The history of high voltage direct current transmission*

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SUMMARY: *Transmission of electricity by high voltage direct current (HVDC) has provided the electric power industry with a powerful tool to move large quantities of electricity over great distances and also to expand the capacity to transmit electricity by undersea cables. The first commercial HVDC scheme connected the island of Gotland to the Swedish mainland in 1954. During the subsequent 55 years, great advances in HVDC technology and the economic opportunities for HVDC have been achieved. Because of the rapid development of HVDC technology many of the early schemes have already been upgraded, modernised or decommissioned. Very little equipment from the early schemes has survived to illustrate the engineering heritage of HVDC. Conservation of the equipment remaining from the early projects is now an urgent priority, while the conservation of more recent projects, when they are retired, is a future challenge.*

1 INTRODUCTION

At the beginning of the electricity supply industry there was a great battle between the proponents of alternating current (AC) and direct current (DC) alternatives for electricity distribution. This eventually played out as a win for AC, which has maintained its dominance for almost all domestic, industrial and commercial supplies of electricity to customers.

As the size of electricity supply systems increased several major challenges for AC systems emerged. There were major difficulties in increasing the voltage (and hence capacity) and the range of undersea cables. Also the development of very large hydroelectric projects in areas quite remote from their load centres became an increasing challenge for AC systems to transport vast quantities of electricity over very great distances. For very large transmission schemes, high voltage direct current (HVDC) is both more efficient and has a greater capability than AC systems. It was recognised as early as the 1920s that there were advantages in the use of DC transmission systems for these more challenging applications. Hence the concept of HVDC emerged, however, development was held back by the lack of a suitable technology for the valves to convert AC to DC and vice versa.

In the late 1920s, the mercury arc rectifier emerged as a potential converter technology, however, it was not until 1954 that the mercury arc valve technology had matured enough for it to be used in a commercial project. This pioneering development led to a number of successful projects. However, at the same time a new technology, the silicon semiconductor thyristor, began to emerge as a viable technology for the valves of HVDC systems. The thyristor valve first came into use in HVDC applications in 1970 and from that time forward the limitations of HVDC were largely eliminated (Asplund et al, 2003).

The technology is now mature and experiencing rapid increases in the voltage, power carrying capacity and length of transmission lines. This has occurred at a time when the efficiency of electricity supply systems is under great pressure due to greenhouse gas considerations, while the development of large hydroelectric schemes is an imperative to decrease the reliance on fossil fuel power generation, which produces a large proportion of the planet's greenhouse gases.

2 TERMINOLOGY

The following terminology and abbreviations are used in this paper:

- AC (alternating current) – a system of electrical energy where the voltage fluctuates around earth potential in the form of a sine wave at a frequency

* Paper presented at the 3rd Australasian Engineering Heritage Conference, "Engineering in the Development of a Region – Heritage and History", 22-25 November 2009, University of Otago, Dunedin, New Zealand.

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of 50 Hz or 60 Hz in typical electricity distribution and transmission systems throughout the world.

- DC (direct current) – a system of electrical energy where the voltage remains constant over time and is either positive or negative with respect to earth. This system is used universally in motor vehicle electrics, small devices operated from batteries and in many industrial applications. It is also used in HVDC systems for specialised high-power, long-range transmission of electric energy. In this paper when the symbol ± is used in association with DC voltages, it signifies that the system operates with one pole above earth potential and one pole below earth potential with the mid-point (zero voltage) at earth potential.
- kV (kilovolt) – the volt (V) is the SI unit of electromotive force. The kilovolt is 1000 V and is the commonly used unit for voltage in high-voltage electricity supply systems. Domestic electricity supplies operate between 120 and 240 V, depending on national standards.
- MW (megawatt) – the watt (W) is the SI unit for power. The megawatt (one million watts) is the measure commonly used for large systems in the electricity supply industry. One MW is equivalent to 1340 horsepower.

