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Foray, D. (1989). Les modeles de compétition technologique: Un revue de la littérature. *Revue d'Économie Industrielle, 48.*

Freeman, C. (1982). *The economics of industrial innovation.* (Third ed.). London: Frances Pinter.

Fridlund, M. (1993). *The 'development pair' as a link between systems growth and industrial innovation: Co-operation between the Swedish State Power Board and the ASEA company* (Trita HST Working Paper 93/9). Stockholm: Royal Institute of Technology, Department of History of Science and Technology.

Giuntini, A. (1993). High speed trains in Italy. In J. Whitelegg, S. Hultén, & T. Flink (Eds.), *High speed trains: Fast tracks to the future* (pp. 55 - 65). Hawes, North Yorkshire: Leading Edge Publishing Ltd.

Gunnarsson, U. (1994). *Banor för snabba tåg i Sverige.* Malmö: Nordisk Banteknisk Ingenjörsutbildning.

Hidefjäll, P. (1997). *The pace of innovation: Patterns of innovation in the cardiac pacemaker industry.* Unpublished Ph.D. Dissertation, Linköping University, Linköping, Sweden.

Hultgren, K. (1981). *Höghastighetståg: Järnvägens tredje generation olika lösningar i olika länder.* Malmö: Frank Stenvalls Förlag.

Linder, G. (1996). *Handbok i offentlig upphandling.* Stockholm: Norstedts Juridik AB.

Lundvall, B.-A. (1988). Innovation as an interactive process: From user-producer interaction to the national system of innovation. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, & L. Soete (Eds.), *Technical change and economic theory* (pp. 349 - 369). London: Pinter Publishers.

Martin, J. F. (1996). *The EC public procurement rules: A critical analysis.* Oxford: Clarendon Press.

Nilsson, C., & Wallner, J. (1993, March 3). *Dagens Nyheter.*

Pålsson, L. (1987). *Upphandling av snabbtåg.* Stockholm: SJ.

SFS 1973:600. (1973). *Kungliga Majestäts upphandlingskungörelse.* Stockholm: Swedish Law.

SJ. (1969). *Höga hastigheter i SJ persontrafik tekniska förutsättningar.* Stockholm: SJ Centralförvaltning Utvecklingsavdelningen.

SJ. (1980). *SJ snabbtågsprojekt: Utredning 1980.* Stockholm: SJ Centralförvaltning.

Teubal, M., Yinnon, T., & Zuscovitch, E. (1991). Networks and market creation. *Research Policy, 20,* 381 - 392.

WS Atkins Management Consultants, & Associates. (1988). *The "cost of non-Europe" in public sector procurement.* (Vol. 5). Luxembourg: Office for Official Publications of the European Communities.

3. PROCURING PRODUCTS AND POWER: DEVELOPING INTERNATIONAL COMPETITIVENESS IN SWEDISH ELECTROTECHNOLOGY AND ELECTRIC POWER

M. Fridlund

1. INTRODUCTION

Competitiveness comes in mysterious ways. Today, the Swedish state, through its power utility, Vattenfall, is a competitor on the European power market and the private Swedish-Swiss firm, ASEA Brown Boveri (ABB), is one of the major international electrotechnical manufacturers. The aim of this study is to investigate the development of one of the tools behind this competitiveness of the Swedish state and industry. The tool in question was the High Voltage Direct Current (HVDC) transmission technology.[1]

The first commercial HVDC plant was inaugurated in 1956 and was the outcome of a public technology procurement project between the Swedish electrotechnical company, ASEA, and the Swedish public power agency, the Royal Board of Waterfalls (Vattenfall). However, the HVDC development neither started nor ended with this project. Therefore the central global and local processes that influenced the prospective HVDC user and producer before and after the formal procurement project are described. The study closes when HVDC reached commercial maturity locally and globally as well as having gone through its first transfer abroad. The procurement process is divided into the phases of Proto-Procurement, Procurement, and Post-Procurement. Note however that this linear division is made in retrospect for analytic purposes and does not resemble the actual perception of the actors involved, who on the contrary were uncertain all through the procurement project – and long after – whether HVDC actually had a commercial future.

[1] ASEA was in 1988 merged with the Swiss Brown Boveri & Co (BBC) into ASEA Brown Boveri (ABB). Vattenfall, formerly the Royal Board of Waterfalls, was in 1992 divided into the state-owned power producing stock company, Vattenfall, and the grid administration agency, Svenska Kraftnät.

2. PROTO-PROCUREMENT: IN SEARCH OF POWER AND PRODUCTS

In the interwar period high voltage alternating current (AC) transmission was the dominant technology for electric power transmissions. That had not always been the case however. The end of the 19th century had seen the "battle of the currents" between proponents of direct current (DC) and AC technologies about which was best for long-distance power transmissions. The battle was decided by the first large-scale transmission project, the American Niagara Falls project. This included building the world's largest power plant and experts had first recommended DC transmission but as the experience of AC increased swayed in favour of AC. In 1896 Niagara started producing hydro power and became a powerful example of the value of AC transmission in utilising "remote waterfalls hitherto running to waste" (Hunter and Bryant, 1991: 254). This decided the battle of the currents and gave AC an hegemony in long-distance power transmission that was to keep its hold until the interwar period and the "second battle of the currents" (Fridlund and Maier, 1996).

2.1 New Beginnings

The interwar period can with the benefit of hindsight be seen as being formative for several crucial procurement resources globally as well as locally by identifying obstacles of a new dimension for AC transmissions. The interwar period saw a rising demand for power reflected in discussions concerning several international "super power transmissions" projects – long-distance transmissions of large amounts of electric power – that were suitable for HVDC. This generated a *proto-demand* for an HVDC innovation-to-be, and created a familiarity of the future user Vattenfall with the critical problems with such a project. Concerning supply, globally novelty and diversity was created through the emergence of several HVDC *proto-technologies* and locally an "absorptive capacity" for transmission technologies was created in the future producer, ASEA. Last but not least, the period saw the structuring of relations in the Swedish electrotechnical sector in that the *development pair* between ASEA and Vattenfall had matured. After a 20-year long period of social learning in different user-producer projects a mutual trust had been developed that became important in the following Procurement Phase.

2.2 Shaping the Needs: Developing Proto-Demand

The technical characteristics of the AC technology made it unsuitable for several super-power projects. Mainly, there were critical problems with the bad electrical stability of long AC transmissions; these could cause power failures and black-outs, and made impossible the building of long underwater cable transmissions using AC. As a solution, it was proposed in the interwar period to use DC transmission, which did not suffer from these problems and also promised to be less expensive. Internationally AC and DC were once again pitched against each other.

2.2.1 Global visions: plans for international interconnections

The largest and most seriously contemplated super power transmission project concerned electric power transmission from Norway to the European continent. WWI had demonstrated to Denmark its large dependency on coal-imports and since Norway had one of the world's largest hydro power resources with only a limited domestic market potential Denmark proposed a project concerning a super power transmission from Norway through Sweden to Denmark. A Nordic commission investigated critical technological and economic problems of such an Inter-Scandinavian power transmission and concluded that it was feasible with either AC or HVDC. However, the world economic crisis of the 1930s made the project unrealistic because of a lack of demand in industry (Svenska Vattenkraftsföreningen, 1921: 68; Fridlund and Maier, 1996).

Large transmission projects were also discussed in Germany, which after the Nazi take-over began to prepare its national power grid for a new war. In connection with this the German military became interested in super power and cable transmission projects (Maier, 1993: Ch. 4.1.2). In Russia, also, there were similar discussions of national super power transmissions.

2.2.2 Local visions: plans for a national grid

In Sweden, the State through the public agency, Vattenfall, was the largest actor in the electric power system. There was no public monopoly on ownership or generation of hydro power. Nevertheless, Vattenfall and the large private or municipal power utilities, because of exclusive regional transmission networks, enjoyed de facto regional monopolies. Vattenfall was in charge of exploiting the waterfalls of the state and it was the largest Swedish power producer with four large power plants. Aside from Vattenfall, three other large power utilities owned interests in inter-regional AC transmission trunk lines and through this had interests in future Swedish super power transmissions. Among the smaller utilities was the ASEA subsidiary, SEV, which was going to be important in the development of the HVDC technology.

