VSC HVDC to reach the 1 GW level. This development looks set to continue for many years to come, until silicon-based technology reaches its theoretical limits. Already, however, other even more capable semiconductor materials, principally silicon carbide, are emerging as the basis of new components. Indeed, silicon carbide devices have already started to appear in lower power applications.

Insulation

The DC voltage withstand of HVDC components and systems is a critical factor to consider when designing reliable and compact electrical systems. DC voltage withstand limits have been pushed ever higher in recent years and systems operating at 1,100 kV have recently been made possible. But better DC voltage

4 Assembly of thyristors at ABB's semiconductors facility

5 ABB StakPak with four and six submodules

withstand has advantages other than higher operating voltages and capacities – converter stations can be made smaller, for example. Gas-insulated solutions for DC will play a major role as will further expansion of the air-insulated switchgear design envelope.

Cable technology

A key enabling product for HVDC is the lightweight polymer-insulated cable, which allows systems with higher transmission capabilities to be built. Recent history shows a dramatic evolution of the cross-linked polyethylene (XLPE) DC cable, for instance. The first HVDC Light systems operated with a system voltage of 80 kV and projects currently under construction will operate at ± 320 kV, enabling 900 MW of power to be transmitted. And there is scope to expand cable development much further: Theoretical limits are well above current ratings and this points to the possibility of future cables performing at levels far above current ones.

DC breakers

Breaking DC currents has, for many years, been seen as a major challenge when applying HVDC on a large scale. However, ABB's new hybrid HVDC breaker has changed this and has thus ushered in a new era of HVDC transmission networks. This paves the way for large multiterminal systems and a future supergrid HVDC system that will be superimposed on the existing AC network.

Control systems

An HVDC system comprises a collection of controllable equipment that needs constant monitoring and control. The semiconductor valve itself, for example, relies on a very fast and reliable automatic control regime to fire the thyristors in the HVDC Classic product, or to fire the on and off signals for the IGBTs in HVDC Light. Apart from this, the entire electrical and auxiliary systems need to be constantly monitored and controlled to ensure all components work in harmony. ABB has developed such dedicated control and protection systems – starting with ones based on vacuum tubes that then evolved into relay-based solutions. The latest systems use, as their basis, advanced electronics that are tailored for HVDC.

The DC voltage withstand of HVDC components and systems is a critical factor to consider when designing reliable and compact electrical systems.

Trends

From day one, pioneering technology has ensured ABB's leading position in the HVDC field. This leadership will be of great importance in the planning of future electrical transmission systems – in which HVDC will play a major role. In addition, the theoretical limits of HVDC's core technologies have not yet been reached, so HVDC holds great potential and is set to become an even more dominant technology for bulk power transmission.

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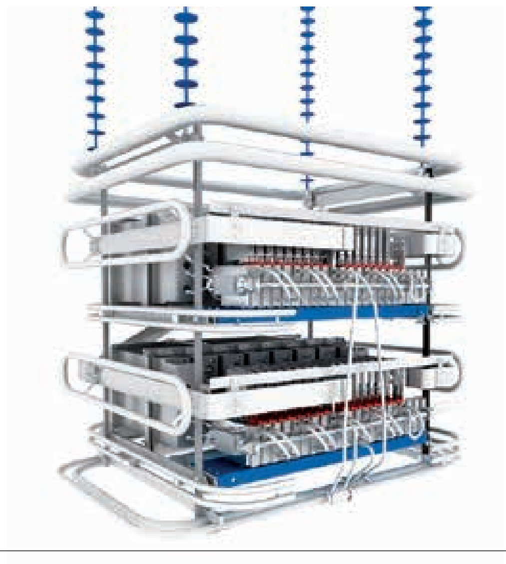
Breaking step