Three types of converter devices have been used in HVDC schemes to date and are referred to in this paper:

- Mercury arc valves – a mercury arc valve consists of an evacuated chamber containing a pool of mercury at the bottom forming the cathode. The anode is a carbon electrode at the top of the chamber. When the mercury pool is heated, an arc can be struck within the chamber that conducts electrons from the cathode to the anode, but not in the other direction. Hence the device operates as a rectifier. The device was invented by Peter Cooper Hewitt in 1902. The mercury arc valve was the technology used to convert AC to DC and vice versa in HVDC schemes, until the introduction of the semiconductor thyristor was applied to HVDC schemes from 1970.
- Thyristor valves – the thyristor is a silicon solid-state semiconductor device with four layers of alternating N and P type materials. They act as bi-stable switches, conducting when their gate receives a current pulse, and continuing to conduct as long as the voltage across the device is not reversed. In HVDC applications, many devices are placed in series/parallel configurations to achieve the desired voltage and current ratings.
- Insulated-gate bipolar transistor (IGBT) – the IGBT is a three-terminal silicon semiconductor device, noted for high efficiency and fast switching. The IGBT is a voltage source converter, meaning that it can be switched off as well as on by gate control. This brings advantages to the control of HVDC valves using IGBT technology. The IGBT is a fairly recent development, first appearing in the 1980s. Third-generation devices were available in the 1990s and quickly gained a reputation for excellent ruggedness and tolerance of overloads. In HVDC applications, many devices are placed in series/parallel configurations to achieve the desired voltage and current ratings.

3 THE PIONEER WORK – MECHANICVILLE

In 1932, the General Electric Company built an experimental HVDC scheme between a hydroelectric powerstation at Mechanicville, New York, and Schenectady, New York, a distance of 37 km. This system used mercury arc rectifiers to create the DC voltage, but the load at Schenectady was DC motors, so in a sense it was only half of a full HVDC scheme, which typically consists of a connection between two AC systems. The line operated at 12 kV and had a capacity of 5 MW. The General Electric Company did not, surprisingly, pursue this technology and the scheme was dismantled after World War II without further development.

4 THE EARLY ENGINEERS

In Sweden in 1929, Uno Lamm, working for the Swedish electromechanical company ASEA, took out a patent on the high-voltage mercury arc valve. An experimental valve, tested in 1933, confirmed the validity of Lamm's earlier patent, although it had only a very short life. Research then continued to improve materials to give the valves a longer life. In 1944, a test rig of 2000 kW capacity operating at 60 kV proved successful. Lamm continued in the field working systematically towards the goal of a commercially-viable system for HVDC.

August Uno Lamm was born on 22 May 1904 at Gothenburg on the Swedish west coast (Gould, 1992). He studied at the Swedish Royal Institute of Technology in Stockholm and obtained a degree in Electrical Engineering in 1927. After military service he joined ASEA and in 1929 was made the manager of a project to develop the high voltage mercury arc valve. He obtained his PhD from the Royal Institute in 1943, studying part-time, while he continued his work on the mercury arc valve.

In 1955 he was made head of the project to build Sweden's first nuclear power reactors. In 1961 he was appointed to head the ASEA team in the joint venture with General Electric in the United States to build the Pacific DC Intertie and moved to Southern California in 1964.

During his career, Lamm took out 150 patents and wrote 80 technical papers. He wrote extensively and was published widely in the Swedish press on subjects as diverse as societal commentary, education, technology, political commentary and economics. He was strongly anti-communist and anti-Nazi, which got him into some difficulties during World War II when he was required to work on ASEA projects in Germany.

In 1973 his portrait was hung in Gripsholm Castle on the outskirts of Stockholm. In this he joined the King and Queen of Sweden and many of his distinguished countrymen who are thus honoured for the credit and recognition they have brought to Sweden.

Lamm received many awards including the Gold Medal of the Swedish Academy of Engineering, Knighthood of Sweden's Royal Order of Vasa, France's Ordre du Merite pour la Recherche et l'Invention and the IEEE Lamme Medal. The IEEE Power Engineering Society established the Uno Lamm High Voltage Direct Current Award in 1981.

Lamm learned to play the violin as a child and retained an interest in the performing arts throughout his life. He was married twice and had four children. He died in June 1989 and is best remembered as the Father of HVDC.

There were of course many other eminent engineers involved in HVDC. Two, who made speeches at the celebrations of the first 50 years of HVDC at Visby, Gotland, in June 2004, must be mentioned.