During the interwar period Vattenfall interconnected the networks of its two hydro power plants in central Sweden. This was the first step in a plan to interconnect all of the State's power plants from the upper North to the South into one national grid and through this use the plants more efficiently. The last of the State's three regional systems was centred around a power plant in the very far north at Sweden's largest waterfall. The system was isolated from the southern systems and in the 1910s it was seen as a utopia to have super power transmissions across the thousand kilometres to central Sweden. In 1930 Vattenfall expanded on its earlier vision of a national grid and put forward a plan with *all* Sweden's power plants – private, municipal and state – interconnected into one national power system. But this got thwarted in the mid-30s when two large private power companies decided to interconnect their systems in the north and south of Sweden with an AC-transmission link. Vattenfall protested to the government, which decided that further development of the long-distance transmission grid was to be carried out in co-operation between Vattenfall and private utilities. The majority of the state's large hydro power resources in the very far North had to wait for demand and technology to progress enough for it to be possible to build new power plants and transfer the power south. And this was seen as coming sometime in the 1960s.

2.3 Shaping the Means: Developing Proto-Technologies

The critical technological obstacle to HVDC transmission problem was the lack of a *converter* between high voltage DC and low voltage AC, which was needed since the majority of customers used low voltage AC electricity to power motors and machines. A competitive development atmosphere was created globally as well as locally in Sweden, as electrotechnical firms and independent inventors competed to present prototype converter technologies to solve the HVDC problem.

HVDC is, as a technology, basically an application of previous technological knowledge and therefore more an example of 'technology as applied technology' than 'technology as applied science' (Rosenberg, 1982; Rosenberg, 1992).[2] In the proto-procurement phase this application of technology came from the know-how accumulated in the industrial processes of incremental improvements on an already commercial technology.[3]

2.3.1 Global search: creating technological diversity

There already existed a DC transmission technology – the Thury system – that in 1906 with a 180 km power link had shown the possibility of long distance DC transmission. However, the Thury system used a very large number of electromechanical converters which were regarded as too costly and clumsy. Starting in the 1920s more promising solutions to the converter problem began to appear. In the 1920s two different experimental prototype converters intended for HVDC transmissions were presented by the large international electric manufacturers English Electric and the American giant General Electric Co. (GE). In 1931 GE stated that there existed no theoretical reasons against HVDC transmissions with their new converter and the press reported that the battle between AC and DC "seems to be entering upon a new and most interesting phase". The same year the German Siemens company reported that their commercial Mercury-Arc Rectifiers now could also be used to convert from DC to AC. Siemens saw this as the solution to the HVDC problem and meant to be ready to start building HVDC transmission systems. The other German giant, AEG, also said they were working on HVDC converters. In May 1932 yet another German converter was presented by the famous scientist and independent inventor Erwin Marx. A devoted German nationalist, Marx wanted to use his converter to further the war effort. HVDC transmission with underground cables was of great military interest because AC power lines disturbed airfields and made industrial plants easy to find by aircraft. Marx's converter therefore became a secret defence project and the focus of the German firms. But after lack of progress it came to be seen in 1937 as a dead-end and the German firms restarted their other converter research (Direct Current, 1963; Maier, 1993: 19, 106 - 8).

In addition to these proto-converters, two Swedish prototypes were presented in the 1930s. The first – the Glesum system – was developed by a famous Swedish independent inventor with help from a professor at the Royal Institute of Technology in Stockholm. When the converter was presented at a meeting in 1934, ASEA "gave the sensational announcement" that it was also working on its own converter technology (Svenska Dagbladet, 1934: 3).

In the mid-30s GE conducted the first field tests of HVDC transmission with a small-scale proto-converter. The experiments were seen as a success and GE planned larger experiments. In 1939, a short HVDC transmission was publicly demonstrated in Europe when the Swiss company, Brown Boveri (BBC), used a converter of their own to transmit DC. Even though the transmitted power was small, BBC claimed that "doubt can no longer exist" about super power transmissions by HVDC and intended to go ahead with larger transmissions. The Swiss demonstration was, however, stopped with the outbreak of WWII (Direct Current, 1963: 4 - 5).

2.3.2 Local search: the factory as learning laboratory

ASEA was the most important Swedish manufacturer of electric power technology and, after the 1930s, the other only independent firm was a cable manufacturer controlled by the Ericsson company. Also the German and Swiss giants Siemens, AEG, and BBC were active in Sweden through Swedish subsidiaries and representatives.

In 1925, ASEA decided to start manufacture of a Mercury-Arc Rectifier for converting low-voltage AC to DC. The use of low-voltage DC had expanded with the growth of city lighting and tramways. Traditionally electromechanical converters had been used for converting AC to DC but since 1904 the electronic mercury-arc rectifier had become a serious alternative.[4] The other large European electrotechnical manufacturers sold rectifiers with BBC as the leader. ASEA being a laggard, first considered acquiring a license on a foreign construction but eventually decided to develop a more independent construction (ABBCA, 1925: 1). In 1927 ASEA wrote a contract with a Hungarian consulting engineer for the construction of a rectifier. The engineer had worked for BBC and supplied ASEA with know-how and drawings in what "most likely was a plagiarism from Brown Boveri" (Håkansson, 1983, 1:5, 1:17; TMA, 1977: 17,

[2] As shown by Lindqvist (1994), HVDC also provides a good example of "science as applied technology".

[3] This is a good example of how strategic absorptive capacity is developed as a by-product of a firm's normal manufacturing. See Cohen and Levinthal (1990).

[4] The mercury-arc rectifier is a vacuum tight vessel filled with mercury gas and a cathode in form of a mercury pool and anode of iron or graphite rods and with a continuous current in the form of an electric arc burning in the mercury gas between cathode and anode. *Alternating* current is transformed to *continuous* direct current because an anode gets "blocked" when the AC-phase becomes negative and the positive current flows in the anode that is experiencing positive AC-phases.

26). In 1928, an experimental rectifier was finished. However, it did not function satisfactorily because of critical material problems and random short circuits, so called "back-fires". ASEA set up a group to solve the critical problems and construct a commercial rectifier. They soon found the engineer's construction not to be "capable of development in many respects" and instead went on and developed an independent rectifier construction (Wollard, 1988: 44; TMA, 1975: 2).

The next step towards a commercial product was to construct a prototype for internal use. This was not a totally independent construction since ASEA had acquired a lot of know-how from the failed experimental rectifier. This was later recognised through royalties to the consulting engineer. As the prototype and confidence progressed, ASEA in 1930 turned to the municipal power utility in Stockholm and asked to be able to install a prototype rectifier to try it out in real use. The utility accepted and a rectifier was delivered in 1932 and worked so well that it was accepted for operation one year ahead of contractual stipulations. Meanwhile, ASEA had also given a tender and delivered a commercial rectifier to the municipal utility in Gothenburg. However it suffered from severe problems and had to be taken back for adjustments. In retrospect these problems served an important purpose in providing important know-how for the further development of low-voltage rectifiers and – later on – for the first HVDC mercury-arc rectifier. Parallel to this ASEA's management worked hard to get an international reference order. The first came in 1932 to the Danish State Railways (DSB) and it was important because of its large size – six rectifiers – but also because it was the first export order. More so, DSB did not dare to give ASEA the whole order because its lack of reference-projects and also ordered three rectifiers from BBC, the leading manufacturer. This meant that ASEA's new rectifier construction was to be measured against its foremost competitor, which especially pleased ASEA. ASEA considered it important to deliver a construction that could match BBC's (ABBCA, 1932: 2 - 3). This was successful and in 1933 ASEA's low-voltage rectifiers had reached technical and commercial maturity.

