Recent advancements in HVDC transmission

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Abstract

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104 REE N° 1/2017 LE DÉVELOPPEMENT DES LIAISONS À COURANT-CONTINU (HVDC)

**DOSSIER 2 Introduction HVDC**

HVDC is a technology of choice for transmitting power efficiently and reliably over long distances. It is ideally suited for integrating renewable energy sources situated in remote and challenging locations. The benefits of reliable, long-distance transmission with minimum losses, combined with features like the ability to connect unsynchronized power grids, have opened new opportunities for this versatile technology. The first commercial submarine HVDC power transmission link was taken into operation in 1954 – a groundbreaking project that used mercury-arc converters and mass-impregnated high-voltage cables to bring electricity from mainland Sweden to the island of Gotland in the Baltic Sea. Over the course of 25 years, Dr. Uno Lamm and his team at ASEA, today a part of ABB, had researched previously unexplored fields to overcome the challenges of HVDC transmission – work that culminated in the commissioning of the Gotland link. Since then, more than 170 HVDC projects have been installed around the world, bringing bulk power from distant locations to where it is needed and playing a key part in
evolution of a stronger grid. A major advance came in the late 1990s, when ABB introduced HVDC Light®, a VSC (voltage sourced converter) technology with the ability to control AC voltage, frequency and reactive power. This is a great advantage compared to LCC technology which is depending on a strong AC grid for the conversion of the alternating current to direct current. After over twenty HVDC Light projects yielding over 170 years of operating experience, this technology is being successfully deployed in an increasing number of applications, thanks to the parallel development of higher converter voltage and power ratings. Today Insulated-gate bipolar transistor (IGBT) semiconductors can work at 3 kA, and extruded cables with solid extruded XLPE-based polymer insulation are capable of operating at 525 kV. By embedding HVDC Light functionalities into an AC network – e.g. voltage support, reactive power compensation and black start – the performance of existing grid assets can be reinforced. References to all projects and technologies described in this paper can be found at the ABB webpage, including video- clips, images, brochures and scientific papers [1]. HVDC and UHVDC Classic LCC-HVDC technology uses thyristors for conversion and typically has a power rating from several hundred megawatts to as high as 12 000 MW, though many are in the 1 000 to 3 000 MW range. HVDC is suitable for overhead lines as well as submarine cables, or a combination of cables and lines. It can also be configured as back-to-back HVDC stations. This configuration enables two asynchronous grids to exchange power and ensures that in the event of a disturbance in one, the other supports it. The interconnection through HVDC does not add to the short-circuit capacity of the networks. This allows for less-frequent replacement of the heavy. Recent advancements in HVDC transmission Magnus Callavik ABB HVDC is increasingly being used as a preeminent technology for interconnecting power markets and integrating massive amount of renewable energy on all continent throughout the world. This paper describes advancements in HVDC technologies, exemplified by recent and ongoing installations, namely the Celilo upgrade, the North East Agra UHVDC link and the NordLink interconnector. ABSTRACT L’HVDC est une technologie de transport d’électricité privilégiée qui connaît un fort développement pour répondre aux besoins d’interconnexion des marchés de l’énergie et pour intégrer une quantité massive d’énergies renouvelables sur tous les continents. Cet article décrit les avancées des technologies HVDC en donnant des exemples d’installations récentes ou en cours de réalisation, notamment la modernisation de la liaison Celilo aux USA, la liaison Nord-Est Agra UHVDC en Inde, et l’interconnexion NordLink entre la Norvège et le Royaume-Uni. RÉSUMÉ MOTS CLÉS : High voltage direct current (HVDC); Ultra high voltage direct current (UHVDC); voltage sourced converter (VSC); Line commutated converter (LCC); Cross-linked polyethylene (XLPE); Flexible alternating current transmission systems (FACTS); Control and Protection; Phase-controlled thyristor (PCT); Insulated-gate bipolar transistor (IGBT), Hybrid HVDC breaker. REE N°1/2017 105 Recent advancements in HVDC transmission duty switching equipment, keeps grids immune from disturbances and minimizes affected areas. By controlling its power flow, an HVDC system stabilizes the grid in the interconnected networks and increases the security of supply. As HVDC systems cannot be overloaded, uncontrolled cascade tripping of lines is avoided. For example, during the massive 2003 blackout that affected the entire northeastern United States, the