50 years

# HVDC

PART I

## ABB – from pioneer to world leader

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**In 1954, at a time when much of Europe was busy expanding its electricity supply infrastructure to keep pace with surging demand, an event was quietly taking place on the shores of the Baltic Sea that would have a lasting effect on long-distance power transmission. Four years earlier, the Swedish State Power Board had placed an order for the world's first commercial high-voltage direct current (HVDC) transmission link, to be built between the Swedish mainland and the island of Gotland. Now, in 1954, it was being commissioned.**

**50 years on, ABB proudly looks back at its many contributions to HVDC technology. Since the laying of that early 90 kilometers long, 100-kV, 20-MW submarine cable, our company has gone on to become the undisputed world leader in HVDC transmission. Of the 70,000 MW of HVDC transmission capacity currently installed all over the world, more than half was supplied by ABB.**

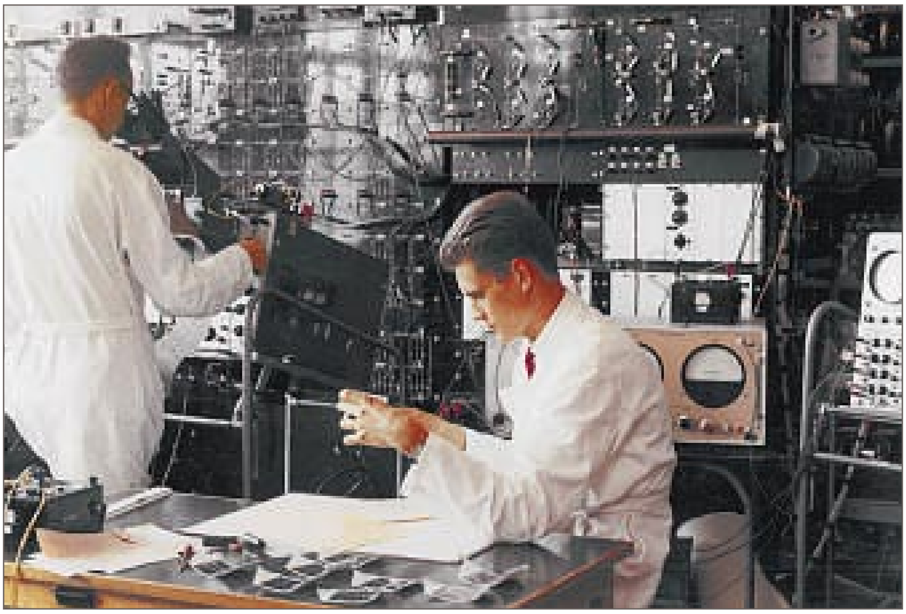
With the arrival of the electric light bulb in the homes and factories of late 19th century Europe and the USA, demand for electricity grew rapidly and engineers and entrepreneurs alike were soon busily searching for efficient ways to generate and transmit it. The pioneers of this new technology had already made some progress – just being able to transmit power a few kilometers was regarded as something fantastic – when an answer to growing demand was found: hydroelectric power. Almost immediately, interest turned to finding ways of transmitting this 'cheap' electricity to consumers over longer distances.

### First direct, then alternating current

The first power stations in Europe and the USA supplied low-voltage, direct current (DC) electricity, but the transmission systems they used were inefficient. This was because much of the generated power was lost in the cables. Alternating current (AC) offered much better efficiency, since it could easily be transformed to higher voltages, with far less loss of power. The stage was thus set for long-distance high-voltage AC (HVAC) transmission.

In 1893, HVAC got another boost with the introduction of three-phase transmission. Now it was possible to ensure a smooth, non-pulsating flow of power.

Although direct current had been beaten at the starting gate in the race to develop an efficient transmission system, engineers had never completely given up the idea of using DC. Attempts were still being made to build a high-voltage transmission system with series-con-



Analog simulator used in the design of the early HVDC transmission systems

nected DC generators and, at the receiving end, series-connected DC motors – all on the same shaft. This worked, but it was not commercially successful.

## AC dominates

As the AC systems grew and power increasingly was being generated far from where most of its consumers lived and worked, long overhead lines were built, over which AC at ever-higher voltages flowed. To bridge expanses of water, submarine cable was developed.

Neither of these transmission media was without its problems, however. Specifically, they were caused by the reactive power that oscillates between the capacitances and inductances in the systems. As a result, power system planners began once again to look at the possibility of transmitting direct current.

## Back to DC

What had held up high-voltage direct current transmission in the past was, first and foremost, the lack of reliable and economic valves that could convert HVAC into HVDC, and vice versa.

The mercury-arc valve offered, for a long time, the most promising line of development. Ever since the end of the 1920s, when the Swedish ASEA – a founding company of ABB – began making static converters and mercury-arc valves for voltages up to about 1000 V, the possibility of developing valves for even higher voltages had been continually investigated.

