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Paper Title	Planning for New Zealand's Inter-Island HVDC Pole 1 Replacement
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Abstract

The original mercury arc valve (MAV) converter equipment comprising Pole 1 of New Zealand's inter-island HVDC link is now over 42 years old. Pole 1 is only one of two mercury arc valve (MAV) based HVDC systems still in service and no other HVDC plant using similar technology has reached 40 years of service before replacement or removal. Given the age and condition of the existing Pole 1 converter plant, and the history of similar converter plant in other HVDC schemes, the retirement and replacement of Pole 1 is being planned.

In parallel with the development of the Pole 1 retirement plan and the economic proposal for its replacement, Transpower has been carrying out detailed planning and engineering studies to evaluate the impact of increased HVDC transfer capacity on AC network development, reactive power requirements, power quality, system stability and equipment ratings. These detailed studies involve the assessment of network and generation development scenarios, including the introduction of additional renewable generation.

The results of these planning and engineering studies will provide key inputs into the development of the performance and equipment specifications necessary for project implementation.

1 Introduction

Over the last 42 years, the inter-island (Benmore to Haywards) high voltage direct current (HVDC) link (Figure 1) has proven itself to be an important part of New Zealand's grid backbone by enabling diversity of generation to both islands. To the North Island, it has brought hydro generation from the South Island and when surplus North Island generation is available, the HVDC link has been used to conserve South Island hydro resources. Since the completion of the original HVDC scheme in 1965, transfer from the South Island has supplied 20% -30% of the North Island's annual electricity requirement [1].

The last major upgrade of the inter-island HVDC link was commissioned in 1993 and the original mercury arc valve (MAV) converter equipment, now forming Pole 1 of the present hybrid link, is now over 42 years old. Pole 1 is only one of two mercury arc valve (MAV) based HVDC systems still in service and no other HVDC plant using similar technology has reached 40 years of service before replacement or removal.

Problems with mercury arc valves in the earlier years and high utilization over much of the life of Pole 1 has necessitated consistently high quality maintenance to achieve continued reliable performance. The availability of re-useable components from other HVDC schemes, no longer in operation, has also contributed to maintaining reliable operation. However, given the age and condition of the existing Pole 1 converter plant, and the history of similar converter plant in other HVDC schemes (up to their removal from service), retirement and replacement of Pole 1 is being planned.



Figure 1: New Zealand's HVDC Link connecting the North and South Islands

1.1 The Original Link

The original inter-island HVDC link was commissioned in 1965. The scheme was the world's fourth HVDC link, and the third to include a submarine cable. In addition to the 40 km cable crossing of Cook Strait, the scheme required construction of 570 km of overhead transmission line between Benmore in the South Island, and Haywards in the North Island. The link consisted of two poles rated at +/-250 kV and capable of transmitting 600 MW north

to meet the initial need to transfer abundant hydroelectric power from the South Island to the growing load centres of the Auckland region in the North Island. Modifications were made later to make the link capable of transmitting power south. The original link utilised mercury arc valves and three submarine cables across Cook Strait (Cables 1,2 and 3 - one of which was used as a spare). The scheme has always been one of the best performed mercury arc valve (MAV) HVDC links in the world.

1.2 The Hybrid Upgrade

Between 1987 and 1992, a major upgrade of the HVDC link was undertaken which resulted in a 1240 MW hybrid link being commissioned in 1993. As shown in Figure 2, the hybrid link consists of two poles, Pole 1 (540 MW) utilising the original mercury arc valve groups upgraded to 270 kV, and Pole 2 (700 MW) using new thyristor valves that operate at 350 kV. New control systems for both poles were also installed as part of the upgrade. At the time of commissioning, the hybrid link used a total of 4 submarine cables - the original Cable 3 in parallel with a new Cable 6 on Pole 1 and new Cables 4 and 5 on Pole 2. At this stage, the original Cables 1 and 2 had been damaged and were decommissioned.