As ASEA's group had worked on the solution to the problems of the low-voltage rectifiers they had also thought about how to construct a converter for the 50 - 100 times higher voltages of super power transmissions. And in 1933 the first experiments on a experimental HVDC converter were "sneaked in" between the work on the low-voltage rectifiers. The practical HVDC development had been initiated because the invention of the Glesum system (Lamm, 1983a: 37; Lamm, 1976: 4). A new company had been formed to exploit the invention, which since 1932 had been further developed by a professor at the Royal Institute of Technology. ASEA had been approached about investing to acquire patents and know-how. But although ASEA's management considered the Glesum system to have solved the converter problem and to be the best solution to the HVDC transmission issue, the international prospects of a commercial HVDC project in the next 10 - 20 years looked extremely small and non-existent in Sweden. This was because an eventual Swedish transmission from upper Norrland would "wait a very long time" and probably use AC. The only possible project that could be conceived in the foreseeable future was transmission of Norwegian hydro power to

the European continent although it was also considered too uncertain (Alm, 1935: 1; ABBCA, 1933b; ABBCA, 1933a: 3 - 4). But the Glesum company did not give up their efforts and in 1933 it gave a successful demonstration of its new converter. ASEA's management discussed acquiring a license to manufacture the new technology, but eventually decided to wait (ABBCA, 1933c: 1).

ASEA's rectifier group wanted to convince ASEA's management that an HVDC mercury-arc converter – an Ion Valve – was a better development path and sped up their development in 1934, in connection with an announcement that the Glesum system would be presented at a public meeting. ASEA's project manager attended the presentation, and when he left ASEA's laboratory on the day of the meeting a new experimental ion valve was finished but hadn't yet been tested. There were great expectations of the Glesum system, and several hundred engineers attended the presentation. During the presentation the eager project manager phoned the laboratory and was told that the ion valve worked fine with a voltage 10 times that of commercial rectifiers. Back at the presentation he announced that ASEA had also worked out an HVDC solution. But the next day he found out that his phone call had come at the "right" time since 20 minutes later "the whole thing collapsed, and after that we never got it going again" (Berneryd, 1992: 10; Svenska Dagbladet, 1934; Lamm, 1976: 6). Although the first ion valve had broken down after a very short time, it seemed to prove that the construction was correct in principle. The construction was based on a patent from 1928 that ASEA's project manager had come up with when trying to improve the back-fire problem of the Hungarian rectifier. ASEA's group continued with more tests but they all suffered from the critical problem of an excessive amount of back-fire that, together with more urgent issues concerning commercial rectifiers, stopped the HVDC development in the mid-30s.(Lamm, 1947: 309; Lamm, 1946: 28).

In 1937, ASEA continued the development on the ion valve solution. The group was now less busy with problem-solving in connection with the commercial rectifier orders and had gained extensive experience and training in solving DC converter problems (ABBCA, 1938a: 2). Crucial to the further development of low-voltage rectifiers and high-voltage ion valves were a number of such critical problems concerning choice of materials. A series of experiments was conducted on a new ion valve construction that succeeded, and in 1940 ASEA came up with a construction that worked longer than a couple of hours and that could be tried in more realistic large-scale HVDC test transmissions (ABBCA, 1938b: 11; Lamm, 1949: 189).

2.4 Shaping the Relations: Developing Informal Institutions

In this period Vattenfall and especially ASEA developed international and national relations that became important in the coming procurement phase. Internationally, ASEA gained a respect among its international competitors and, nationally, ASEA and Vattenfall formed a long-term and intimate user-producer relation around the development of new technologies. Both these relations led to ASEA asserting and strengthening its independence and developmental capacity.

2.4.1 Global institutionalisation: gaining an international respect

From its foundation ASEA was set on competing with the major electrotechnical firms and being a respected international company. In the 1920s and 1930s ASEA established itself as a major electrotechnical enterprise and was accepted on a more or less equal basis into a market cartel with the German giants. It managed to keep its independence from the foreign giants which included staving off an attempted take-over by the American giant General Electric. In the 1930s, when industrial R&D became institutionalised among the electrotechnical giants, ASEA followed this example and began considering R&D as a tool for international competitiveness. That led to the establishment of a high voltage laboratory and a new will to invest in more strategic and long-term R&D such as HVDC.

2.4.2 Local institutionalisation: establishing a national development pair

The joint HVDC development between Vattenfall and ASEA was not unique but rather one link in a series of previous intimate and informal user-producer development collaborations around advanced technologies. This joint history of long-term collaborations in uncertain projects on high-risk technologies had matured in the 1930s and established the trust relation between the two partners that I call a Development Pair. This relation goes back to 1909, when Vattenfall and ASEA conducted joint experiments to improve ASEA's circuit breakers. These collaborations were taken up again in the 1920s, when Vattenfall erected a power line of 130.000 volts to interconnect their two regional systems in central Sweden. This was the first European project to use such a high voltage and through this it provided incentives to Vattenfall and ASEA to initiate their a large joint strategic development project. ASEA's high voltage transformers were not up to international standards. When ASEA got a procurement order on transformers for the power line, it got the chance to catch up. Through joint tests ASEA and Vattenfall could develop transformers comparable to foreign ones. After this Vattenfall initiated a new strategic project to improve ASEA's circuit breakers. With the use of Vattenfall's power plants for advanced experiments ASEA in the 1930s could improve their constructions and also develop a completely new type of breaker (Fridlund, 1995; Glete, 1984a).

This collaboration was characterised by a "spirit of national engineers" among Swedish electrical engineers. The historian Jan Glete argues that when discussing the collaboration between Vattenfall and ASEA one must "take into account a positive interest in encouraging Swedish industry and Swedish technology". There were nationalistic sentiments connected to Swedish technology concerning national prestige and the "guarding of the national technology and ambitions to foster it were strong ambitions in Swedish industry". Sweden was a country that stood outside the wars and the struggle for national eminence came to be fought on the industrial battlefield instead of the military.[5] This "spirit of national engineers" characterised the electric power sector up to the late 1950s (Glete, 1984b: 43, 69).

3. PROCUREMENT: HVDC IN THE MAKING

3.1 Developing a Problem: Putting HVDC on the Agenda

In 1940 DC transmissions once again became an issue globally as well as locally in Sweden. The global interest was shown by Soviet plans for exploiting large waterfalls in Siberia and Caucasus and to use HVDC to transmit 600 megawatts (MW) over 900 km (VA, 1940b: 1, 15). The local interest was shown when a Swedish HVDC project proposal of about less than one-hundredth the size of the Soviet plans was put forward to Vattenfall. This was in a conversation about Swedish transmission projects between the Director General of Vattenfall and the general manager of ASEA's subsidiary power company, SEV. ASEA through SEV owned several smaller Swedish utilities and waterfalls. This involvement in the power sector made ASEA into a customer and sometimes competitor to Vattenfall. Usually this was not a problem, but on this occasion in 1940 it was. ASEA owned a utility on the island of Gotland that it wanted to supply with power from one of its waterfalls 450 km away on the Swedish mainland. The power could be transferred via Vattenfall's existing power lines but since Gotland's distribution net was isolated from the mainland it would also require an undersea power cable to Gotland. SEV's manager proposed this power transfer should be with HVDC. The amount of power transmitted should be rather small and the Director General found the project interesting but nevertheless objected because it might strain Vattenfall's capacity in times of crisis (VA, 1940a: 3).

This market-directed interest in HVDC projects from ASEA is also shown through two 'market surveys' conducted in 1940. The first concerned what previously had been written about possible HVDC transmissions and gave ASEA a view of the potential global demand for HVDC. Based on this ASEA did an internal survey of the technical and economic reasons for and against HVDC. It concluded that there could be no doubt that HVDC was going to "obtain a footing" and also be used in Sweden. Also two critical problems for a successful future HVDC transmission were identified. The first was technical and was to develop converters for high voltages; the second was social and concerned establishing a development project "in collaboration with those power companies concerned to try to get a plan for the gradual testing of equipment on a practical scale for larger and larger power." To develop the social collaboration was considered "as important" as developing the technology since

> "those on the first hand economically justifiable projects are so large that their realisation must be preceded by the execution of smaller DC-transmissions, which in themselves might not generate any eventual economic profit, but would give experience necessary to determine if it will be possible to risk the realisation of the larger projects. [...] When one goes about executing projects involving such large investments, one usually avoids large technical risks, in that one seeks to apply constructions and principles that have proven their trustworthiness and operational reliability in smaller projects" (ABBCA, 1940: 9).

