Grid Systems HVDC

The early HVDC development
The key challenge in the HVDC technique

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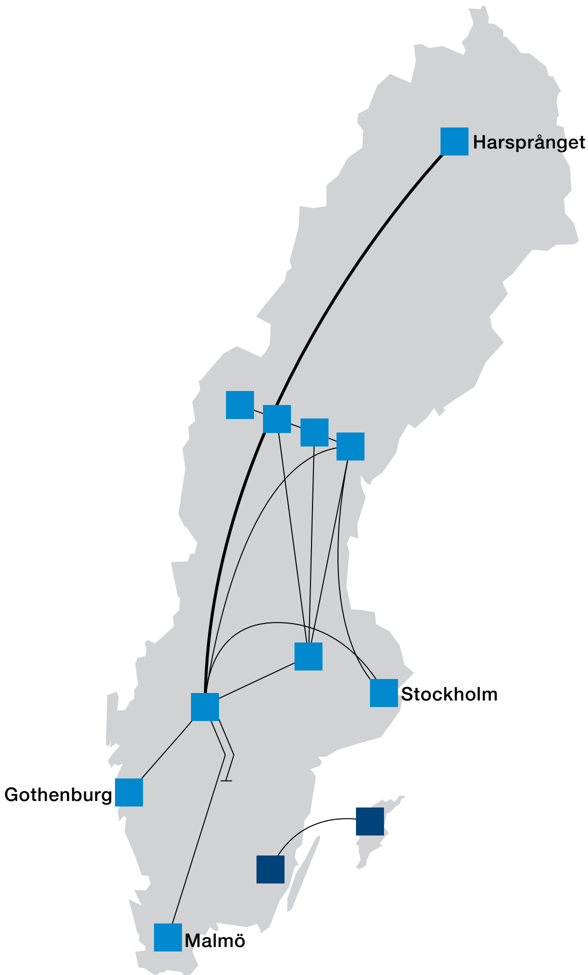
The early challenges of long distance transmission.
During the 1940's the Swedish State Power Board (now Vattenfall AB) was planning the long transmission system from the new Harsprånget hydroelectric power plant in the far north to the load centers in the southern part of the country. High-voltage direct current (HVDC) was considered for the Harsprånget transmission, but the system and component development work that was being made by ASEA (now ABB) had not yet advanced sufficiently for a practical application of the technique. Therefore it was decided to build a 400 kV AC transmission system. The first part of this system was energized in 1952 and it was then the highest voltage used anywhere in the world.

The key challenge in the HVDC technique was the development of reliable and economic valves which could convert high-voltage alternating current into high-voltage direct current and vice versa. Experiments performed in different parts of the world on mechanical moving contact devices did not prove successful. On the other hand, the mercury-arc valve offered one possible line of development. From the end of 1920's, when ASEA embarked on the development and manufacture of static converters and mercury-arc valves for voltages up to about 1,000 V, the possibilities of developing valves also for higher voltages were investigated.

This necessitated the study of completely unknown fields, where earlier technical experience could only be applied to a limited degree. For a number of years it was indeed an open question whether there existed any solution at all to the challenges. When the HVDC system finally proved to be a technical reality, there still remained uncertainty as to whether it could compete in practice and be economical. By then the already established power transmission systems had also made significant progress.

While electrical machines, transformers, etc., can be designed with great precision with the aid of mathematically formulated physical laws, the design of the mercury-arc valve must be based to a large degree on empirically acquired knowledge. When trying out higher voltages, one is confronted by specific physical challenges. In a power line or high voltage apparatus raising the voltage is met by increasing the insulation clearances. In the mercury vapor atmosphere of the mercury-arc valves it does not help at all to increase the spacing between the electrodes.



Trunk line system in Sweden 1952 with the first 400 kV line and the 220 kV network. In 1954 the world's first HVDC link was installed between the Swedish mainland and the island Gotland.

