50 years HVDC

PART II

The semiconductor 'takeover'

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Mercury-arc valve based HVDC had come a long way in a short time, but it was a technology that still harbored some weaknesses. One was the difficulty in predicting the behavior of the valves themselves. As they could not always absorb the reverse voltage, arc-backs occurred. Also, mercury-arc valves require regular maintenance, during which absolute cleanliness is critical. A valve that avoided these drawbacks was needed.

The invention of the thyristor in 1957 had presented industry with a host of new opportunities, and HVDC transmission was now seen as a promising area of application. A new era was about to unfold.

All through the first half of the 1960s, as a result of the huge interest being shown in semiconductor applications, work had continued on development of high-voltage thyristor valves as an alternative to the mercury-arc type. In the spring of 1967, one of the mercury-arc valves used in the Gotland HVDC link was replaced with a thyristor valve. It was the first time anywhere that this kind of valve had been taken into commercial operation for HVDC transmission. After a trial of just one year, the Swedish State Power Board ordered a complete thyristor valve group for each converter station, at the same time increasing the transmission capacity by 50 percent.

Around the same time, tests were carried out on the Gotland submarine cable, which had been operating without any problems at 100 kV, to see if its voltage could be increased to 150 kV – the level needed to transmit the higher power. The tests showed that it could, and this cable was subsequently operated at an electrical stress of 28 kV/mm, which is still the worldwide benchmark for large HVDC cable projects today.

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The new valve groups were connected in series with the two existing mercury-arc valve groups, thereby increasing the transmission voltage from 100 to 150 kV. This higher-rated system was taken into service in the spring of 1970 – another world's 'first' for the Gotland transmission link.

With the advent of thyristor valves it became possible to simplify the con-

Gotland 1 extension, with the world's first HVDC thyristor valves

verter stations, and semiconductors have been used in all subsequent HVDC links. Other companies were now entering the field. Brown Boveri (BBC) – which later merged with ASEA to form ABB – teamed up with Siemens and AEG in the mid-1970s to build the 1920-MW Cahora Bassa HVDC link between Mozambique and South Africa. The same group then went on to build the 2000-MW Nelson River 2 link in Canada. This was the first project to employ water-cooled HVDC valves.

The late 1970s also saw the completion of new projects. These were the Skagerrak link between Norway and Denmark, Inga-Shaba in the Congo, and the CU Project in the USA.

The Pacific Intertie was also extended twice in the 1980s, each time with thyristor converters, to raise its capacity to 3100 MW at ±500 kV. (ABB is currently upgrading the Sylmar terminal with state-of-the-art technology.)

Itaipu – the new benchmark

The contract for the largest of all HVDC transmission schemes to date, the 6300-MW Itaipu HVDC link in Brazil, was awarded to the ASEA-PROMON consortium in 1979. This project was completed and put into operation in several stages between 1984 and 1987. It plays a key role in the Brazilian power scheme, supplying a large portion of the electricity for the city of São Paulo.

The scale and technical complexity of the Itaipu project presented a considerable challenge, and it can be considered as the start of the modern HVDC era. The experience gained in the course of its completion has been in no small way responsible for the many HVDC orders awarded to ABB in the years since.

After Itaipu, the most challenging HVDC project was undoubtedly the 2000-MW Québec – New England link. This was the first large multi-terminal HVDC transmission system to be built anywhere in the world.

HVDC cables have kept pace

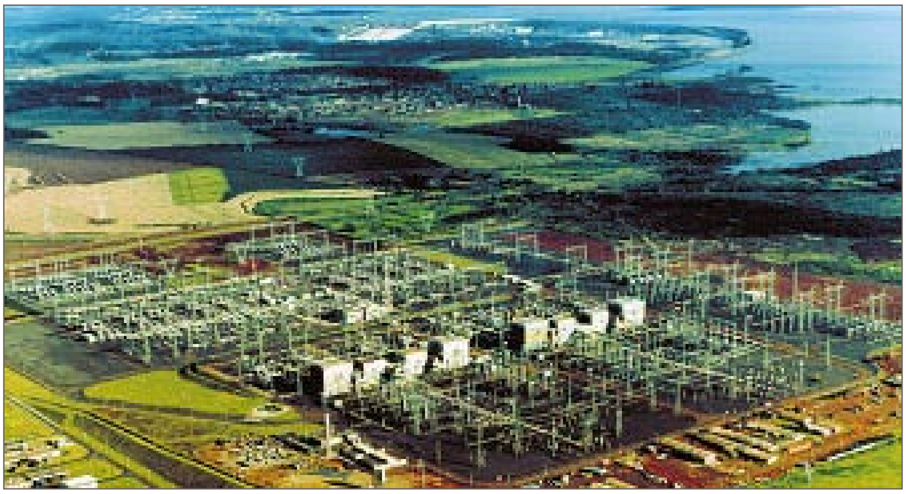
As the converter station ratings increased, so too did the powers and voltage levels for which the HVDC cables had to be built.