[5] The view that nations battled each other through their technological development was prevalent and that nationalism was connected to technological development from the late 19th century onwards is supported by a lot of historical research. See Eriksson (1978), Fritzsche (1992), Ekström (1993), Björck (1993), Samuels (1994), Fridlund and Maier (1996), Elam (1997), Fridlund (1997).

In 1941, Vattenfall's Director General and ASEA's project manager met to discuss Swedish HVDC projects. The Director was an enthusiastic expert on the issue, as he had worked on the previous Inter-Scandinavian project and on a plan to use HVDC to export power from one of Vattenfall's power plants to Denmark. He had several practical ideas and suggestions and offered ASEA the use of Vattenfall's transmission network for HVDC experiments as, in a similar way, it had been allowed to use it to test their circuit breakers (VA, 1941: 1 - 2). The project manager stressed the risks with an HVDC transmission to Gotland but despite this the Director was very optimistic about possibly finishing a transmission within two years. If Swedish cable manufacturers – to which an ASEA subsidiary belonged – would be willing to sell a cable without any profit, an immediate purchase could be possible (VA, 1941: 2 - 4). But despite Vattenfall's optimism, it did not become an 'immediate purchase' and HVDC came instead to be considered for a much larger transmission project, a Swedish super power project.

3.2 Enter Procurement: Formalising the Process of Problem-Solving

In 1942 Vattenfall started preparations for a future super power transmission from the northern Norrland region of Sweden. In central Sweden, only 20 % of the exploitable hydro power remained untapped and was rather expensive to develop, while in lower and upper Norrland around 70% and 90% was still unused (Rusck, 1945: 155). To keep the number of large transmission lines from Norrland from becoming too many, though, it would be necessary to develop a technology with higher transmission capacity than before.

The previously mentioned state inquiry had concluded that the future large power transmissions should be built in collaboration between the major power utilities. In 1942 the Swedish Collaborative Committee for Superpower Transmissions was formed to investigate the problems concerning a future transmission from Norrland. It consisted of representatives from Vattenfall, the three other large utility companies owning power lines of 220.000 volts, and the potential Swedish manufacturers, ASEA and a cable company. Its main task was to investigate the alternative possibilities of using HVDC or AC transmission with much higher voltages than before. This project was much larger than those previously discussed and the Director General was less optimistic about HVDC and more doubtful concerning the assurances made about its usefulness. Nevertheless, he found it "very laudable" that ASEA had started developing HVDC converters, even if he doubted whether ASEA with its limited resources would manage to solve a problem "where the major international firms have not succeeded" (VA, 1942: 1 - 2; VA, 1943: 1).

ASEA had constructed an improved Ion Valve prototype and after the first committee meeting Vattenfall investigated the possibility of using one of its power lines for large-scale and long-term construction experiments on the new prototype. The problem with constructing the Ion Valve was that it was too complex a construction to make possible its development on the basis of known laws of electromagnetism and theoretical models. Instead, it had to be based on results from empirical trial-and-error testing of prototypes. This had to be done in realistic full-scale tests with almost operational voltages. Furthermore, it was necessary to test each modification of the prototype during a very long period of operation because of the possible critical problems of "ageing" of the valve material and random and unpredictable back-fires. All this made the development very time consuming and expensive, as well as the fact that it needed access to large amounts of electric power (VVA, 1942; Direct Current 1960/61: 224; Lamm, 1976: 6 - 7). The result of the committee's main investigation about AC versus DC confirmed that HVDC should give lower transmission cost than AC, estimated as 2/3 the cost of AC. Following this, ASEA and Vattenfall decided to go ahead with more formalised co-operation (Borgquist, 1968: 19; Lamm, 1976: 2).

3.2.1 Contracting to procure joint know-how

In 1943, ASEA and Vattenfall signed an agreement to "jointly establish and operate" an experimental power transmission for HVDC to give the "most complete experience basis for the consideration of a possible use of HVDC for future super power transmissions from Norrland to central Sweden." This experimental transmission set-up would consist of a power line connecting two converter stations, one to be built in Vattenfall's hydro power plant Trollhättan and the other 50 km away in a small substation belonging to Vattenfall. Except for supplying the power for the experiments and building the two converter stations Vattenfall supplied personnel to operate the power line while ASEA supplied the Ion Valves and necessary personnel and equipment for the experiments. All other expenses should be divided equally between the two parties. According to the contract the results from the experiments should be freely available to both parties although they could not be communicated to outside parties (VVA, 1943: 1, 3). The transmission was estimated to cost 1.3 million Crowns to build and the experiments were planned to commence during the end of 1944 and be finished in 1948. While waiting for the experimental transmission link to be set up, ASEA continued its experiments and in late 1943 they performed the first successful long-term experiments on their Ion Valve prototype (Sylwan, 1944: 57; [Helén], 1957: 105; Lamm, 1949: 189). But crucial tests still missing were to actually transmit power over longer distances and to try out how and if the converters also worked outside the laboratory, out in the field.

3.2.2 Confronting critical technical problems

A great advantage for HVDC transmissions would be the possibility of using 'earth-return'. This meant that, rather than using a closed DC circuit of two power lines for each transmission, the returning DC current could instead be transmitted through the earth between the two converter stations (or through the sea, in the case of undersea transmission). This would mean that only one power line was needed instead of two without earth-return or three with AC. Since a large cost of the transmission link usually consisted of the cost for lines or cables, this would mean very large savings for DC compared to AC.

However, an important critical problem with using earth-return was that it might damage or disturb other large technical systems such as telephone cables or signal systems of the railway networks. To investigate this Vattenfall and ASEA in 1944 started a series of large-scale experiments in collaboration with the Swedish Telecommunication Administration (STA), the State Railways and Chalmers Institute of Technology. First earth-return was investigated at the joint experimental transmission link at Trollhättan in a 50 km low-voltage DC transmission. After this the scale of the experiments gradually increased until it was almost spanning the whole length of the country. The first of the more large-scale field experiments was conducted during a Saturday night in November, when DC was transmitted more than 300 km via one of Vattenfall's long power lines. During the five minutes the experiment lasted all railway traffic in central Sweden was stopped because of the danger of faulty signalling. The experiment also showed that a real super power transmission with earth-return could cause wrong railway signals within 150 km of each electrode. The critical problem still remained unsolved. During 1945 these 'macro-experiments' were continued with "one of the most exceptional electrotechnical experiments performed in recent time". This was a DC transmission of 300 km along the Norrland coast but this time using the Baltic Sea as a return conductor (sea-return). This was a continuation of a previous failed test to transmitting power with sea-return more than 450 km. By using sea-return, it was hoped to avoid disturbing the mainland telephone and railway systems (Blomqvist 1946: 21; Lundholm, 1947: 321). This experiment succeeded in the sense that this seemed to be the case for the major part of the current.

Meanwhile, the completion of the experimental stations at Trollhättan had been delayed by a year because of a nation-wide strike at the end of the war. The transmission set-up was finished in the end of 1945 but then the preconditions for the HVDC experiments were altered because of the earth-return issue that had changed from a possible advantage to an actual obstacle. This was because the large risk of disturbing the railways and telephone cables around the Trollhättan power plant made it impossible to conduct any long-distance transmission tests. What could be done, however, was to simulate such a long-distance power transfer in the Trollhättan power station (with an AC/DC-converter connected over a large resistance – 'the power line' – to a DC/AC-converter).

The most important part of the experiments was however the testing of the Ion Valves which now could be moved from ASEA's laboratory to the Trollhättan power plant. This empirical testing was done through 'life-time' experiments wherein teams of ASEA's specialists together with Vattenfall's operators worked around the clock in Trollhättan for several months of time. A vivid description of the reasons for this long and arduous engineering work has been provided by ASEA's project manager:

> "[We] have tested [...] different modifications of the interior design of the valves, many of them in two or more samples. The more fruitful modifications have been run for a period of about half a year, or longer, while quite a number have been run unchanged for several years. One would like, of course, to finish the test on one modification before one goes on with the design of the next, but as the time that elapses between building a new modification from the first sketches and obtaining the first test results can generally not be cut down below 9 months, it is quite obvious that one must work with a great number of modifications 'in parallel'. The setting out of a design, therefore, often has to include a lot of guesswork regarding the outcome of previous designs which are still under construction in the works" (Lamm, 1956: 10).