The mercury-arc valve

This challenge was solved in 1929 by a proposal, which was subsequently patented and which in some ways can be considered as forming the cornerstone of the development work on the high-voltage mercury-arc valve. An experimental valve, tried out in 1933, confirmed the validity of this principle during its brief life. At the same time it was found there still remained major material challenges to be solved. However, after continued development work it proved possible, in 1944, to operate a rectifier and an inverter in the laboratory at Ludvika with a DC load of 2,000 kW at a voltage up to 60 kV. The development work was lead by Dr. Uno Lamm, who has been named ”The father of HVDC”.

Dr. Uno Lamm

Dr. Lamm was the man most responsible, as an engineer and manager, for research and development that led to the first practical application of an HVDC connection between two AC systems. The keys to solution of this program were the development of an electric valve, which could be used in high capacity, high voltage converters, and a fundamental system technology.

Dr Uno Lamm graduated from the Royal Institute of Technology, Stockholm 1927 and acquired his Doctorate of Technology in 1943. He joined ASEA in 1928 with the task of developing mercury arc rectifiers as an early assignment. During his career with ASEA, he received progressively more responsible appointments: Head of the Rectifier Department; Head of ASEA’s Nuclear Department; Electrotechnical Director; and Consultant to the President of ASEA. He was a Fellow of IEEE and the 1965 recipient of the Benjamin Lamme Medal.

The Uno Lamm High Voltage Direct Current Award was established by IEEE Power Engineering Society in 1980 to recognize outstanding achievements in the HVDC field.

Dr. Lamm passed away in 1989 at the age of 85.

The Gotland link

The time was now ripe for service trials with larger powers than permitted by the resources at Ludvika. A test station at Trollhättan, run jointly by the Swedish State Power Board and ASEA, was established in 1945, and a 50-km power line was made available for service trials.

In 1950 the State Power Board placed an order with ASEA for equipment for the first HVDC transmission, between the island of Gotland and the Swedish mainland. In the

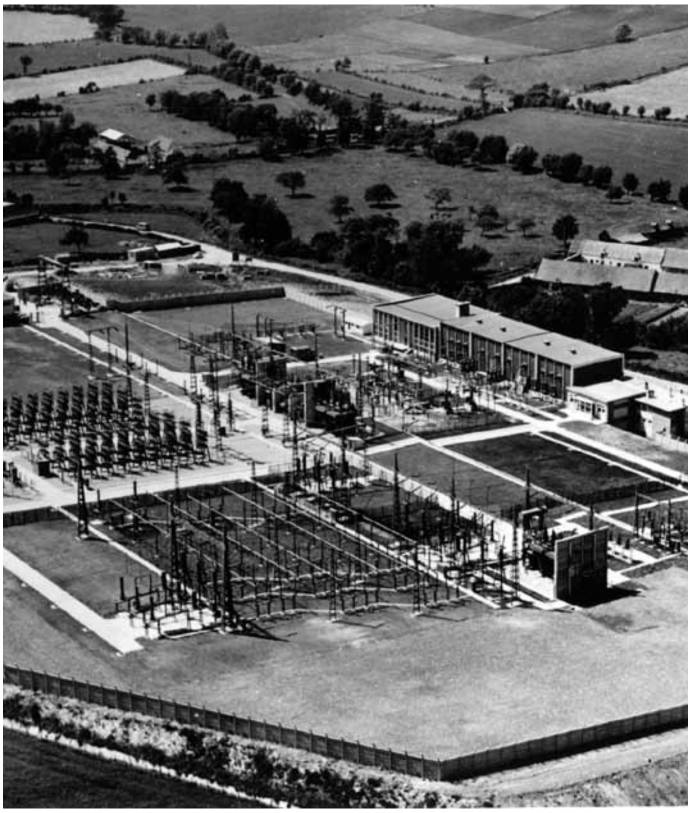
Dr Uno Lamm – “The father of HVDC”

Test station at Trollhättan

following year a larger test station was taken into service at Trollhättan, possessing adequate resources for the empirical development of large high- voltage mercury-arc valves. Accelerated development work resulted in the solving of the final challenges in 1953, and the design of the most critical component, the mercury-arc valve, was fixed.