ABB's unique hybrid HVDC breaker is a key component for future grids

1 ABB's new hybrid HVDC breaker will revolutionize the HVDC field by making multiterminal HVDC grids possible.



JÜRGEN HÄFNER, REZA DERAKHSHANFAR, PETER LUNDBERG – The best way to transport large quantities of electrical power over long distances with minimal losses is to use high-voltage direct current (HVDC) technology. Because more, and more remote, renewable power sources are coming online and urban centers of consumption are pulling in power from further and further afield, the importance of HVDC is growing rapidly. However, since the dawn of HVDC technology, almost a century ago, one major com-ponent has been missing – a low-loss breaker that is appropriate for the high voltages and high speeds required. The absence of this critical component has confined HVDC topology to point-to-point configurations; an HVDC grid has remained infeasible. All this has changed with the launch of ABB's new hybrid HVDC breaker.

The many HVDC transmission lines scattered around the globe have one thing in common: They are all point-to-point connections. There is no HVDC grid. The reason for this has been the absence of a breaker that could handle the high voltages and high response speeds involved, and that could operate within acceptable loss limits.

This 100-year-old electrical engineering problem has now been solved by the introduction of ABB's new hybrid HVDC breaker → 1.

The hybrid HVDC breaker melds reliable power electronics already used in HVDC converter stations and fast-disconnecting gas-insulated switchgear technology to fill a gap in the products needed to build large multiterminal systems with multiple protection zones.

The hybrid HVDC breaker opens up a new era not only for the transport of renewable energy but also for all other types of generated power that has to be transmitted over long distances, including under large bodies of water. Further, the ability to create HVDC grids will improve overall grid reliability and enhance the capability of existing AC networks.

Technical background and system requirements

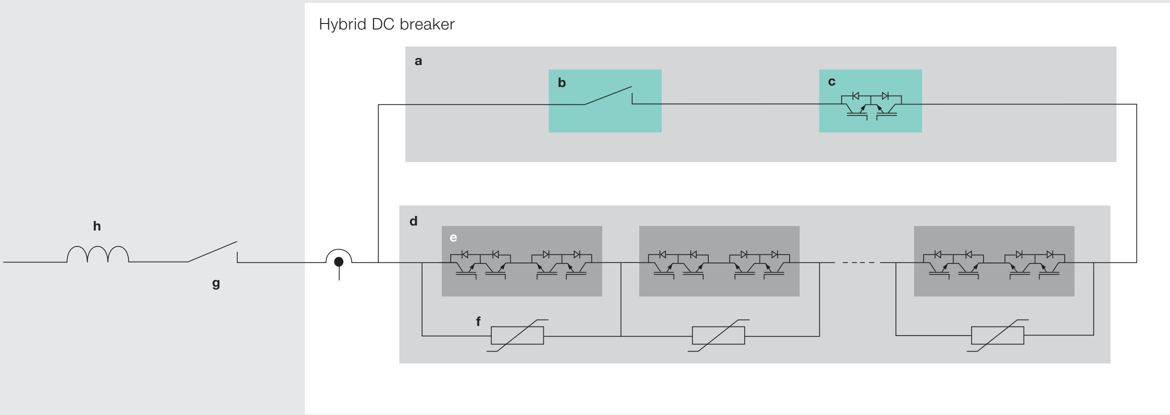
Until now, protecting a multiterminal HVDC grid in the event of a fault would demand a coordinated operation by all the terminals to abort the active power flow in the entire multiterminal system.

Building multiterminal HVDC systems with more than one protection zone would increase the robustness of the system during DC faults and would be of great value to the customer. However, the absence of a suitable breaker has, until now, limited the feasibility of this.

DC breakers are required to protect voltage source converters from line faults in DC grids and to enable a reactive power compensation mode for voltage stabilization in point-to-point and multiterminal HVDC applications. The relatively low impedance of HVDC systems presents a challenge when short-circuit faults occur in a DC link because the fault penetration is faster and deeper compared with the AC equivalent. Consequently, ultrafast HVDC breakers are needed to isolate faults and avoid a collapse of the common HVDC grid voltage. In DC systems, fault currents grow steadily in one direction. The lack of (naturally occurring) zero crossings and the response speed requirements have long been the main challenges [1].