3.2.3 Eliminating an institutional obstacle

Another obstacle for future Swedish super power transmissions was of an institutional nature and concerned the ownership and operation of the future super power lines. Except for the state, private companies owned hydro power in Norrland and it would not be considered practically and economically justifiable that every owner of power in Norrland that wanted to transfer it south should build its own super power transmission. Therefore they had to transfer their power on transmission lines owned by other companies. Since it was decided that the future power system was going to be developed in co-operation between private and public utilities it was predicted that several critical problems would arise concerning ownership of the power transmitted, etc. As a solution to this institutional obstacle, Vattenfall in early 1945 proposed to the three other main power companies owning power in Norrland that the four of them should form a joint company that should take over all old transmission lines and build all new super power transmission lines. None of the other companies was really interested in the proposal, but after hard negotiations Vattenfall managed to get them to agree on the proposed company. This company should own, build and operate all large Swedish transmission lines in the future. During the spring of 1945 Vattenfall asked the government to approve the proposed company. Opinions differed among the parties of the coalition government and the decision had to wait for the change of government following the end of WWII. In November the new Social Democrat government decided that the State – i.e. Vattenfall – should own and be responsible for any new Swedish super power transmission lines. This also meant that it became the sole responsibility of Vattenfall to decide what technology to use (Bjurling, 1982: 140).

3.2.4 Increasing demand and de-selecting supply

In 1946, the HVDC experiments continued with smaller power transmissions between the two experimental stations. Furthermore, Vattenfall performed a series of joint experiments with STA on radio disturbances from HVDC power lines. In September, 1946, yet another large-scale experiment was performed with earth-return. This was a full-scale experiment in its true sense since it was a transmission of 1,000 km. The north electrode of the transmission line was placed down in a mine in upper Norrland and the south in a fjord outside Gothenburg. But the experiment gave rather few positive results and strengthened the negative ones from previous experiments that had shown HVDC super power transmission to cause serious disturbances of the railway and telephone systems (Lundholm, 1952/53: 82; Rathsman and Glimsted, 1949a: 43).

During the autumn of 1946 the plans for developing the large waterfall at Harsprånget were suddenly brought forward by the Parliament. The anticipated post-war depression did not come and instead there was an increase in the demand for electric power. Therefore it was seen as necessary to start exploiting the hydro power in upper Norrland earlier than foreseen. Vattenfall already had to decide what technology to use for the super power transmission already during 1946. Both AC transmissions with 300 - 400,000 volts and HVDC were considered risky options. HVDC did not exist and the highest AC voltage previously used was 287,000 volt. ASEA did not dare to take the risk with the untried HVDC system and stated "that there are *no* chances to get the DC system fully ready and sufficiently tested in time for the first stage of the exploitation of Harsprånget, while the prospects look good to have it ready in time for it to be applied to the major part of the [further] developments in upper Norrland" (Lamm, 1947: 311). In December 1946 Vattenfall decided to chose AC technology for the development of Harsprånget and entered into a public technology procurement project with ASEA around developing a 380,000-volt AC technology. The project was successful and the first power line from upper Norrland was inaugurated in 1952. But this had not meant the end for HVDC.

3.3 Reconstructing Procurement: Return of an Old Project

Vattenfall and ASEA in 1947 decided to continue the HVDC collaboration with the aim of developing Ion Valves for future Swedish super power transmissions from upper Norrland. The old experimental station in Trollhättan would be too small for the new experiments and in 1948 it was decided to build another larger joint laboratory next to the old one. The new laboratory would make possible experiments on Ion Valves of up to eight times the power (25 MW) as that of the old laboratory (Lamm, 1947: 314; Rathsman, 1954b: 12).

At the same time an older much smaller HVDC project had been reopened when, barely a month after the decision to chose AC for Harsprånget, the question was raised anew in the Parliament about the possibility of supplying Gotland with electric power from the mainland. Gotland was the only Swedish region without its own hydro power or connection to the national power grid. Because of this 'power isolation' and high fuel costs, the electricity prices on Gotland had been much higher than in the rest of Sweden during WWII. The government approved a state inquiry and ordered Vattenfall to investigate it. Vattenfall conducted the inquiry jointly with the manager of the ASEA subsidiary that owned the only power plant on Gotland. Such an HVDC transmission to Gotland would be a very suitable first reference project for ASEA, in that it would be of a 'lagom' – Swedish for 'not too big, not too small' – scale and difficulty. The amount of power transmitted was only a tenth of that of a super power transmission. Furthermore, in case the project failed, there was no risk of law suits or claims of damage from dissatisfied customers since ASEA owned the island's one and only power company.

As for the super power transmission, it was crucial that the HVDC transmission did not disturb or damage surrounding infrastructure systems and as a part of the inquiry several experiments were performed. With the help of Chalmers Institute of Technology, potential disturbances to the telephone cables to Gotland were investigated. Furthermore, the transmission was not allowed to damage sea life because "possible demands from the fishing industry" might bring to nothing the economic gain of using sea-return. In the summer of 1949 Vattenfall together with the Royal Board of Fisheries conducted model experiments on the effect of DC sea-return on the flora and fauna of the sea. In these experiments a small (1000 m) scale-model of a transmission link with sea-return was used. The investigations showed that any disturbances could easily be avoided. The joint Vattenfall–ASEA inquiry was finished in January 1949 and recommended an HVDC cable transmission because it did not suffer the same large loss of power as an AC cable transmission. It stated the primary advantage of the transmission to be lower electricity prices on Gotland, and furthermore, an operational HVDC transmission "for reasonable power" would also be positive for the development of larger super power transmissions (Rathsman and Glimstedt, 1949a: 45, 60 - 62; Deines, 1949: 108).

In 1949 Vattenfall followed the inquiry's recommendations and presented the government with a proposal to build an HVDC power transmission to Gotland. The government and Parliament followed the proposal and in 1950 the procurement contract between ASEA and Vattenfall for a 20 MW Gotland transmission could be signed. According to Lamm, the technology was not considered as completely safe since it was still under development and all involved knew that the project meant "considerable technical risks" (Lamm, 1950: 146). The new Ion Valve laboratory was finished in 1951 and all experiments now became focused on developing the Ion Valves for the Gotland transmission. The two converter stations should each have two converter groups of 10 MW each with every group consisting of six normal Ion Valves and an extra 'by-pass' Ion Valve. This by-pass valve was ASEA's second solution to the problem of back-fires. It had been possible to decrease but not to eliminate completely the back-fire problem. Since it had been found impossible to completely eliminate them, even in commercial low-voltage rectifiers, the group had found it to be "sound realpolitik" to accept them and, instead, 'invent around' the problem. This was done by using a method developed for the commercial rectifiers. When a back-fire occurred, all the Ion Valves were automatically blocked and the faulty current was passed through a by-pass valve. When the back-fire had died out, the current came back as normal (Lamm 1947: 311 - 2). After the decision one and a half years were spent on further development of the Ion Valves. This time was used to test different modifications. When the decision was taken in 1953 to freeze the Ion Valve construction, around 140 different Ion Valve constructions had been tried, with several in two or more versions.

3.4 Supplying the Product: Laying the Link

The set up of the Gotland transmission began in 1952. The whole transmission consisted of two converter stations and one underwater cable. In the mainland converter station power was taken from the national grid and converted to DC and then transmitted through the cable to the converter station on Gotland. Here the power was converted back to AC before it was sent out to consumers on Gotland. The transmission used only one cable and the circuit was closed by sea-return. The station buildings were built so that it would be possible to increase the power to 40 MW at a later stage by doubling the number of converters and by laying an extra cable. The 96 km long cable was put out in 1953 and the transmission started in 1954. During the try-out transmission that followed, it was possible to tune in the equipment and to do "some measurements under realistic conditions" and, based on this, construct and manufacture some supplementary details (Rathsman and Svidén, 1956: 12). According to the contract the try-out transmission should continue until 1957. However, since Vattenfall was very satisfied with the trial results it was decided to bring forward the take-over one year and on January 1st, 1956, the transmission was taken into commercial operation by Vattenfall.