Lennert Haglöf joined ASEA in 1954 and became involved in HVDC in 1962. Before he left engineering in 1987 to join the Group Management Staff, he had been intimately involved in the design, installation and commissioning of a number of HVDC projects, including Sakuma in Japan, the Pacific DC Intertie in the USA and Itaipu in Brazil.

Per Danfors was active in HVDC from 1960 to 1980. During the Mercury Arc Era in the 1960s, he spent seven years working on the Pacific DC Intertie from concept to commissioning, and during the 1970s he was involved in launching the Thyristor Valve Era up to and including the Itaipu project.

5 FIRST COMMERCIAL PROJECT – GOTLAND 1

Lamm's efforts were finally realised in 1954 when the island of Gotland off the east coast of Sweden was connected to the mainland by a HVDC scheme. The Gotland 1 project operated at 100 kV and consisted of 98 km of undersea cable between Västervik on the mainland and Ygne on the island. The valves were of the mercury arc type, which Lamm and his team had spent 25 years developing. The initial scheme had a rating of 20 MW.

The Gotland scheme, generally considered to be the first truly commercial scheme in the world, also became the test site for a series of new technology breakthroughs in the development of HVDC. This site is therefore the most significant heritage site in the development of HVDC for several reasons.

From the commissioning of the Gotland scheme, ASEA (later to become ABB) pursued commercial success with the HVDC technology and has remained the leader in the field ever since. After the success of the Gotland 1 scheme, HVDC did not immediately become an unreserved commercial success for ASEA. Many potential customers were concerned about the possible fragility of the mercury arc valves, although history showed that the complex technology was remarkably robust. ASEA implemented six projects from Gotland 1 in 1954 to the Pacific DC Intertie in 1970 using mercury arc valves.

In 1970 the Gotland scheme was re-engineered to 30 MW and 150 kV using the first thyristor valves to be used in a HVDC application. The original mercury arc valves remained in service alongside the new thyristor valves proving, not for the last time, that the two technologies could work harmoniously together.

The arrival of the thyristor valve was the key to large-scale commercial development of HVDC schemes throughout the world.

6 THE MERCURY ARC VALVE ERA

During the Mercury Arc Era, 11 schemes were built (Haglöf, 2004). The first was Gotland 1 in 1954 and the last was Kingsnorth in 1972. These schemes spanned the world with one in New Zealand, one in Japan, three in North America and six in Europe.

In 1961, a Cross Channel HVDC link was built between France and England. This project consisted of a 64 km undersea cable and converter stations at Echingen in France and Lydd in England. The system operated at 100 kV and had a capacity of 160 MW. The system was shut down in 1984 after only 23 years service. The main contractors were CGEE Alsthom on the French side and English Electric (later GEC) on the United Kingdom side.

The Konti-Scan 1 scheme, commissioned in 1964, between Denmark and Sweden was a 250 kV, 250 MW link consisting of 87 km of undersea cable and 89 km of overhead line. The scheme is still in operation, however, the mercury arc valves were replaced with thyristor valves in 2006. This scheme was built by ASEA.

In 1964 the Russians built a HVDC scheme known as the Volgograd-Donbass scheme with its terminal stations at Volzhskaya and Mikhailovskaya. The scheme operated at ±400 kV, a very high voltage for this time, and had a capacity of 750 MW. The transmission was all overhead line over a distance of 475 km. It is known that this scheme has been modernised with thyristor valves but is now operating at only 25% of its design capacity. The manufacturer of the original equipment is not known to the author.

The French Mediterranean island of Corsica and the Italian island of Sardinia were connected to the Italian mainland by a three-converter scheme in 1965. The scheme operated at 200 kV, 200 MW consisting of 304 km of undersea cable and 118 km of overhead line. The scheme is still in operation, however, the mercury arc valves were replaced with thyristor valves in 1986. The main contractors were English Electric for the Italian converter stations and CGEE Alsthom for the Corsica section.