This 100-year-old electrical engineering problem has now been solved by the introduction of ABB's new hybrid HVDC breaker.

2 Hybrid IGBT DC breaker



a Main current branch (when current is flowing) consisting of:
b Ultrafast disconnector
c Load-commutation switch (semiconductor-based)

d Main HVDC breaker consisting of:
e Semiconductor interrupter
f Arrester bank

g Residual current breaker
h Current limiting reactor

3 The ultrafast disconnector

DC breakers should have negligible transmission losses and be easy to integrate into a converter station design. Mechanical breakers have very low losses, but developing a very fast mechanical HVDC breaker is a challenge. Semiconductor-based HVDC breakers, on the other hand, easily surmount the limitations of switching speed and voltage, but generate high transfer losses.

ABB's hybrid HVDC breaker system [2] overcomes these hurdles with a combination of mechanical and semiconductor devices. It has an opening time of less than 5 ms, a few tens of kilowatts of on-state losses and a size that increases the footprint of an HVDC converter station by only 5 percent. This breaker is a milestone in the history of electrical transmission and solves a central problem of HVDC grids.

How it works

The hybrid HVDC breaker consists of a main breaker branch made up of semiconductor switches and a bypass branch composed of a semiconductor-based load-commutation switch (LCS) in series with a mechanical ultrafast disconnector (UFD) ➔ 2.

The main breaker path is separated into several sections with individual arrester banks that are dimensioned for full voltage- and current-breaking capability. The LCS is dimensioned for a lower voltage and energy capability. After fault clearance, a disconnecting circuit breaker interrupts the residual current and isolates the faulty line from the HVDC system in order to protect the arrester banks from thermal overload.

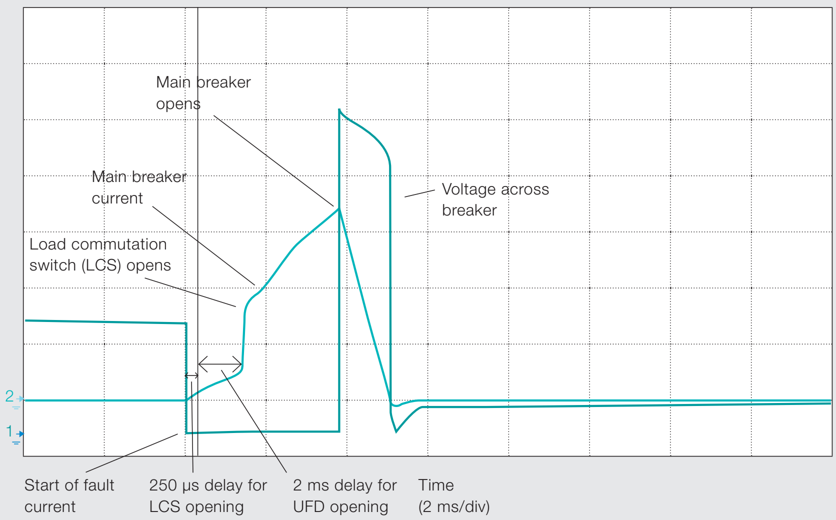
Each main breaker section contains semiconductor stacks composed of series-connected insulated-gate bipolar transistor (IGBT) DC breakers. Due to the large di/dt stress during current breaking, a mechanical design with low stray inductance has been adopted. Application of ABB StakPak IGBTs enables a compact stack design and ensures a stable short-circuit failure mode in case of component failure. Individual resistor-capacitor-diode (RCD) snubbers across each IGBT module ensure equal voltage distribution during current breaking. Optically powered gate units enable operation of the hybrid HVDC breaker independent of current and voltage conditions in the HVDC system.