The whole transmission had originally been estimated to cost 9.5 million Crowns but had increased to 19 million because of an additional build-out of the converter stations. This was, however, cheap, considering that Vattenfall got the equipment for the same price as ASEA's manufacturing cost (Rathsman, 1954a: 7; Glete, 1983: 175). The price of 19 millions can also be compared to a Vattenfall assessment from 1959, which estimated Vattenfall's total costs for the HVDC development work in Trollhättan 1943 - 54 to be 2.6 million Crowns.[6] The hydro power from the mainland transferred through the new transmission link lowered the price of power on Gotland to half of what it had been before. Furthermore, ASEA also gave up the right to control the operations of its Gotland steam plant to Vattenfall (Rathsman and Glimstedt, 1949b: 99). A lagom cost for a lagom first HVDC order. The next step was to go from "lagom" to "big".

4. POST-PROCUREMENT: RE-MAKING PRODUCTS AND POWER

In 1957, the English and French public power utilities, British Electricity Authority (BEA) and Electricité de France (EdF), placed an order with ASEA for Ion Valves for an HVDC transmission under the English Channel. The transmitted power was to be eight times the amount in the Gotland project and the total cost was 70 million Crowns, including ASEA's share of 16 million Crowns (Vi Aseater, 1960: 20). Although the formal procurement process began in 1957, this project – which was of an adaptive procurement kind – also had its proto-procurement phase.

It started in 1950, when a joint French-English committee began to investigate the possibility of establishing a power exchange between the two countries. This would save building power plants of 300 MW in the two countries (Teknisk Tidskrift, 1954: 556). The distance over the Channel was rather short (40 km) which made both AC and HVDC possible. The committee's official report came only three weeks after the Gotland link started trial transmission. The report proposed using AC. Concerning HVDC, for which "so far no tangible success has been commercially demonstrated", the report declared that it was not immediately practicable because of its immature state

[6] Calculations are based on information in handwritten memos VVRA (1959a) and VVRA (1959b).

of development (ABBCA, 1954: 4). It nevertheless stated that an experimental HVDC transmission under the Channel merited serious consideration. When the report was due to be publicly presented in London, ASEA's project manager travelled there together with Vattenfall's Director General and vice Director General. During the meeting they provided information about the Gotland transmission and showed pictures from its opening. Although the report had settled the technical preconditions in favour of AC, ASEA with the help of Vattenfall lobbied to convince EdF and BEA of the advantages and trustworthiness of HVDC. The committee had envisioned an AC transmission using four cables, wherein the fourth cable was a spare cable that would use sea-return to experiment on HVDC transmission. If that worked well, a change-over would be made from AC to HVDC. However, this was unacceptable to the powerful British Admiralty, because the sea-return would create a small error in compass inclination in the heavily trafficked English channel. Although the error was insignificantly small, EdF and BEA thought it "would take 10 years to convince the Admiralty" about that (Berneryd, 1992: 86). Therefore, it was impossible to make a gradual change-over from AC to DC and the choice between HVDC or AC had to be taken from the outset. The great advantage of DC was that the expected economic savings would be around 4 million Crowns compared to 1.3 millions with AC; moreover, it promised to be more reliable (Vi Aseater, 1960: 20; Aseas Tidning, 1962: 17).

The discussions continued between ASEA and EdF and BEA in 1954 and 1955. After a while, ASEA's engineers were allowed to participate informally in the committee meetings. Later still, these meetings turned into serious negotiations. Finally, in 1957, the power companies placed their orders with ASEA. The transmission had been changed to an HVDC cable transmission with Ion Valves of twice the current and voltage of the Gotland transmission, and with eight times the power. This was also a procurement project of the adaptive variety, wherein the major adaptive innovation activities concerned the further development of the ion valves and the regulation system of the link. The transmission was brought into operation in December, 1961. The HVDC technology had matured and taken its first steps out onto the international market.

5. CONCLUSIONS: PRIVATE AND PUBLIC COMPETITIVENESS

The Channel project had been the first project in which ASEA managed to export its new product – the HVDC transmission technology. This project was followed in the 1960s by other export projects for long underwater transmissions in Italy, Sweden-Denmark (Konti-Skan, see below) and New Zealand. HVDC also found application in its originally intended Swedish use – as an overland transmission link for super power transmission. This was in 1965, when ASEA and GE got a joint order for the so-called Pacific Intertie. This was a more than 1.300 km long transmission of 1.440 MW from the Colorado River in Oregon to Los Angeles in California. Thanks to this, HVDC proved its superiority over AC for long super power transmissions. This was also a public procurement project, as the major buyers were two federal and municipal power companies. And, like the Channel project, this too was technology procurement of an adaptive kind, with Ion Valves developed to more than 15 times the power of those at Gotland (Lamm, 1983b).

Up until the 1970s ASEA had a practical monopoly on HVDC technology worldwide, with a profit margin of 20 %. In the 1970s the HVDC Ion Valve converter technology met harsh competition from new Semiconductor HVDC Thyristor converters. ASEA switched to the new technology trajectory and thanks to its experience in the Ion Valve technology managed to keep its leading position. The economic result of ASEA's HVDC Ion Valve technology was orders of 545 million Crowns in 1954 - 73 with net profits of around 74 million Crowns. The latter amount accounted for 13.5 % of the HVDC turnover (Glete, 1983: 287). Up until 1951, ASEA had spent 5 million Crowns on the HVDC development work, to be compared with the around 2.2 million Crowns spent by Vattenfall. In 1960, ASEA had spent around 22 million Crowns, to be compared to around 6.4 million Crowns by Vattenfall. But Vattenfall profited from its investments in its next large super power transmission project, which it started in 1960.

HVDC was never used by Vattenfall for its intended purpose, to transmit power from Norrland directly south. Further transmissions in the 1950s and 1960s used the existing AC technology and, instead, HVDC came to be used in another large power project, whereby Vattenfall redefined its demand from local Swedish to European in the 1960s. This was a project of building a power link between the Scandinavian peninsula and the European continent. The large development of hydro power in Norrland had created a power surplus that could be used for a "profitable" export to West Germany (Lalander and Gradin, 1962: 1189; Vi Aseater, 1963). In the early 1960s, discussions started concerning a power exchange between Sweden and Denmark and West Germany which would mean great savings because of the complementary diversity of different national consumer patterns and energy resources (hydro power vs. steam power). A joint committee of the involved power companies concluded that HVDC was the most suitable technology for this "Konti-Skan" link.

The super power transmission was for 250 MW and the whole project cost around 100 million Crowns. Vattenfall in 1963 ordered equipment for 50 millions (equalling around 400 million Crowns in 1997) from ASEA (Vi Aseater, 1963: 4). This project was seen as meaning cost reductions and profits of the same order of magnitude through reduction of the needs of thermal power in Sweden and export of surplus power. This cost can be compared with the sum of 6.4 million Crowns, which was the estimate of Vattenfall's cost until 1960 for the joint HVDC development work in Trollhättan (Konti-Skan, 1962: 35, 51; VVA, 1959a; VVA, 1959b). The Konti-Scan project was successfully inaugurated in 1965. It was described as "the European highway of electric power" and as opening the gate for "a complete European exchange of power" (Vi i Vattenfall, 1963). Through this, both ASEA and Vattenfall had succeeded on the European market with the help of their new HVDC technology.

REFERENCES

ABBCA (1925). "Protokoll hållet vid konferens den 29 och 30 december 1925", *ABB Central Archives, Västerås (ABBCA)*, D:N7 02-005 [361/D-1002], Direktionskonferenser: Protokoll 1921 - 1932 (Ing. Hambergs).