The Gotland transmission with a rating of 20 MW, 200 A, 100 kV came into service in 1954. The accelerated work during the latter stages of the development project involved the tackling and solving of a series of challenges at the same time as new challenges and obstacles were discovered. Over one hundred modifications were systematically tried out. The number of possible development lines, which at the beginning appeared to be very large, gradually shrank. Finally, there remained only a few alternatives, and among these was found the way which led to the final solution.

Design work on other components in the converter stations and transmission such as transformers, reactors, switchgear and protective and control equipment took place in parallel with the development work on mercury-arc valves. AC system technology, which had been built up over half a century by power specialists the world over, could only be partly applied to a DC system. This meant that a completely new system technique became necessary. However, this did not require empirical work as in the case of the mercury- arc valves. Advanced mathematical methods and network models (TNA) could be applied.



The English Channel HVDC transmission 1961. Echinghen station, France.

With these aids, ASEA‘s specialists in Ludvika led by Dr. Erich Uhlmann tackled the comprehensive complex of challenges and developed a system concept, that was applied in the Gotland transmission. This concept proved to be very successful, and has remained basically unchanged until today.

The English Channel

At the beginning of the 1950‘s, the British and French power administrations planned a power transmission across the English Channel. A few weeks after the commissioning of the Gotland transmission, the study committee appointed for this purpose published its report, which recommended AC cables. The distance was sufficiently short for this to be possible. After lengthy deliberations and studies of the experiences from the Gotland transmission, the HVDC alternative was chosen instead and ASEA received their second order for transmission equipment. It was an extremely favourable circumstance for developments that a transmission project of such a moderate scope as the Gotland link happened to take place just at the time it did. No power administration would dare to embark on a completely unproven system for bulk power transmission. However, the foundation stones were laid with the Gotland project, even if there remained much work to do in the development of converters for twice the voltage and 10 to 20 times higher power required by the subsequent installations.