In 1997, Cable 3 had deteriorated to such an extent that it was decommissioned. The remaining new cables were then reconnected to optimise the power transfer with Cables 5 and 6 connected to Pole 1 (540 MW) and Cable 4 connected to Pole 2 (500 MW). The link is presently continuously rated for 1040 MW transfer north and 626 MW transfer south.

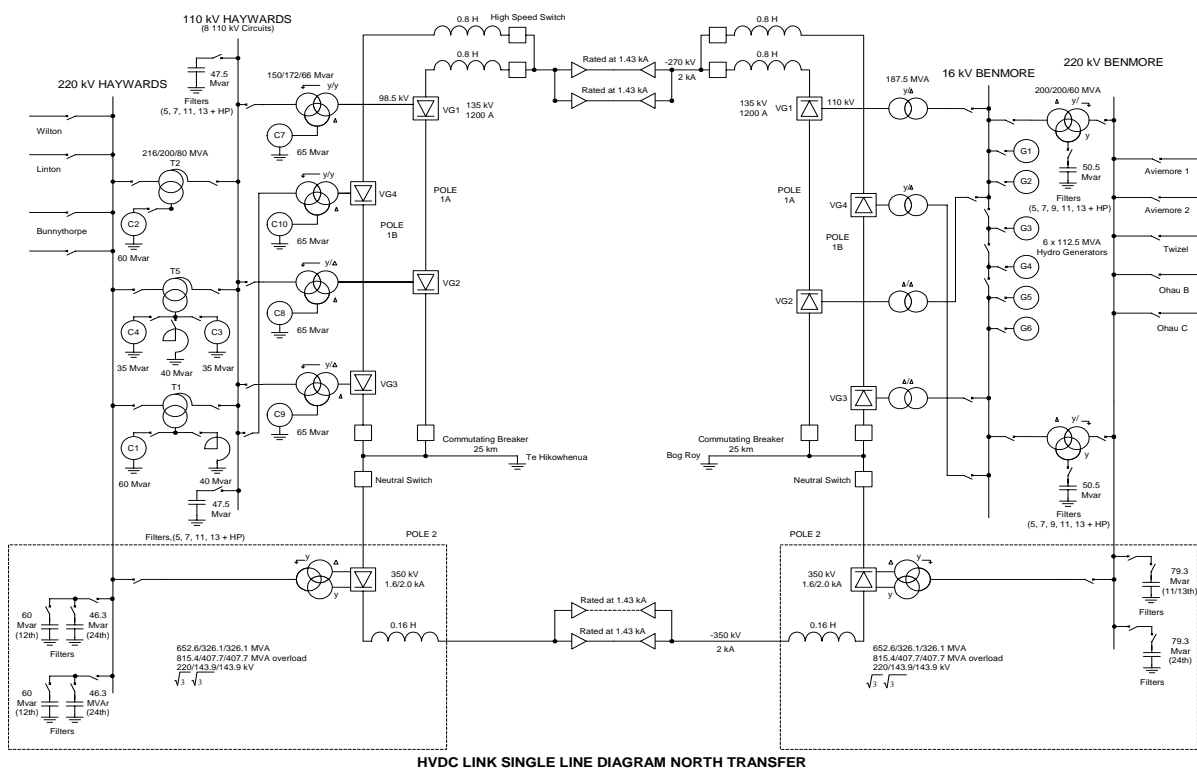


Figure 2: New Zealand Hybrid HVDC link (Established in 1992)

As shown in Figure 2, Pole 1 has connection points to the AC system as follows:

- South Island – 16 kV generator busbar at Benmore
- North Island – 110 kV busbar at Haywards

Interconnecting capacity is provided between these busbars and the 220 kV transmission systems in each island. Pole 2 is connected directly to the 220 kV AC transmission system in each island at Benmore and Haywards.