HVDC connections shielded the Quebec system in Canada from frequency swings [2]. HVDC lines use the right of way (m/ MW) very effectively and can also be operated at reduced voltage in case some section of a line has issues with insulation withstand capability. HVDC technology enables long underwater transmission links with low losses. Traditional AC transmission systems with underwater cables cannot be longer than about 60 to 100 km as it would require massive reactive compensation en route. VSC-HVDC Using advanced converter technology developed by ABB, the world’s first HVDC transmission with voltage source converters began to transmit power in 1997. This technology was introduced as HVDC Light. The new transmission link ran along a 10 km route between the Swedish towns of Hellsjön and Grängesberg. It was a small first system rated at 3 MW/± 10 kV DC, but contained several unique features such as overhead lines and power electronic-based DC breaker. Due to its unique characteristics, HVDC Light has expanded the range of system applications beyond what has been possible with HVDC Classic. New uses include remote offshore applica- tions, weak system interconnections, long land cables and black start. A look at a few of the recent significant HVDC Light projects tells the story of how ABB has linked the development of this technology to meeting customer needs [1]. Control and protection systems, the transmission system brain 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 the main trends of development. ABB has used the opportunity of recent advancement to upgrade the MACH™ system, after 20 years, with a new 64-bit multicore microprocessor sor unit and new multicore DSP units, all connected by the peripheral com- ponent interconnect (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. Further, less power is used, so fans are not necessary – thus increasing reliability. There is backwards software compatibility so that applications deve- loped for earlier systems using ABB’s function block programming language, HiDraw, can be recompiled and run in the newest systems. 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 envi- ronmentally hardened I/O units. These can be distributed further afield and placed, for example, in junction boxes of breakers or transformers. In this way, the traditional copper cabling connecting the devices back to the control system is replaced by optical fibers. Figure 1: Two key components of ABB’s digital control and protection system MACH™3. The PS700 high speed versatile computer and the distributed I/O depicted left and right, respectively – Source: ABB. 106 REE N°1/2017 LE DÉVELOPPEMENT DES LIAISONS À COURANT-CONTINU (HVDC) DOSSIER 2 The introduction of the new MACH system brings the backbone needed to take HVDC converter
stations into the new digital era. Computer processing power, connectivity, and new sensors will continue to increase in the years to come and this will bring further improvements in the capabilities of control and protection systems, as well as monitoring and predictability of system performance allowing a modern asset management strategy. Advanced semiconductors, the heart of the matter Converter valves rectify and invert AC to DC or DC to AC, respectively. The heart of the valve is the power semiconductor device. The power electronics revolution, which over the past few decades has swept across the power delivery and automation sectors, has opened up a wide range of possibilities in terms of controlling the way electrical energy is transported and used. At the heart of this revolution lies the power semiconductor device: this device performs the actual task of modulating the energy flow to suit the demands of the application. The main trend in the development of power devices has always been increasing the power ratings while improving overall device performance in terms of reduced losses, increased robustness and better controllability, as well as improving reliability under normal and fault conditions. The HVDC-applications market is small but important for semiconduc-tors. Progress in the domain of power devices has in the past largely been dependent on technologies developed for lower power applications, which were then scaled to handle higher voltages and currents. In HVDC applications today, the two main types of switching devices are the phase-controlled thyristor (PCT) and the insulated-gate bipolar transistor (IGBT). Also important is the power diode found in a range of applications spanning rectification, snubber and freewheeling. The IGBT is a MOS-controlled bi-polar switch and presents the inherent advantages of that technology including a controlled low-power driving require-ment and short-circuit self-limiting capability. The IGBT has experienced many performance breakthroughs in the past two decades. ABB has developed a cus-tomized press-pack module (StakPak) for series connection of IGBT and diode chips to be used in grid applications. The mechanical design is optimized to clamp the press packs in long