ABBCA (1932). Letter Lindén to Edström, 21 July 1932, *ABBCA*, D, 526/1448, Diverse extern korrespondens: 1930, 1932.

ABBCA (1933a). R. Liljeblad, "Utlåtande angående den av von Platenska uppfinningen av anordningar för genererande och utnyttjande av högspänd likström", 4 October 1933, *ABBCA*, D, 544/1472, Diverse extern korrespondens: 1933 - 1934.

ABBCA (1933b). Letter Lindén to C.G. Langenskiöld, 7 October 1933, *ABBCA*, D, 544/1472, Diverse extern korrespondens: 1933 - 1934.

ABBCA (1933c). "Protokoll fört vid konferens 18/12 1933", *ABBCA*, D:N7 02-001 [401/D-1110], Diverse sammanträdesprotokoll 1906 - 1938.

ABBCA (1938a). U. Lamm, "Redogörelse för verksamheten under år 1937", 18 February 1938, *TM 1578*, 2, *ABBCA*, Tekniska Meddelanden, H:C1 03-018, TM 1550 - 1589.

ABBCA (1938b). Å. Karsberg, "Undersökningar av anodkonstruktioner för högspända likriktare: *Konfidentiellt*", 23 March 1938, *ABBCA*, Tekniska Meddelanden, H:C1 03-018, TM 1550 - 1589.

ABBCA (1940). U. Lamm, "Tekniskt-ekonomiska skäl för och emot kraftöverföring med högspänd likström", 11 December 1940, *TM 1794*, 9, *ABBCA*, D, 500/1387, Diverse Extern och Intern korrespondens: 1940.

ABBCA (1954). D.P. Sayers, M.E. Laborde & F.J. Lane, "The Possibilities of A Cross-Channel Power Link between the British and French Supply Systems", (Proof to be published in *Proceedings of the Institution of Electrical Engineers*, London, received 21 January 1954), 4, *ABBCA*, D, 1072/2059, Högspänd likström 1943 - 1957.

Alm, E. (1935). Report 347: le système Glesum: un système électromagnétique noveau pour la production et l'utilisation du courant continu a haute tension. In *Conférence Internationale des Grands Réseaux Électriques a Haute Tension: Compte-rendu des travaux de la 8ieme Session*, vol. 3. Paris.

Aseas Tidning (1962). Likströmsöverföringen för Engelska Kanalen invigd. *Aseas Tidning*, 54, 17.

Berneryd, J. (1992). Uno Lamm: Framgångar och baktändningar. *Polhem: Tidskrift för teknikhistoria*, 10, 82 - 91.

Bjurling, O. (1982). *Sydkraft–samhälle: En berättelse i text och bild*. Malmö: Sydkraft.

Björck, H. (1993). *Teknikens art och teknikernas grad: Föreställningar om teknik, vetenskap och kultur speglade i debatterna kring en teknisk doktorsgrad, 1900 - 1927*. Stockholm Papers in the History and Philosophy of Technology TRITA-HOT 2025. Stockholm: Kungliga Tekniska Högskolan.

Borgquist, W. (1968). Svensk elkraftförsörjning. In *En del om el: Minnesskrift utgiven till Sveriges Elektroindustriförenings 50–årsjubileum 1968*. Stockholm.

Cohen, W. M. and Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, 35, 128 - 52.

Deines, W. (1949). Elströmmens inverkan på havsfaunan. *ERA*, 22, 108 - 11.

Direct Current (1960/61). The development of a valve. *Direct Current*, 6, 224 - 34.

Direct Current (1963). The history of d.c. transmission: part IV. *Direct Current*, 8, 2 - 5 & 27.

Ekström, A. (1993). *Den utställda världen: Stockholmsutställningen 1897 och 1800-talets världsutställningar*. Uppsala: Nordiska Museets förlag.

Elam, M. (1997). National imaginations and systems of innovation. In C. Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations*. London: Pinter.

Eriksson, G. (1978). *Kartläggarna: Naturvetenskapens tillväxt och tillämpningar i det industriella genombrottets Sverige 1870 - 1914*. Uppsala Studies in the Humanities 15. Umeå: Acta Universitatis Umensis.

Evans, P. (1995). *Embedded Autonomy: States and Industrial Transformation*. Princeton: Princeton University Press.

Fridlund, M. (1993). The 'development pair' as a link between systems growth and industrial innovation: cooperation between the Swedish State Power Board and the ASEA company. Working papers from the Department of History of Science and Technology 93/9. Stockholm: Department of History of Science and Technology, Royal Institute of Technology.

Fridlund, M. (1995). Ett svenskt utvecklingspar i elkraft: Aseas och Vattenfalls FoU-samarbete, 1910 - 1980. *BI Forskningssenteret forskningsrapport* 1995/2 & *Senter for elektrisitetsstudier* 1995/312/7. Sandvika: Handelshøyskolen BI.

Fridlund, M. (1997). Teknikens konstruktion av nationen: svensk nationalism och industrialisering kring sekelskiftet 1900. In B. Brenna and K. M. Fjeldstad (eds.), *Kollektive identiteter, ting og betydninger*. TMV skriftserie 24. Oslo: Pensumtjeneste.

Fridlund, M. and Maier, H. (1996). The second battle of the currents: a comparative study of engineering nationalism in German and Swedish electric power, 1921 - 1961. Working Papers from the Department of History of Science and Technology 96/2. Stockholm: Department of History of Science and Technology, Royal Institute of Technology.

Fritzsche, P. (1992). *A Nation of Fliers: German Aviation and the Popular Imagination*. Cambridge: Cambridge University Press.

Glete, J. (1983). *ASEA under hundra år: 1883 - 1983 : Ett studie i ett storföretags organisatoriska, tekniska och ekonomiska utveckling*. Västerås: ASEA.

Glete, J. (1984a). High technology and industrial networks: some notes on the cooperation between Swedish high technology industries and their customers. Paper presented at International Research Seminar on Industrial Marketing, organised by the Stockholm School of Economics, Stockholm, August 29 - 31.

Glete, J. (1984b). *Storföretag i starkström: Ett svenskt industriföretags omvärldsrelationer - en sammanfattning baserad på "ASEA under hundra år"*. Västerås: ASEA.

[Helén, M.] (1957). *Den tekniska utvecklingen: 1883 - 1948*, vol. 3 of *ASEA:s historia: 1883 - 1948*. Västerås.

Hunter, L. C. and Bryant, L. (1991) *The Transmission of Power*, vol. 3 of *A History of Industrial Power in the United States, 1780 - 1930*. Cambridge, Mass.: MIT Press.

Håkansson, N. G. (1983). *Historik för lågspända jonventiler, 1927 - 65*. Ludvika.

Konti-Skan (1962). *Konti-Skan: Untersuchungen über die Voraussetzungen für eine dem Verbundbetrieb zwischen der BR Deutschland und den Skandinavischen Ländern dienende Hochspannungsverbindung / Studier av förutsättningarna för upprättande av en samkörningsförbindelse mellan Västtyskland och de skandinaviska länderna*, 2 vols. Stockholm.

Lalander, S. and Gradin, R. (1962). Konti-Skan. *Teknisk Tidskrift*, 92, 1185 - 89.

Lamm, U. (1946). Report 133: Mercury arc converter stations for high voltage d. c. power transmission. *The International Conference on Large Electric Systems (C.I.G.R.E.), 11th Session*, vol. 1., Paris.

Lamm, U. (1947). Grundläggande problem vid högspänd likströmsöverföring. *Teknisk Tidskrift*, 77, 307 - 14.

Lamm, U. (1949). Kraftöverföring med högspänd likström – ett utvecklingsarbete. In *Företagande, ekonomi och teknik: Studier tillägnade Marcus Wallenberg*. Stockholm.

Lamm, U. (1950). Kraftöverföring med högspänd likström från fastlandet till Gotland. *Aseas Tidning*, 42, 145 - 6.

Lamm, U. (1956). Report 9: High voltage direct current transmission. *In Proceedings High Voltage Symposium*. Ottawa.

Lamm, U. (1976). Utvecklingen av högspänd likströmsöverföring. *In Eliasson–föreläsningarna 1976*. Göteborg: Chalmers Tekniska Högskola.