> Even when HVDC transmission finally proved technically feasible, it was doubted for a long time whether it could compete with HVAC in the marketplace.

This necessitated the study of new fields in which only a limited amount of existent technical experience could be applied. In fact, for some years it was debated whether it would be possible at all to find solutions to all the various problems. When HVDC transmission finally proved to be technically feasible there still remained uncertainty as to whether it could successfully compete with HVAC in the marketplace.

Whereas rotating electrical machines and transformers can be designed very precisely with the aid of mathematically formulated physical laws, mercury-arc valve design depends to a large degree on knowledge acquired empirically. As a result, attempts to increase the voltage in the mercury-vapor-filled tube by enlarging the gap between the anode and cathode invariably failed.

The problem was solved in 1929 by a proposal to insert grading electrodes between the anode and cathode. Subsequently patented, this innovative solution can in some ways be considered as the cornerstone of all later development work on the high-voltage mercury-arc valve. It was during this time that Dr. Uno Lamm, who led the work, earned his reputation as 'the father of HVDC'.

## The Gotland link

The time was now ripe for service trials at higher powers. Together with the Swedish State Power Board, the company set up, in 1945, a test station at Trollhättan, where there was a major power plant that could provide energy. A 50-km power line was also made available.

Trials carried out over the following years led to the Swedish State Power Board placing, in 1950, an order for equipment for the world's first HVDC transmission link. This was to be built between the island of Gotland in the Baltic Sea and the Swedish mainland.

Following on this order, the company intensified its development of the mercury-arc valve and high-voltage DC cable, while also initiating design work on other components for the converter stations. Among the equipment that benefited from the increased efforts were transformers, reactors, switchgear and the protection and control equipment.

Early mercury-arc valve for HVDC transmission

Only some of the existing AC system technology could be applied to the new DC system. Completely new technology was therefore necessary. Specialists in Ludvika, led by Dr. Erich Uhlmann and Dr. Harry Forsell, set about solving the many very complex problems involved. Subsequently, a concept was developed for the Gotland system. This proved to be so successful that it has remained basically unchanged right down to the present time!

Continual development of the mercury-arc valve secured a level of reliability that has resulted in some HVDC projects with these valves still being in operation after 35 years.

Since Gotland is an island and the power link was across water, it was also necessary to manufacture a submarine cable that could carry DC. It was seen that the 'classic' cable with mass impregnated paper insulation that had been in use since 1895 for operation at 10 kV AC had potential for further development. Soon, this cable was being developed for 100 kV DC!

Finally, in 1954, after four years of innovative endeavor, the Gotland HVDC transmission link, with a rating of 20 MW, 200 A and 100 kV, went into operation. A new era of power transmission had begun.

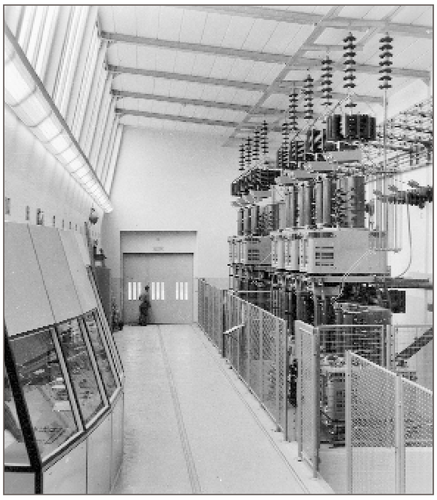
The original Gotland link was to see 28 years of successful service before being finally decommissioned in 1986. Two new links for higher powers have meanwhile been built between the island and the Swedish mainland, one in 1983 and the other in 1987.

### Early HVDC projects

The early 1950s also saw the British and French power administrations planning a power transmission link across the English Channel. High-voltage DC transmission was chosen, and the company won its second HVDC order – this time a link for 160 MW.

The success of these early projects generated considerable worldwide interest. During the 1960s several HVDC links were built: Konti-Skan between Sweden and Denmark, Sakuma in Japan (with 50/60 Hz frequency converters), the New Zealand link between the South and the North Islands, the Italy – Sardinia link and the Vancouver Island link in Canada.

The largest mercury-arc valve HVDC transmission link to be built by the company was the Pacific Intertie [1] in the USA. Originally commissioned for 1440 MW and later uprated to 1600 MW at ±400 kV, its northern terminal is sited in The Dalles, Oregon, and its southern terminal at Sylmar, in the northern tip of the Los Angeles basin. This project was undertaken together with General Electric, and started operating in 1970.



Mercury-arc valves in the first Gotland link, 1954

In all, the company installed eight mercury-arc valve based HVDC systems for a total power rating of 3400 MW. Although many of these projects have since been replaced or upgraded with thyristor valves, some are still in operation today, after 30 to 35 years of service!

**Part II: 50 years of HVDC transmission – the semiconductor 'takeover'**
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**Reference**

[1] **L. Engström:** More power with HVDC to Los Angeles. ABB Review 1/88, 3–10.