stacks. The module remains fully functional due to its design with individual press-pins for each chip. Furthermore, the choice of materials is optimized to achieve high reliability. Recent advancements in IGBT development has resulted in higher current capacities up to 3,000 A. This new semiconductor device combines the IGBT and the diode and is named Bi-Mode Insulated Gate Transistor (BIGT). In contrast to the IGBT, the PCT is not a turn-off device. It is nevertheless the device of choice for line-commuted converter HVDC systems (HVDC Classic) due to its exceptionally low on-state losses and extremely high-power handling capability. Until very recently, state-of-the-art single devices were rated at 8.5 kV and 4,000 A. With the increase in demand for even higher power HVDC system ratings, larger area 150 mm PCTs with current ratings up to 6,250 A were developed for the latest Ultra HVDC systems operating at ±800 kV. The device is now being implemented during construction of power links in China, for instance the first ±1,100 kV link between Changji and Guquan. Powering the world In this paragraph, three recent installa-tions are briefly described to exemplify the rapid development and introduc-tion of new HVDC technology described earlier. The Pacific Intertie, North-East Agra and NordLink project are examples aiming to bring renewable and reliable power from remote locations to megaci- ties and to interconnect power markets across all continents of the world. Upgrades: Pacific Intertie For nearly 50 years, the Pacific Inter-tie has played a key role in integrating stable renewable hydro power into the grid and transmitting electricity between the Pacific Northwest and Los Angeles in southern California. Pacific Intertie was the first major HVDC link in US trans-mission history, originally commissioned by ABB in 1970. Recently, ABB comple- ted the fourth upgrade of the Celilo station, including the introduction of the world-leading MACH HVDC control and protection system. In addition to moder-nizing the converter station, its capacity has also been increased from 3,100 up to 3,800 megawatts. End of 2016, ABB was entrusted to upgrade also the Sylmar station operated by Los Angeles Department of Water and Power (LADWP). The Celilo converter operated by Bonneville Power Authority (BPA), loca-ted near the Columbia River, is the nor-Figure 2 : Thyristor and IGBT-based semiconductor devices – Source : ABB. REE N°1/2017 107 Recent advancements in HVDC transmission thern station of the 1,360 kilometer HVDC link. It transmits electricity to as many as three million households in the greater Los Angeles area. During winter, the north consumes significant quantities of power for heating while the south requires less, but in summer demand is reversed with more power needed in the south for cooling. The Pacific Intertie HVDC link enables the balance of supply with demand between these regions. Key components of the station upgrade include valves, controls and transformers as well as switchgear and cooling equipment. The station is managed by ABB’s MACH system, the most advanced HVDC HVDC control and protection solution on the market. Celilo was the first installation in the world to benefit from the latest genera-tion of this system, providing an unprecedented level of control and helping to secure power supplies. UHVC: North East Agra ABB was selected by Power Grid Corporation of India Ltd. to deliver the world’s first multi-terminal UHVDC transmission link. The ±800 kV North-East Agra UHVDC link will have a record 8,000 MW converter capacity, including a 2,000 MW redundancy, and transmit clean hydroelectric power from India’s northeast region to the city of Agra, a distance of 1,728 km. The link comprises four terminals in three converter stations with a 33 percent continuous overload rating, enabling an 8,000 MW conversion – the largest HVDC transmis-sion system ever built. North-East India has abundant untapped hydropower resources scattered over a large area, but load centers are hundreds or even thousands of kilome-ters away. One converter station will be in the northeastern state of Assam, and a second in the state of West Bengal in eastern India. The other end of the DC line will terminate at Agra, where two bipolar converters will be connected in parallel. The multi-terminal solution considerably reduces costs compared to the alternative of running separate power links from multiple hydropower plants to Agra. This is the second ABB-built multi-terminal HVDC link. In 1990-1992, a large-scale three terminal transmission link was constructed in North America called the Québec - New England HVDC Transmission, the first of its kind in the world. This link was upgraded in 2016 by ABB. One pole of the North-East Agra is already in operation. At full capacity, the North-East Agra UHVDC link will be able to supply enough electricity to serve 90 million people based on average national consumption. By using ultrahigh volt-age, transmission losses are minimized Figure 3 : Celilo station after upgrade in 2016. Map of Pacific Intertie. Figure 4 : North-East Agra converter valve during dielectric laboratory tests. North-East Agra control room – Source: ABB. 108 REE N°1/2017 LE DÉVELOPPEMENT DES LIAISONS À