1.3 Impact of Deregulation

The original link was planned and operated in a vertically integrated electricity industry initially. This was also reflected in the way the design of Benmore generators were integrated as part of the original bipole (MAV) link. Generation dispatch was based on merit order with all generation treated in a priority stack with the aim of minimising total cost of generation. Benmore generators were treated as an integral input to HVDC dispatch. This was not a problem given both were under same owner. HVDC was block dispatched for extended periods of time with very high utilisation.

With the disaggregation of the electrical industry and division of asset ownership, the availability of assets and dispatch of generation are now driven by electricity market conditions. The market conditions have changed the way HVDC link operates, from a long term block dispatch to a frequently varying interconnection acting as an energy balancing link between the two islands. Although this provides benefits to both islands by way of economic use of generation regardless of location, the average energy utilisation has been reduced.

Although Pole 1 power flow variations are usually minimised by mainly utilising Pole 2 for this purpose, increased variations in the power flow in Pole 1 can result in an increased frequency of arc-backs within the MAVs. Arc-backs on the MAVs effectively place short-circuits on converter transformers causing severe mechanical stresses on associated transformer windings thereby impacting remaining transformer life and overall link capacity as described in section 2.3.

2 Retirement Plans and Replacement Benefits

2.1 Background

With the decommissioning of Pole 1 originally planned for 2010, Transpower had previously evaluated whether to replace the mercury arc valves with a thyristor pole [2]. The need and economic justification for new investment on a replacement pole were considered as part of the Grid Upgrade Plan (GUP) [2], submitted to the Electricity Commission (Commission) in 2005. This plan targeted a replacement project start date of July 2006 and completion at the end of 2010. However, the plan and project were unable to proceed as the replacement proposal was suspended in June 2006 until a clear assessment framework could be established for the application of the Grid Investment Test (GIT). This framework has now been established and a revised proposal is presently being developed. Based on the lead times of similar replacement projects throughout the world, 2012 is now the earliest year within which a replacement for the existing MAV based Pole 1 can be commissioned.

By 2012, the Pole 1's primary equipment will be over 47 years old and its control systems over 20 years old.

2.2 Retirement Plan

Equipment failures can occur unexpectedly and quite independently from the replacement plan. This is particularly true where the equipment is older than that used elsewhere in the

world and nearing the end of its life. However, the probability and impact of such failure can be managed through developing and implementing a suitable retirement plan. As such, Transpower continues to review its retirement plan for Pole 1 taking into account the possibility of extending operation through to 2012. The purpose of the Pole 1 retirement plan is to:

- identify and quantify risks, foreseeable consequences and potential mitigation measures;
- achieve the best possible availability and reliability through to 2012 via the implementation of suitable mitigation actions;
- outline contingency actions to advise the market and cater for failures that may impact on continued availability and reliability;
- set out a decommissioning plan identifying the key steps in the eventual cessation of operation, removal and safe disposal of equipment.

In addition to reviewing the retirement plan to identify various means of extending operation of Pole 1 through to 2012, Transpower will continue normal maintenance to ensure the best possible performance of Pole 1. However, major works for life extension beyond 2012 are not being considered.

2.3 Risk of Continued Operation

Transpower's assessment of the existing Pole 1 equipment has identified a number of significant risks that could impact its continued operation. These risks are categorised as:

- technical obsolescence of equipment;
- health and safety;
- seismic;
- fire;
- main circuit equipment performance;
- control system equipment performance; and
- submarine cable condition

Specific risks associated with Pole 1 are detailed further in Transpower's 2007 Annual Planning Report (APR) [3] and the 2005 GUP [2].

In particular, mercury arc valve converters are inherently subject to major disturbances on a relatively frequent basis, and these cause severe mechanical shocks to the converter transformer windings. There is an increasing risk that a converter transformer will fail during one of these disturbances. Failure modes could include a tank rupture with oil spill to the surrounding area. While a single spare transformer is held for each type in service, these are also in poor condition. Given the time required to replace a failed transformer winding, and the possibility of multiple failures, it is increasingly likely that converter transformer failures will lead to an extended loss of capability.