A cooling system is not required for the main breaker, as the semiconductors are not exposed to the line current during normal operation – then, the current will only flow through the bypass. The LCS opens proactively at a certain fault current level in order to commutate the fault current, almost instantaneously, into the main breaker. Thereafter, the UFD opens in less than 2 ms to disconnect the load commutation switch from the main breaker. After the UFD is opened, the main circuit breaker is ready for operation.

One IGBT for each current direction is sufficient for the LCS to fulfill the requirements of the voltage rating. The transfer losses of the hybrid HVDC breaker are thus significantly reduced – to less than 0.01 percent of transmitted power. Parallel connection of IGBT modules increases the rated current of the hybrid HVDC breaker; series-connected, redundant IGBT positions improve the LCS reliability. A three-by-three matrix of IGBT positions for each current direction was, therefore, chosen

The hybrid HVDC breaker melds reliable power electronics already used in HVDC converter stations and fast-disconnecting gas-insulated switchgear technology.

4 Hybrid HVDC breaker test results showing fault current and voltage versus time



for the base design. A minor cooling system is required due to the switch's continuous exposure to the line current.

The UFD opens at zero current with low-voltage stress and can, thus, be realized as a disconnector with a lightweight and segmented contact system ➔ 3.

System validation and key component testing

Successful verification testing at device and component level has proven that the system performs as required. The complete hybrid HVDC breaker has been verified in a demonstrator setup at ABB facilities. The diagram in ➔ 4 shows a breaking event with peak current of 8.5 kA and a 2 ms delay time for opening the UFD in the branch parallel to the main breaker. Switching performance of the UFD has been verified for 2,000 consecutive open and close operations, including subsequent dielectric integrity tests. Other synthetic tests typical for high-voltage circuit breakers have been performed, verifying the required performance at full ratings. The maximum rated fault current of 8.5 kA is the limit for the generation of semiconductors used during initial testing. Application of bimode insulated-gate transistor (BiGT) devices allows for breaking currents exceeding 16 kA [3].

The purpose of the tests was to verify the switching performance of the power electronic parts and the opening speed of the mechanical UFD. The test object consisted of one 80 kV unidirectional main breaker cell. The higher voltage rating is accomplished by the series connection of several main breaker cells. A similar series connection approach is also used to test HVDC Light and Classic valves. To verify reliable and safe operation, tests have also been carried out with IGBTs that have deliberately been made defective [4].

Benefits, markets and applications

Fast, reliable and nearly zero-loss HVDC breakers and current limiters based on the hybrid HVDC breaker concept have been verified at component and system levels for HVDC voltages up to 320 kV and rated currents of 2 kA. The next step is to test such breakers in a real HVDC transmission line. An increase of voltage rating to accommodate 500 kV HVDC systems by improving UFD insulation extends the range of possible applications of the hybrid HVDC breaker from cable-based DC grids to embedded HVDC links utilizing overhead lines.

The hybrid DC breaker is the key technical element that finally makes a true multiterminal DC grid with multiple protection zones possible. In the extension of existing point-to-point systems and in the construction of new HVDC grids will be where the hybrid DC breaker will be premiered. The hybrid DC breaker will finally allow the long-held visions of HVDC grids spanning Europe and other regions to become a reality.

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Fast and reliable

The MACH™ control and protection system for HVDC

HANS BJORKLUND – High-voltage direct current (HVDC) transmissions have always differed from alternating current (AC) transmissions in that the conduction pattern of an HVDC converter is fully controllable. Indeed, this property is what provides many of the outstanding features of HVDC transmission. To make sure that the HVDC valve conduction sequence is tightly adhered to and that the system is run within the foreseen operating envelope, a fast and reliable control and protection system is required. And the better this system is, the better the HVDC transmission will operate. For this reason, ABB's HVDC control and protection products have always been very quick to exploit the very latest and best technology. In fact, the story of HVDC control and protection systems over the past 60 years mirrors that of the main trends in computing technology.