Also in 1965, an unusual project was commissioned in Japan. In this project at Sakuma the two converter stations are on the same site and the HVDC scheme operates as a frequency converter between 50 Hz and 60 Hz sections of the Japanese AC Grid. The system operates at 125 kV with a capacity of 300 MW. The scheme is still in operation, however, the mercury arc valves were replaced with thyristor valves in 1993. The main contractor was ASEA, but when the scheme was later upgraded to thyristor valves, the contractor was Toshiba.

A third system, in New Zealand, was commissioned in 1965 between Benmore on the South Island and Haywards (near Wellington) on the North Island. This operated at ±250 kV with a rating of 600 MW initially, although it was upgraded later. The transmission system consisted of a 40 km undersea cable and 535 km of overhead line, mostly on the South Island. The scheme is still in operation and has mercury arc valves still in standby service working alongside newer thyristor valves added in 1991. This scheme was built by ASEA.

In 1968 a scheme known as the Vancouver Island scheme was commissioned between Delta and North Cowichan in British Columbia, Canada. This was a 260 kV, 312 MW scheme consisting of 42 km of undersea cable and 33 km of overhead transmission line. The scheme was upgraded with thyristor valves in 1977. The main contractor was ASEA. This scheme has now been replaced by an AC transmission system, however, the HVDC scheme is being kept available for service during the early years of operation of the AC system.

In 1970 the Pacific DC Intertie was commissioned in the United States (Litzenberger, 2008; n. d.). This project was developed in several stages starting at ±400 kV and 1440 MW, but finally rising to 500 kV and 3100 MW. The scheme was entirely overhead lines, but over a great distance, 1362 km between hydroelectric power stations in the state of Oregon and the load centre in Los Angeles, California. This project started with mercury arc valves, but these were later changed to thyristor valves. This scheme was built by a joint venture between ASEA and GE (General Electric). The scheme clearly demonstrated the benefits of HVDC for the transmission of huge amounts of energy over great distances. Nevertheless the records set by the Pacific DC Intertie would be broken many times over the next four decades.

The Manitoba Hydro scheme from the Nelson River area in northern Canada to Winnipeg in central Canada was commissioned in 1971. The first bipole consisted of a 450 kV, 1620 MW scheme with 895 km of overhead line. The main contractor was English Electric, which became GEC in 1968. Bipole 2 was added in 1985 using thyristor valves with converter stations at different locations to Bipole 1 (Ingram, 2005).

The last project to incorporate mercury arc valves was a three-converted scheme across London, England. The transmission system consisted entirely of land cable with a total length of 85 km between Kingsnorth, Beddington and Willsden, operating at 266 kV. The system was commissioned in 1972 and shut down in 1987. The main contractor was GEC. This scheme was never upgraded to thyristor valves.

7 RAPID DEVELOPMENT OF HVDC TECHNOLOGY

The first project to incorporate thyristor valves from its inception was the Eel River project in New Brunswick, Canada, in 1972. This was a back-to-back scheme operating at 80 kV with a capacity of 320 MW.

Following the Eel River project, a further 75 schemes incorporating thyristor valves and 12 incorporating IGBT valves were commissioned or were in the process of commissioning in the 37 years up to 2009 when this paper was written. This work was shared between several companies although ASEA, now called ABB after a merger with BBC in 1987, continues to dominate the worldwide HVDC industry with 60% of the market. The other significant HVDC manufacturers are Siemens and Areva. Tens of thousands of megawatts of capacity have been constructed and the technology has continued to advance. While it was the introduction of the solid-state thyristor valve that ignited the industry, the companies involved in the industry have continued to develop technology and there have been many innovations that are beyond the scope of this paper.

The rapid increase in system voltages and capacities has been the driver for meeting greater and greater needs of the electricity supply industry in the late 20th and early 21st century.

The use of IGBT transistors in place of thyristors for some projects has extended the "economic range of HVDC transmission down to just a few tens of megawatts". This technology is being marketed by ABB as "HVDC Light" (ABB Power Technologies, n. d.), with an emphasis on applications such as connection of wind farms to AC grids, undergrounding of power lines in areas where approval for overhead lines cannot be obtained for environmental reasons, provision of electricity to offshore oil and gas platforms, and the connection of asynchronous grids.