The HVDC converter transformer failure and fire experienced on the Konti-Skan 1 link (Figure 3), prior to its decommissioning, illustrates the potential risks associated with Pole 1 which is of similar age to Konti-Skan 1.



Figure 3: HVDC Converter Transformer Fire (Konti-Skan 1, Sweden)

2.4 The Need for Replacement and the Benefits

While Pole 1 presently provides a similar and often better availability than overseas links of similar mercury arc valve technology, its performance compared to the newer Pole 2 and other key components of the HVDC link underlines that better availability can be expected with a replacement pole [2].

Transpower and the New Zealand electricity market require a reliable HVDC inter-island link to enable better economic and energy efficient decisions around generation. The reliability benefits of a replacement HVDC link would positively impact a number of aspects including energy security and system stability. These and other beneficial functions including transient stability functions are discussed in more detail in the 2005 GUP [3]

2.4.1 Energy Security

The critical concern regarding the HVDC link is the need to provide south transfer during dry hydrological periods in the South Island. Historically, during dry years, power transmission through the HVDC link from the South Island to the North Island reduces significantly. For extended periods during dry years, power flows are often north to south. If during periods of continual southward power flows across the HVDC link an extended outage occurs on the HVDC, then the energy security to the South Island cannot be maintained during dry years.

This requires a secure HVDC link to be able to manage the reverse power flow and to take advantage of the excess energy in both islands. It is expected that the future link will also be able to offer such services to the market by building in the necessary control features.

2.4.2 Ramp-Up Facility

The HVDC link provides a ramp-up facility by increasing the output of one or both poles after interruption (i.e. tripping of one pole or generator), to try and maintain frequency within specified bands. The power controller will then maintain that limit until action is taken by the operator.

The HVDC control ramp-up and stabiliser functions utilise the overload capability of the remaining pole if it is available. This facility is very important since it reduces the spinning reserve requirements in each island. The spinning reserve requirement is dictated by the need to limit the frequency excursions either for the loss of a single element such as a HVDC pole

or the loss of the bipole. It also allows the HVDC link to provide all or partial “self-cover” for tripping of a pole, thereby reducing the spinning reserve requirements in each island.

By contrast, a monopole HVDC link would not be able to provide self cover and would require significant additional reserves (over that of the largest existing generating unit) to be available in both islands to cover a tripping. The requirement to carry additional reserves, may mean that the HVDC could potentially not be utilised to its full capacity due to the overhead of having to carry these additional reserves.

2.4.3 System Stability

The HVDC controls incorporate several power and current modulation functions which exploit the high degree of controllability inherent in the HVDC link. The net market benefit derived from the special control functionality provided by the HVDC link is difficult to quantify but forms an essential part for maintaining the stability and economic operation of the grid.

2.4.4 Frequency Control/Stabiliser

The HVDC frequency stabiliser provides a temporary fast reaction to frequency changes in either or both islands following system disturbances. This assists in arresting the frequency drop as a result of system disturbances. Without this function, more reserves or load shedding would need to be available to ensure the frequency is kept to the limits defined in the Electricity Governance Rules (EGRs) [4]. This would have a consequential flow-on effect in terms of increased costs for generators and consumers.

2.4.5 Spinning reserve Sharing

The HVDC link enables spinning reserve sharing between islands. It provides a slow but permanent reaction to frequency changes in either or both islands in a similar manner to the frequency stabiliser. This functionality enables sharing of spinning reserves between the two islands, enables more competition in the reserves market and reduces the overall reserves cost for the market.