The modern era of HVDC transmission began in 1954 when the island of Gotland was linked to the Swedish mainland by an HVDC connector. At that time, AC systems still relied on electromechanical relays for protection and control, but the nature of HVDC demanded that the Gotland HVDC link have a very different and much faster system. The best technology available was used: amplifiers based on vacuum tubes – technology unheard of in other areas of power systems at that time ➔ 1. The vacuum tubes were replaced by transistors as soon as they became available in the late 1950s, which greatly increased reliability.

The need for ever faster and higher-precision control systems for HVDC meant that ABB always adopted the latest and most advanced electronic technologies as soon as they became available.

Microprocessors

In the 1970s, the microprocessor was introduced and ABB immediately (in 1973) adopted the Intel 8008 in thyristor monitoring systems. In 1975, the brand-new Intel 8080 was used in ABB's emergency power control system.

The advent of microprocessors finally made it possible to build single board computer (SBC) systems that had everything needed for one function (inputs, A/D converters, microprocessor and output circuitry) on one board. HVDC protection is very different from AC protection in that it has to be much faster (sub-millisecond response) and has to mix DC and AC current and voltage measurements.

1 Original Gotland converter firing control system based on vacuum tubes

An HVDC control system can benefit from a calculation capacity higher than an SBC can provide, so from the early 1980s, solutions that employed parallel-bus backplanes hosting multiple processing boards began to appear. It was fully digital-converter firing control running on multiprocessors that made the world's first fully redundant control system possible in Gotland 2 in 1983.

> The need for ever faster and higher-precision control systems for HVDC meant that ABB always adopted the latest and most advanced electronic technologies as soon as they became available.

SBCs are ideal for this. A 16-bit SBC that could implement all HVDC station protection functions by just using different software, was introduced in 1983 for the Gotland 2 transmission link. A few years later, the SBC found large-scale use in the Itaipu project in Brazil, where several hundred were used to implement all protection functions in the HVDC converters.

DSP and FPGA

In the 1990s, two new technologies appeared: the digital signal processor (DSP), with an instruction set tailored for very fast calculations (allowing control system cycle times below 100 µs) and the field programmable gate array (FPGA), which opened up the possibility of implementing larger-scale programmable logic in HVDC applications.

Combining circuit boards using these technologies with the latest 32-bit micro-processors on a fast parallel multiprocessor backplane resulted in

2 PS700, the latest main computer for MACH

3 Distributed I/O unit

the first-generation ABB MACH™ (modular advanced control for HVDC) control system, which was introduced in 1991. The first installation using the MACH system, a cable between Norway and Denmark, was put into commercial operation in late 1993.

PCI bus

When the high-speed PCI (peripheral component interconnect) bus was introduced, it allowed even faster microprocessors to be used, thus further improving the performance of the control and protection system. The PCI bus also allowed ABB to take advantage of DSP computing muscle and introduce, for the first time in the industry, floating-point DSP clusters. When ABB introduced the second generation of the MACH system in 1999, these powerful control and protection computers were combined with a revolutionary input/output (I/O) system that was connected only by serial buses, even for the highest speed measurement signals. This was the first time a control and protection system for a power system application had been built using solely serial buses for all I/O needs (voltage and current measurement, breaker trip and close operations, etc.). This resulted in an extremely flexible control and protection architecture in which the location of the different components could be chosen much more freely than in a conventional system where all signals have to be brought to the various controllers and protection devices by discrete wiring.

PCI Express bus

The use of parallel backplane buses involves many signals and complex connector arrangements. This can introduce unreliability when data transfer speeds increase. Therefore, the industry is moving to multiple serial buses and the PCI bus has now been replaced by the software-compatible PCI Express bus. ABB has used this opportunity to upgrade the MACH system, after 20 years, with a new 64-bit multicore microprocessor unit and new multicore DSP units, all connected by the PCI Express bus. This latest advance means that a control system can be built much smaller, yet with 10 to 100 times the calculation capacity ➔ 2. Further, less power is used, so fans are not necessary – thus increasing reliability. There is backwards software compatibility so that applications developed for earlier systems using ABB's function block programming language, HiDraw, can be recompiled and run in the newest systems.