The most powerful HVDC submarine cables to date are rated 600 MW at 450 kV. The longest of these are the 230 km cable for the Baltic Cable link between Sweden and Germany, and the 260 km cable for the SwePol link between Sweden and Poland.

HVDC today

The majority of HVDC converter stations built today are still based on the principles that made the original Gotland link such a success back in 1954. Station design underwent its first big change with the introduction of thyristor valves in the early 1970s. The first of these were air-cooled and designed for indoor use, but soon outdoor oil-cooled, oil-insulated valves were also being used. Today, all HVDC valves are water-cooled [1].

Good examples of modern bulk power HVDC transmission are the links ABB



Foz do Iguaçu converter station with the Itaipu 12,600-MW power station in the background

Baltic Cable HVDC converter station

is installing for the Three Gorges hydroelectric power plant project in China. (An article on the Three Gorges project begins on page14 of this issue.)

In 1995 ABB presented a new generation of HVDC converter stations: 'HVDC 2000' [2]. HVDC 2000 was developed to meet stricter electrical disturbance requirements, to provide better dynamic stability where there was insufficient short-circuit capacity, to overcome space limitations, and to shorten delivery times.

Submarine cable for the 600-MW Baltic Cable HVDC link between Germany and Sweden

A key feature of HVDC 2000 was the introduction of capacitor commutated converters (CCC). This was, in fact, the first fundamental change to have been made to the basic HVDC system technology since 1954!

HVDC 2000 also includes other ABB innovations, such as continuously tuned AC filters (ConTune), active DC filters, outdoor air-insulated HVDC valves, and the fully digital MACH2™ control system.

The first project to employ HVDC 2000 with CCC and outdoor valves was the Garabi 2200-MW HVDC back-to-back station in the Brazil – Argentina HVDC Interconnection.

HVDC Light™

HVDC technology has become a mature technology over the past 50 years and reliably transmits power over long distances with very low losses. This begs the question: where is development work likely to go in the future?

Most of the HVDC converter stations built today are still based on the principles that made the original Gotland link such a success.

It was conceived that HVDC development could, once again, take its cue from industrial drives. Here, thyristors were replaced a long time ago by voltage source converters (VSC), with semiconductors that can be switched off as well as on. These have brought many advantages to the control of industrial drive systems and it was realized that they could also apply to transmission systems. Adapting the technology of voltage source converters to HVDC, however, is no easy matter. The entire technology has to change, not just the valves.

As development of its VSC converter got under way, ABB realized that the insulated gate bipolar transistor, or IGBT, held more promise than all the other available semiconductor components. Above all else, the IGBT needs only very little power for its control, making series connection possible. However, for HVDC a large number of IGBTs have to be connected in series, something industrial drives do not need.

In 1994, ABB concentrated its development work on VSC converters in a project that aimed at putting two converters based on IGBTs into operation for small-scale HVDC. An existing 10-km-long AC line in central Sweden was made available for the project.

At the end of 1996, after comprehensive synthetic tests, the equipment was installed in the field for testing under service conditions. In 1997 the world's first VSC HVDC transmission system, HVDC Light™ [3], began transmitting power between Hellsjön and Grängesberg in Sweden.

In the meantime, seven such systems have been ordered, and six of them are now in commercial operation in Sweden, Denmark, the USA and Australia. HVDC Light is now available for ratings up to 350 MW, ±150 kV. ABB is to date the only company that has managed to develop and build VSC HVDC transmission systems [4].

Shoreham station, 330-MW HVDC Light™ Cross Sound Cable link, USA

HVDC Light land cable

One advantage of HVDC Light is that it allows an improvement in the stability and reactive power control at each end of the network. Also, it can operate at very low short-circuit power levels and even has blackstart capability. The HVDC Light cable is made of polymeric material and is therefore very strong and robust. This makes it possible to use HVDC cables where adverse laying conditions might otherwise cause damage. Extruded cable has also made very long HVDC cable transmission on land now economically viable. An example is the 180-km-long HVDC Light™ interconnection 'Murraylink' in Australia.

The introduction of capacitor commutated converters was the first fundamental change made to the basic HVDC technology since 1954!

And the next 50 years?

HVDC transmission has come a long way since that first Gotland link. But what does the future hold for it?

Bulk transmission is likely to rely on thyristor-based technology for many years since it is reliable and low in cost, plus losses are low. Increasing the voltage is one way to go here as it would allow much higher powers and very long distances for the links.

HVDC Light has the potential to be developed further. One direction might be toward higher voltages and powers, but low power and relatively high voltages are also conceivable for systems for smaller loads and generators.

The development of HVDC Light cable has made it possible to link up networks across very deep waters that have previously made such schemes unthinkable. The most interesting prospects for HVDC Light, however, lie in its potential for building multi-terminal systems. In the long term it might offer a genuine alternative to AC transmission, which today completely dominates this sector.

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Further information on HVDC can be found at www.abb.com/hvdc