COURANT-CONTINU (HVDC) DOSSIER 2 and grid efficiency is improved. Compared with AC, the transmission losses are reduced with several 100's of MW, the equivalent of the power consumption of several million Indian citizens. Ano-ther first in this project is that the 800 kV equipment yard at Agra will for the first time be placed indoor. Interconnectors: NordLink NordLink is an excellent example of how interconnecting grids using HVDC technology can help countries to reach their targets for a renewable energy mix. The link is 623 km long, making it the second longest HVDC intercon- nection in Europe, next to North Sea Link in construction between Norway and UK. The increased use of vola- tile renewable energy sources, such as wind power, requires both the in- feed of a more stable power supply, such as hydropower, into the Germany grid and the inherent stabilizing features of VSC- HVDC technology. The HVDC system will join two of Europe’s main power grids, the conti- nental ENTSO-E grid and the Nordic grid. These two grids have an installed capacity of close to 600 GW and 100 GW, respectively; however, the increa- sing share of renewable power calls for more trading capacity. Therefore the link is fundamental to connect Scandinavia with Germany and is designated as one of the European Commission’s Projects of Common Interest (PCI) to help create an integrated European Union energy market. It will add capacity to the pre- vious six links which have been installed over the last four decades, to increase the power transfer capacity between the grid in Norway, Sweden, Finland and Western Denmark, known as the Nor- dpool region, and Europe’s continental grid. The NordLink interconnector will be the first connection between the countries of Norway and Germany. To Statnett and TenneT, ABB supplies two ±525 kV, 1,400 MW HVDC Light converter stations in a bipole configu- ration and a 525 kV mass impregnated (MI) cable system in the German sec- tor, which consists of a route of 154 km of subsea and 54 km of underground cable. While bipoles are the usual confi- guration for LCC-HVDC to ensure redundant big blocks of power, NordLink is the first VSC-HVDC system in a full bipole VSC-HVDC configuration. Bipoles are the logical choice when power ratings are increased.

Hybrid HVDC breaker With only a few exceptions all existing HVDC lines are point-to-point links. The inability to interrupt the flow of power, and thus enable creation of a DC grid, has been a huge roadblock for HVDC. That is, however, until very recently. In 2012, ABB announced a major breakthrough in the development of the DC grid – the Hybrid HVDC brea- ker. The breaker combines low loss L'AUTEUR Dr. Magnus Callavik is the head of technology for business unit Grid Integration at ABB Power Grids which spans HVDC, FACTS and other AC-related power electronic applications, high voltage cables, semiconductors and substations applications. He joined ABB in 1999. He has an executive MBA and is certified project management pro- fessional. Figure 5 : Representation of the NordLink converter station in Edsmyra, Norway. Map of Nordlink route. REE N°1/2017 109 Recent advancements in HVDC transmission mechanical components and extremely fast power electronic switching that enables it to interrupt power flows of up to 1 GW – equivalent to the out- put of a large power station – within less of 5 ms. This innovation is paving the way for a more efficient and reliable electricity supply system. Any future lar- ger HVDC network will acquire the ability to isolate faults to prevent powering down the whole DC power, for preven- tion of a major impact on the AC grid connected to the HVDC Grid. Here brea- king the load of DC connection current is a unique feature of the Hybrid HVDC breaker. A breaker can also be used in point-to-point VSC-HVDC links to clear DC faults on overhead lines while main- taining converter voltage support to the AC grid. From ABB’s experience the breaker would give a fast response, while maintaining very low losses during normal operation. The use of such breakers for overhead line VSC-HVDC networks is already in planning in China for larger multi-terminal HVDC systems, such as the planned Zhangbei multi-ter- minal grid which will feed wind power into the Beijing area. Concluding remark The examples of recent groundbrea- king introduction of new technologies and recent upgrades given in this paper show the life-time commitment of ABB in the area of HVDC to enable stron- ger, smarter and greener grid for the utility companies of today and tomorrow by maintaining the largest portfolio of HVDC systems and products. References [1] www.abb.com/hvdc [2] http://energy.gov/sites/prod/files/ oeprod/DocumentsandMedia/OutageFinal-Web.pdf Figure 6 : Hybrid HVDC Breaker.

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