I/O units

The full assortment of well-proven modular MACH I/O units is still available, but, with the latest MACH generation, ABB is also introducing a series of environmentally hardened I/O units ➔ 3. These can be distributed further afield and placed, for example, in breaker junction boxes or transformers. In this way, the traditional copper cabling connecting the devices back to the control system is replaced by optical fibers.

Computer processing power will continue to increase in the years to come and this will bring further improvements in the capabilities of control and protection systems, and deliver many new and fascinating applications.

The interfaces used in the MACH system have been chosen very carefully so that MACH can continue to evolve and remain the base for ABB's HVDC control and protection systems at least for the next 30 years. Maybe it will even live to see the Gotland HVDC link celebrate its centenary in 2054.

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HVDC grid simulation

A new HVDC grid simulation center brings deeper understanding of multiterminal HVDC control and protection

TOMAS LARSSON, MAGNUS CALLAVIK – It is predicted that the coming years will see an increase in the use of electricity generated by sources remote from load centers and increased integration of electricity markets. High-voltage direct current (HVDC) technology is emerging from being a relatively specialized technology to becoming a central element of the future transmission assets necessary to make this happen in a timely and efficient way. A supergrid or overlay grid based on HVDC is considered to be feasible and also to be the most efficient technology to use for a future extended high-voltage electric network. However, the development will come in steps. As the first building blocks of an HVDC grid are being planned now, there is already a demand for systems for control and protection of converters, lines and DC/AC grid interconnectivity. To advance understanding in this field, ABB has constructed a real-time HVDC grid simulator with control and protection hardware- and software-in-the-loop.

New transmission assets are being planned and constructed to connect power markets and to bring power from remote renewable generators into load centers. HVDC, being the superior technology for transportation of bulk power over long distances, is becoming a major player in this new transmission infrastructure. In the long term, a supergrid or overlay grid based on HVDC is considered to be a very feasible proposition [1]. It makes sense to integrate individual HVDC lines on the DC side of a converter into a grid when the HVDC density in the transmission network increases. Recent developments in voltage source converters (VSCs), cable technologies and DC breakers mean that the time has arrived to plan for such scenarios.

In order to master HVDC grids and to ensure everything is handled in a safe and efficient manner, the behavior, control and protection of converters, lines and DC/AC grid interconnectivity must be understood in a fundamental way. To advance this understanding, ABB has constructed a real-time HVDC grid simulator with control and protection hardware- and software-in-the-loop [2] ➔ 1.

1 Working with hardware in the HVDC grid simulation center

ABB HVDC grid simulation center

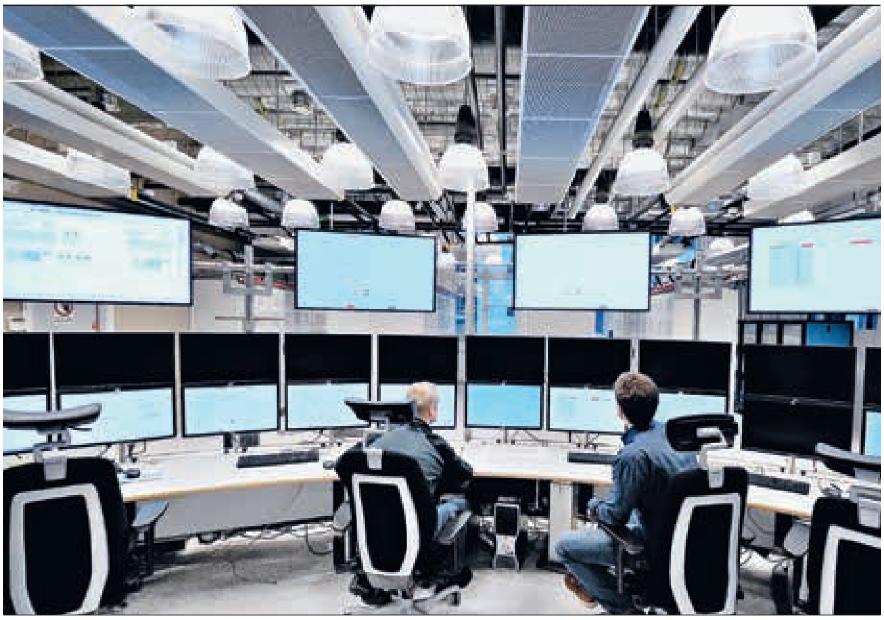
The HVDC grid simulation center is a state-of-the-art installation where ABB's ability to meet market requirements and handle the challenges thrown down by DC grids are demonstrated. It forms part of ABB's HVDC response to the growing number of renewable energy sources coming onto the grid, to integration of electric power markets and to the growing problem of power system bottlenecks becoming more frequent as power systems are run closer to their thermal and electrical stability limits.