Three projects from the modern era are described in the following paragraphs to place the more recent development of the HVDC technology in context with the early Mercury Arc Era work. One is the Basslink project between Victoria and Tasmania, Australia, because of its local interest to this audience and because at the time of writing it incorporated the longest undersea power cable in the world at 298.3 km. The second is the Xianjiaba to Shanghai project in China, which at 6400 MW and ±800 kV is the largest HVDC project undertaken to date. The third is an IGBT project with a modest 50 MW capacity, again on the island of Gotland where HVDC was born.

7.1 Basslink HVDC project

This project forms a 600 MW link between Tasmania, with its almost entirely hydroelectric electricity generation system, and Victoria, which has vast resources of brown coal and a group of large coal fired powerstations in the Latrobe Valley, east of Melbourne. There are economic and strategic advantages in linking hydroelectric stations with predominantly "peaking" capability with inherently "base-load" large coal-fired stations.

7.2 Xiangjiaba to Shanghai

The rapid expansion of industry and urban development in eastern China in recent years has been truly spectacular. This has led to the development of very large hydroelectric projects such as the Xiangjiaba project on the Jinsha River (known in the west as the Yangtse River), about 230 km west of the city of Chongping. The city of Shanghai has a population of over 20 million and is heavily industrialised. The demand for electricity is enormous. This transmission link, one of many HVDC schemes built, or being built, in China in the last decade, has a capacity of 6400 MW at a voltage of ±800 kV. In this case, the transmission system is entirely overhead with a length of 2071 km. The system will be commissioned with one pole (half capacity) in 2010 and bipolar in 2011. The equipment is being supplied by ABB and the valves will be of the thyristor type with a rating of 8000 A.

7.3 Gotland HVDC Light project – Näs to Bäcks

This project links a wind farm in the south of the island of Gotland to the grid in the vicinity of Visby. The transmission is at ±80 kV and consists entirely of underground polymer-insulated cable over a route distance of 70 km. The capacity of the system is 50 MW. The converters are of the IGBT type, using the ABB HVDC Light product, and are an example of the economic application of HVDC to smaller projects, in this case involving quite a long underground cable.

8 THE FUTURE FOR HVDC TECHNOLOGY

In recent times the technology has divided into two distinct streams. Very large, very high-voltage schemes, some of prodigious capacity, are increasingly being used to move large blocks of electricity from powerstations to load centres. Most of these projects involve hydroelectric projects with the focus of development in China and India. Voltages, transmission distances and capacities are still rising to meet these demands, and there is every reason to believe that this will continue. The prospect of million volt transmission links with capacities in excess of 10,000 MW over distances in excess of 3000 km appear likely in the next decade.

Meanwhile, IGBT valve technology is finding economic applications in smaller applications.

In this age of concern for greenhouse-gas-related issues, the high efficiency of HVDC is a compelling feature. Historically, losses in AC transmission systems have been high, but there are now serious attempts to rectify this situation. HVDC will offer a solution in many cases.

9 THE LEGACY OF THE GOTLAND PROJECTS

ASEA, BBC and ABB have maintained their corporate interest in the HVDC market segment for more than 80 years, and ABB remains the market leader. The companies have tended to use the island of Gotland as a field test facility for each emerging HVDC technological development.

Gotland 1 was the first successful commercial application of mercury arc valve technology and was later extended by using the first thyristor valves in commercial service. Gotland 2 was built later to increase the capacity available on Gotland, and Gotland 3 replaced the ageing Gotland 1 scheme in 1987. In 1999 a scheme between Näs and Visby on Gotland was built to connect a wind farm in the south of the island to the grid. This was the prototype for the HVDC Light product, and featured IGBT valves and modular construction techniques to reduce costs.

10 THE FATE OF THE MERCURY ARC VALVES

After the introduction of thyristor valves from 1970 onwards, ASEA ceased development of mercury arc valves as they were, correctly, confident that the thyristor valves were the way forward and would open the door to higher voltages, higher powers and greater reliability.

Gradually, as the old mercury arc schemes aged, their valves were replaced by thyristors or retired. In some cases there were periods of hybrid operation with converter stations operating with old mercury arc valves and newer thyristor valves in the same converters. In one case, Vancouver Island, the HVDC scheme was replaced by an AC system.