Lamm, U. (1983a). Kraftöverföring med högspänd likström: den tidiga utvecklingen : jonventilepoken. In P. Barnevik, et al., *Teknik i ASEA: 1883 - 1983*. Västerås: ASEA.

Lamm, U. (1983b). ASEAs lansering av kraftöverföring med högspänd likström (HVDC) i USA. In Barnevik et al.

Lindqvist, S. (1994). Spatial networks of technological change: social mobility between industry and university. *In The Curt R. Nicolin Seminar: Knowledge as Substitute for Natural Resources*. Stockholm: Royal Institute of Technology.

Lundholm, R. (1947). Likström genom jorden över långa avstånd. *Teknisk Tidskrift*, 77, 319 - 22.

Lundholm, R. (1952/53). Return current through the earth for high voltage d.c. transmission. *Direct Current*, 1, 79 - 86.

Maier, H. (1993). *Erwin Marx: (1883 - 1980) : Ingenieurwissenschaftler in Braunschweig, und die Forschung und Entwicklung auf dem Gebiet der elektrischen Energieübertragung auf weite Entfernung zwischen 1918 und 1950*. Stuttgart: GNT Verlag.

Rathsman, B. G. (1954a). Likströmsöverföringen till Gotland. *Teknisk Tidskrift*, 84, 1 - 8.

Rathsman, B. G. (1954b). Forskning bakom 380 kV systemet. *Teknisk Tidskrift*, 84, 301 - 5.

Rathsman, B. G. and Glimstedt, U. (1949a). *De tekniska och ekonomiska möjligheterna att överföra kraft från fastlandet till Gotland*. Stockholm: Vattenfallstyrelsen.

Rathsman, B. and Glimstedt, U. (1949b). Elkraftöverföring till Gotland. *ERA*, 22, 96 - 99.

Rathsman, B. G. and Svidén, S. (1956). *Likströmsöverföringen från fastlandet till Gotland*, Blå-vita serien 15. Stockholm: Vattenfallsstyrelsen.

Rissik, H. (1935). *Mercury-Arc Current Converters: An Introduction to the Theory of Vapour-Arc Discharge Devices and to the Study of Rectification Phenomena*. London.

Rosenberg, N. (1982). *Inside the Black Box: Technology and Economics*. Cambridge.

Rosenberg, N. (1992). Science and technology in the twentieth century. In G. Dosi, R. Giannetti and P. A. Toninelli, (eds.), *Technology and Enterprise in a Historical Perspective*. Oxford: Clarendon Press.

Rusck, Å. (1945). Svensk kraftförsörjning i dag och i morgon. In *Morgondagens teknik: Aktuella problem och framtidsperspektiv inom teknik och naturvetenskap*. Stockholm: Teknisk Tidskrifts förlag.

Samuels, R.J. (1994). *"Rich Nation, Strong Army": National Security and the Technological Transformation of Japan*. Ithaca: Cornell University Press.

Svenska Dagbladet (1934). Högspänd likström även från Asea: von Platens system får svensk konkurrent, *Svenska Dagbladet*, 17 February 1934, 3.

Svenska Vattenkraftsföreningen (1921). *Svenska Vattenkraftsföreningens tolfte ordinarie årsmöte den 29 april 1921*, Svenska Vattenkraftsföreningens publikationer 130. Stockholm.

Sylwan, E. (1944). Storkraftöverföring: svensk försöksanläggning för kraftöverföring med högspänd likström. *ERA*, 17, 55 - 57.

Teknisk Tidskrift (1954). Elkabel under Engelska kanalen. *Teknisk Tidskrift*, 84, 556.

TMA (1975). "Intervju med Uno Lamm", 1 July 1975, *Archives of Tekniska Museet, Stockholm (TMA)*, 3771, IVA's Teknikhistoriska råds intervjuer, Uno Lamm.

TMA (1977). [N.–G. Håkansson], "Försökslikriktaren : jonventilepokens inledningsskede", LFA 151A. Ludvika: ASEA, *TMA*, 3771, IVA's Teknikhistoriska råds intervjuer, Uno Lamm.

Vi Aseater (1960). Asea håller tiden i kanalprojektet. *Vi Aseater*, 23 (8), 20.

Vi Aseater (1963). Konti-Skan: ett verkligt kraftprojekt. *Vi Aseater*, 28 (1963), No. 4, 4 - 6.

Vi i Vattenfall (1963). "Europaväg för elkraften". *Vi i Vattenfall*, 16 (3), 3.

Wollard, K. (1988). Uno Lamm: inventor and activist. *IEEE Spectrum*, 25 (March), 42 - 45.

VA (1940a). Letter Borgquist to Sylwan, 27 July 1940, *Vattenfall Archives, Råcksta (VA)*, KB, F1BA:8, ASEA:II.

VA (1940b). A. Olsson, "Några litteraturdata rörande kraftöverföring med högspänd likström", 18 October 1940, 1, 15, *VA*, EBB, Allmänt, F1AA:3204, Storkraftöverföring:I - III.

VA (1941). Letter Borgquist to Lamm, 1 April 1941, *VA*, KB, F1BA:8, ASEA:II.

VA (1942). Letter Borgquist to ÖD et al., 11 May 1942, *VA*, EBB, Allmänt, F1AA:3204, Storkraftöverföring:I - III.

VA (1943). Åke T. Vrethem, "PM beträffande försöksanläggning for högspänd likström", 8 October 1943, 1, *VA*, EBB, Allmänt, F1AA:3204, Storkraftöverföring:I - III.

VVA (1942). Letter Rusck to Elektrobyggnadskontoret, 11 June 1942, *Vattenfall Väst Archives, Trollhättan (VVA)*, HK, F1ABC:68, Försöksanl. för högspänd likström 1942 - 1947.

VVA (1943). "Avskrift: Avtal", 20 December 1943 & 28 December 1943, *VVA*, DA, F1CC:1, Högspänd likström Juli - Dec 1944.

VVA (1959a). "Sammanställning över gjorda investeringar och driftskostnader jämte pålägg och beräknad ränta", n.d. but probably 1959, *VVA*, HK, F1ABC:68, Kontrakt.

VVA (1959b). "PM. angående kostnader i samband med försöksanläggningen för högspänd likström", 31 December 1959, *VVA*, HK, F1ABC:68, Kontrakt.

4. A CASE STUDY OF THE SWEDISH PUBLIC TECHNOLOGY PROCUREMENT PROJECT "THE COMPUTER IN THE SCHOOL" (COMPIS), 1981-1988

T. Kaiserfeld

1. INTRODUCTION

The object of this study is to describe and analyse the Swedish public technology procurement project Compis (Computer in School) aiming to develop a Swedish school computer, from 1981, when the Swedish government decided to sponsor the project, until production of the computer was discontinued in 1988.[1] The Compis project was a public technology procurement project proper: a government agency, The Swedish Board for Technical Development (*Styrelsen för teknisk utveckling*), formulated a functional specification of requirements for a product, personal computers for use in schools, which did not exist at the time (1981). After this the Board formally invited bidders, placed an order and signed a contract with the bidder judged most favourably. Since additional or new technological development work was required to fulfil the demands of the buyer, the Compis project was an "ideal type" of public technology procurement project. Moreover, since new products were supposed to be created, it was a creation-oriented project and therefore a developmental public technology procurement.

The Compis was a technical product whose creation had two purposes: to provide the Swedish compulsory school and upper secondary school with modern and inexpensive computers, partly in order to introduce computer science, and to give Swedish industry the chance to develop new technology. A school computer was called for by the Ministry of Education and its agency the Swedish Board of Education (*Skolöverstyrelsen*), whose enquiries had established that there was no computer on the Swedish market meeting the necessary performance standards to ensure the success of the plans to introduce the new subject. At the same time as the Board of Education made its enquiries, the Swedish computer industry, and particularly the two largest manufacturers, Datasaab and Luxor, began to run into financial difficulties (Sjöström, 1996,

[1] The project has also been treated in Kaiserfeld (1996).