Further, since the versatility, reliability and availability of a DC grid will help a customer to create a business case, the simulation center provides a forum where practical demonstrations that underline these advantages can take place – for example, by showing the capabilities of a hybrid DC breaker.

> Since the versatility, reliability and availability of a DC grid will help a customer to create a business case, the simulation center provides a forum where practical demonstrations that underline these advantages can take place.

A visitor to the ABB HVDC grid simulation center will initially encounter the simulated environment of an operator that represents ABB's proposal as to what an operator would face in his daily work ➔ 2. The operator's computers collate and display information from the simulated power system and transmit orders from the operator to a real HVDC MACH™ control system. All parts of the control system in the HVDC grid simulation center are identical to their counterparts in real-life installations, so everything is operated in real

2 HVDC grid simulation center: a visitor's view



time and the operator experiences exactly the same as he would in a real control room.

Responses from the process – ie, the HVDC converters and the AC and DC power systems – are also obtained in real time, but with one significant difference to a field installation: In the simulation center they are simulated by a model running in a real-time digital simulator (RTDS). For the MACH control system, then, it is a real-world experience, but with one major advantage: Because the high-voltage equipment is simulated, it can be stressed with contingencies, faults and other exceptions that, in some cases, would be totally impossible to perform in a real field installation. This allows verification of responses from troublesome cases that are run in offline simulations. This is of great interest for time-critical processes, such as when a fault in the DC grid is combined with requirements for robust selective tripping involving fast-rising fault currents. By having the real control system in the loop, confidence is gained that the protection in real life will secure the DC grid by fast-tripping only parts that belong to the faulty zone while keeping the healthy circuitry on line.

To advance this understanding, ABB has constructed a real-time HVDC grid simulator with control and protection hardware- and software-in-the-loop.

For an HVDC grid, ABB's philosophy involves overlaying a master controller in order to optimize system disposition. This functionality too has been implemented in the HVDC grid simulation center. Besides assisting the operator in finding an optimal operation point of the DC grid, the master controller also helps to restore the DC grid after a fault. A typical case would be a DC fault in a cable attached to a converter that is acting as a DC voltage controller. The protection system would, after the fault, first clear the fault by disconnecting the cable. The isolated converter could then stay connected on the AC side and, if required, work as a Statcom, eg, SVC Light, providing reactive power compensation. The rest of the system will be intact after the fault clearance but for a short while, given that the DC voltage controlling station tripped, be without a common DC voltage control. In the interim, every converter has its own local functionality to control the DC voltage until the master controller has assigned a new DC voltage controlling station and calculated new optimal set points for the remaining stations.

Apart from demonstrating ABB's performance and ideas in the context of a DC grid, another task of the ABB HVDC grid simulation center is to deliver results to ongoing ABB-internal research and development projects – for example, applications of the DC breaker in a power system.

As the spread of HVDC grids widens in future years, the ABB HVDC grid simulation center will continue to increase in sophistication and scope, and continue to provide insight into HVDC protection and control for ABB and customers alike.