At the time of writing, the only mercury arc valves still in service are those in the New Zealand Inter-Island scheme and the Vancouver Island scheme. In both cases, these valves are in a standby role, able to be used if necessary but the operators have some reluctance to placing the stresses of operation on the old valves. The mercury arc valves in the New Zealand scheme are scheduled to be replaced by thyristors by 2012-2014 (Transpower New Zealand, 2005; 2009).

The remaining mercury arc valves in the Vancouver scheme are still available for service. The operator, British Columbia Transmission Corporation, stated that "we are still relying on this system to provide system backup while the new AC system is going through its first few years". Apparently no specific date for retiring these valves has been set at the time of writing. There are 16 valves on each side.

The retirement of these two systems will bring the Mercury Arc Era to an end after more than half a century of successful operations around the globe.

11 SURVIVING HERITAGE OF MERCURY ARC ERA PROJECTS

This rapid rate of change in the HVDC environment has made the preservation of a representative heritage of the Mercury Arc Era technology problematic. Furthermore it can be argued that it is more difficult to demonstrate significant heritage values with a technology whose origin only goes back about half a century.

We face the problem that unless we are careful, the engineering heritage of the Mercury Arc Era HVDC will be lost before it is recognised that it has great significance. It would be a tragedy if all the mercury arc valves, which were instrumental in igniting the concept of HVDC, were lost in the race to change them over and replace them by the more recent technology.

While my research has not gathered data from all sources, the current conservation status of the three early projects and the 11 Mercury Arc Era schemes is thought to be as follows:

- At the Mechanicville hydroelectric powerstation, which is still in operation, there are some relics of the Mechanicville HVDC scheme. The room that contained the HVDC equipment still exists, but is scheduled for demolition. This room has been used for other purposes since the HVDC equipment was removed, but it still contains several wall mounted insulators thought to be connected with the HVDC apparatus. The station also has the drawings of the HVDC equipment and the log books for the HVDC scheme.
- The only known relic of the Elbe Project is a piece of cable in the Deutsches Museum, Munich.
- No conservation of any of the equipment of the Moscow to Kashira scheme is known.
- There has been considerable preservation of equipment from the original Gotland 1 scheme. "On both sides of the Gotland Link, Västervik (mainland) plus Ygne (on the island of Gotland) there is one phase left with old valves, two valves per site. Furthermore there are five panels left with the old controls. There is one anode-porcelain, cut up so all the grids are exposed through the opening. There is also an Ignition and Excitation unit displayed plus a few more bits and pieces". ABB advises that there is a mercury arc testing unit, thought to be of the Gotland 1 era, at the ABB Museum at Ludvika.
- No conservation of any of the equipment of the original Cross Channel scheme is known.
- No conservation of any of the equipment of the original Konti-Skan scheme is known.
- No conservation of any of the equipment of the Volgograd-Donbass scheme is known.
- No conservation of any of the equipment of the Italy/Corsica/Sardinia scheme is known.
- One mercury arc valve from the Sakuma Frequency Converter Station is held by the Tokyo Electric Power Company (TEPCO) Electric Power Historical Museum. Also one mercury arc valve has been preserved at the Sakuma Frequency Converter Station.
- The mercury arc portion of the New Zealand Inter-island scheme is still in reserve service (see above). There are plans to retain the mercury arc valves, provided that mercury residues can be eliminated. The operator, Transpower, advises that "this may involve a display that features the outer view of a valve but with all contents removed".
- The mercury arc portion of the Vancouver Island scheme is still in reserve service (see above). Plans for preservation after decommissioning are unclear. There are currently no plans about what to do with the valves once they are retired. The operator, British Columbia Transmission Corporation, has stated: "We observed also that most electrical museums typically archived station and generation related equipment. It is a great idea to have HVDC technologies and related history retained in some forms to demonstrate one of the major achievements in electrical power transformation and delivery in the 20th century."
- One 133 kV mercury arc valve from the original Pacific DC Intertie and a 100 kV mercury arc valve from Gotland are on display in the ground floor lobby area of the Celilo Converter Station in The Dalles, Oregon. The displayed Pacific Intertie valve was taken out of service in 2004. The facility is not open to the general public but tours can be arranged.