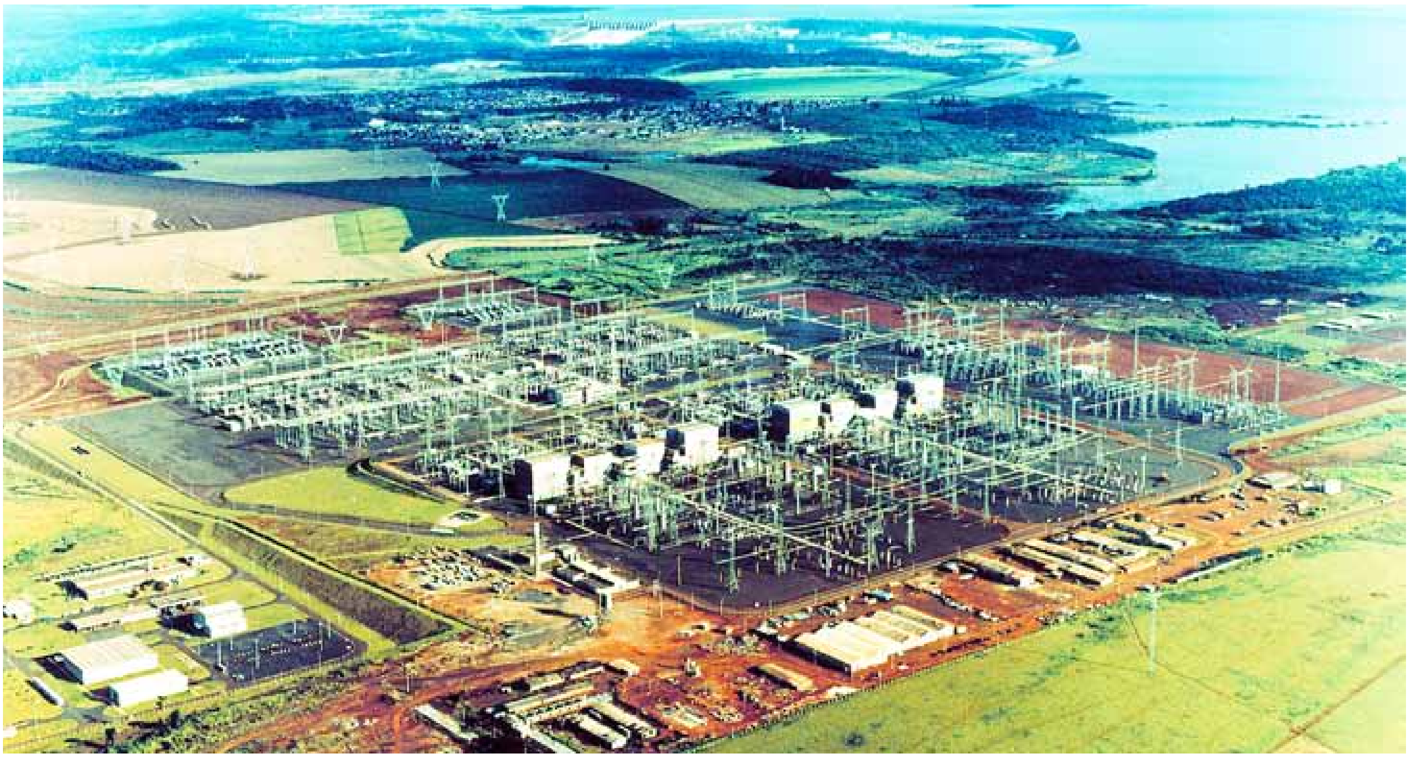
The HVDC market grows

Following the English Channel project, several HVDC transmissions using mercury-arc valves were built during the 1960’s. These were Konti-Skan, Sweden–Denmark, Sakuma, the New Zealand transmission and the Italy–Sardinia link.

The largest mercury-arc valve transmission built by ASEA was the Pacific HVDC Intertie in the USA.

This is a 1,440 MW (later re-rated to 1,600 MW) ±400 kV transmission from The Dalles, Oregon to Los Angeles, California. This project was undertaken by a joint venture formed by ASEA and the General Electric Co. The Pacific Intertie started operating in 1970.

The Pacific HVDC Intertie has been further extended with modern technology and now has a capacity of 3,100 MW and a voltage of ±500 kV.



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Foz do Iguaçu converter station in the Itaipu 6,300 MW transmission.

The thyristor takes over

In view of ASEA's extensive activities in the semiconductor field, it was natural that the company also worked on the development of high-voltage thyristor valves as an alternative to mercury-arc valves. In the spring of 1967 one of the mercury-arc valves in the Gotland transmission was replaced by a thyristor valve, the first in the world to be taken into commercial operation for HVDC transmission.

After about one year of trial operation, the Swedish State Power Board ordered a complete valve group for each converter station in order to increase the transmission capacity by 50 %. The new valve group was connected in series with the two existing mercury-arc valve groups, thus increasing the transmission voltage from 100 to 150 kV. This enlarged transmission was taken into service in the spring of 1970 - the Gotland transmission had once more become a world pioneer.

Semiconductor valves made it possible to simplify the converter stations, and they have been used in all subsequent HVDC transmissions. A number of large HVDC transmissions were built by ASEA and BBC, the predecessors of ABB, during the 1950's. These were the Cahora Bassa, Mozambique–South Africa, Skagerrak, Norway–Denmark, Inga-Shaba, DR Congo, CU Project, USA, and Nelson River 2, Canada.

The contract for the then largest of all HVDC transmissions in the world, the 6,300 MW Itaipu HVDC transmission in Brazil, was awarded to the ASEA-PROMON consortium in 1979. It went into operation in stages between 1984 and 1987 and is an important element in the Brazilian power supply delivering a large portion of the electricity needs of the city of Sao Paulo.

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