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Gas-insulated HVDC switch-gear

Flexible and compact power routing

1 Examples of DC GIS components

1a DC GIS surge arrester

1b Gas-insulated disconnector and earthing switch

PER SKARBY – Gas-insulated switchgear (GIS) is much more compact and requires far less clearance than air-insulated switch-gear (AIS). Another advantage is the routing flexibility of the ducts compared with cables. GIS is now replicating its AC success in the world of HVDC.

DC GIS has two principal advan-tages: Installa-tions can be made far more compact than the air-insulated switchgear (AIS) equivalent and they have a sig-nificantly lower sensitivity to am-bient factors.

As in AC power systems, DC GIS technology spans a number of switchgear components, eg, bus ducts, disconnect switches, earthing switches, and current and voltage measurement sensors → 1. DC GIS has two principal advantages: Installations can be made far more compact than the AIS equivalent and they have a significantly lower sensitivity to ambient factors.

The most obvious cost-saving potential can be found on offshore converter platforms where the air clearance required for AIS would lead to a large and heavy offshore structure. By using DC GIS, where the live parts are encapsulated in a pressurized and grounded enclosure, the need for air clearance around the components is completely eliminated and the volumetric space of the switchgear component can be drastically reduced, typically by 70 to 90 percent. Furthermore, the space savings obtained can accommodate new functionality. An example of this functionality is a multiterminal DC system (MTDC) – ie, a set of onshore or offshore marshalling points for multiple cable connections. Using these, an offshore wind park with a converter platform can be connected to different grids in different countries, combining the utility of wind park grid

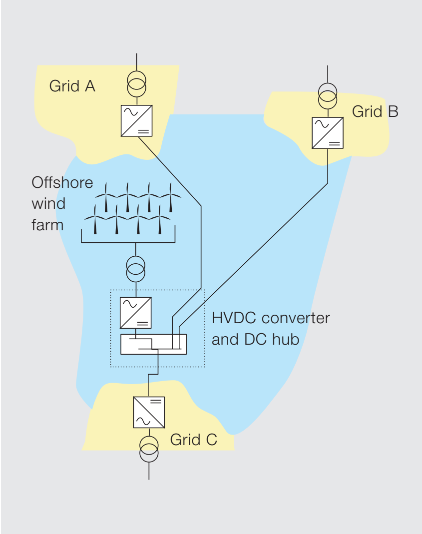
It is anticipated that DC GIS com-ponents with rat-ings up to 500 kV DC will be devel-oped and offered to the market in the near future.

connection with the facility of cross-border trading → 2. This increases the utilization of the cables and the security of supply, and can provide redundancy of the wind park transfer capacity in case of capacity reduction at one of the receiving ends.

HVDC installations on shore may also be drastically reduced in footprint and building height by applying DC GIS to selected components of the converter station.

Due to the combination of solid and gaseous insulation in GIS and the composite dielectric stress of both direct and impulse voltages, special care needs to be taken in the design of the insulating components. The support insulators inside the enclo-

2 DC GIS can provide compact grid interconnections in multiterminal HVDC systems.



The most obvious cost-saving potential can be found on offshore converter platforms where the air clearance required for AIS would lead to a large and heavy offshore structure.

sure, also known as GIS spacers, must be able to withstand not only the direct rated voltage but also transient switching and lightning overvoltages of different polarities. All these factors need to be considered in the design of the insulators.

A direct application of existing AC GIS components is typically not possible but these have been shown to be an excellent starting point in developing DC GIS components [1].

Based on the fact that well-established AC GIS technology with voltage ratings up to 1.1 GV is available, it can be anticipated that DC GIS components with ratings up to 500 kV DC will be developed and offered to the market in the near future.

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Reference

[1] M. Mendik, *et al.,* "Long term performance verification of high-voltage DC GIS," *IEEE Transmission and Distribution Conference,* New Orleans, LA., April, 1999, vol. 2, pp. 484–488.

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