- One mercury arc valve and accessories from the original Nelson River scheme has been retained by the owner, Manitoba Hydro. This valve is currently in store while the Manitoba Electrical Museum sources funds for a suitable building for the valve. This valve is an example of the largest mercury arc valves built for HVDC service.
- No conservation of any of the equipment of the Kingsnorth, London, scheme is known.

The preservation of the mercury arc valves from the two schemes to be retired in the near future (New Zealand and Vancouver Island) is of great importance considering the small number of survivors elsewhere among the mercury arc valves built for all other schemes. Transpower in New Zealand has indicated that it will not be possible to retain a complete pole, or section of a pole, at either converter station primarily because of space considerations with the development and modernisation of the scheme. It is therefore imperative that the owners of Vancouver Island scheme consider the preservation of the whole converter stations containing the mercury arc valves and not just isolated examples of valves as has occurred elsewhere. The pressure is particularly on British Columbia Transmission Corporation (BCTC), owner of the Vancouver Island scheme, as this scheme is not being redeveloped with newer HVDC technology and has in fact already been replaced by an AC system. This provides BCTC with an ideal opportunity to preserve an entire HVDC Mercury Arc Era converter station.

In addition to the provisions listed above by the operators of HVDC schemes, there is an initiative in Västerås, Sweden (about 90 km west of Stockholm) by a group of retired electrical engineers to create a technical museum to house machinery from various HVDC schemes. The museum will be housed in an old powerstation. A mercury arc valve from the Gotland 1 scheme has already been acquired and there are plans to acquire a mercury arc valve from the New Zealand Inter-island scheme. It is hoped that this museum will open in 2010.

Conservation of equipment from the Thyristor Era is an issue for the future. All these schemes are still in service except three back-to-back schemes, two in Austria and one in Germany. Experience suggests that little planning for heritage conservation will be made, if it is made at all, until the decommissioning of the equipment is imminent. At this point the concern for the preservation of thyristor technologies is less urgent as there are still many in service. Keeping a watching brief on this situation as the technology becomes older and is superseded is a future challenge.

12 CONCLUSION

HVDC technology has progressed very rapidly since the first commercial project in 1954. Two distinct eras have emerged – the Mercury Arc Era and the Thyristor Era. A very large proportion of the equipment from the Mercury Arc Era has already been destroyed.

Heritage conservation has not been a high priority to the HVDC industry, although three museums, in Sweden, Canada and Japan, have Mercury Arc Era valves on display or plan to do so.

Great effort is required by the engineering heritage community to ensure that conservation of the remaining Mercury Arc Era equipment still in reserve service in New Zealand and Canada is achieved.

A future generation of conservation and heritage engineers will have the task of ensuring preservation of HVDC equipment from the Thyristor Era and the related IGBT schemes. Much of this equipment is much larger, currently in service in HVDC schemes of a magnitude that would have been unimaginable to the early engineers working in the field. This represents a great future opportunity, but also a challenge as accommodation of such large machinery in museums is always difficult.

ACKNOWLEDGEMENTS

My thanks to the following people who provided critical information for this paper: Jim Besha of Albany Engineering, owners of the Mechanicville hydroelectric scheme; Chris Hunter, Director of Archives and Collections, Schenectady Museum and Suits-Bueche Planetarium; Siemens Energy Customer Support Centre; Lennart Enström of MAV Consulting, Denmark; Mie-Lotte Bohl, Manager Marketing Communications HVDC and FACTS, ABB, Sweden; Graeme Steele, Europe and Interconnectors Manager, National Grid, UK; Takehisa Sakai, Electric Power Development Company Limited, Japan; Bob Simpson, Chief Engineer and Adele Fitzpatrick, Transpower, New Zealand; Lan Phan of British Columbia Transmission Corporation; Douglas Johnson, Bonneville Power Administration, United States; Jenett Richter, Electrical Museum Administrator, Manitoba Hydro; and Lindsay Ingram, retired Director of the System Planning Division of Manitoba Hydro.

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