3 Detailed Planning and Engineering for Replacement

In parallel with the development of the Pole 1 retirement plan and the economic proposal for its replacement, Transpower has been carrying out detailed planning and engineering studies to evaluate the impact of increased HVDC transfer capacity on AC network development, reactive power requirements, power quality, system stability and equipment ratings. These detailed studies were enabled by the Electricity Commission’s approval of Transpower’s application for Interim Grid Expenditure (IGE) [4] in December 2005.

3.1 Scope of Work

The IGE works are focused on carrying out detailed investigations essential to identifying potential problems and solution associated with the HVDC proposal within the 2005 GUP [2] and includes the scope described in Table 1.

While being conducted in parallel with the revised economic proposal (which is actively considering alternatives other than the 2005 GUP proposal), the detailed IGE planning and engineering studies are providing key common inputs into the development of the performance and equipment specifications that will be necessary for project implementation.

This approach is prudent given the timeframe associated with the retirement of the existing Pole 1.

The replacement solution which forms the basis of the IGE works comprises:

- Construction of a new 700 MW thyristor converter pole at Haywards and Benmore substations including associated bipole controls systems;
- Reconfiguration of Haywards and Benmore AC substations for connection of new pole and associated reactive power support equipment;
- New 350 kV, 500 MW submarine cables in Cook Strait;
- Replacing the HVDC control system for Pole 2 at Haywards and Benmore;

Table 1: HVDC IGE Activities

HVDC IGE Activity	Scope of Work
System Investigations	Loadflow, dynamic and harmonic analysis, initial design studies, and production of performance specifications.
Engineering Investigations	Engineering studies relevant to overload rating of Pole 2, synchronous condensers at Haywards, noise assessments, seismic issues, civil work requirements, AC switchyard layouts, submarine cables, and improved cost estimates.
Environmental Investigations	Identifying HVDC Environmental issues, setting up process for approval and resource Consents

3.2 System Investigations

Any change to the existing inter-island HVDC link needs careful power system analysis to identify possible AC/DC system interaction issues. The studies listed below are presently in progress and their results will enable robust performance specifications including desired control system functionality to be prepared.

Table 2: System Investigations

Activity	Objectives
Planning Studies	Identify potential substation configurations, transfer capacity requirements and preliminary design considerations including system strength and reactive support requirements.
Harmonic Analysis	Determine applicable distortion limits, harmonic levels harmonic impedances and parameters for inclusion in performance specifications for the harmonic filters and control system.
Reliability Assessment	Determine the optimal configuration and converter rating for Pole 1 taking into account the spares requirement and the ability to interchange equipment between the two poles
Initial Design Studies	Consolidate finding from the preceding activities and to identify the preferred system configuration for detailed analysis and provide input into the Engineering Investigations.
Transient Stability Analysis	Verify the operation of the HVDC system at possible operating conditions, acceptable dynamic interaction can be achieved and identify the need for any special dynamic control or special protection.
Control System Studies	Verify steady state and transient performance and tune controllers for desired performance.
Performance Specifications	Produce performance specifications for all major systems including the converter poles, and control and protection systems for Pole 1, Pole 2 and Bipole.

3.3 Engineering Investigations

Engineering Investigations including an overload investigation of Pole 2, a submarine cable survey and route investigation, and engineering feasibility studies have commenced. These investigations will ultimately provide final proof of concept and detailed input necessary to produce the performance and equipment specifications for the replacement project.

3.3.1 Pole 2 Overload Investigation

During bipole operation, the trip of a pole may require the remaining pole to cover a portion of the lost transfer capacity. The larger the portion of this transfer compensated by the remaining pole the lower the spinning reserve required to cover for a HVDC pole outage. Given that there is a degree of freedom to choose the capacity and overload of new equipment, the existing Pole 2 will ultimately impose overload constraints and define the reserve coverage required. The overload capability is dependent on the complete HVDC circuit including converter equipment, lines, submarine cables and reactive support equipment. Assessment of Pole 2 converter equipment, specifically the smoothing reactor, valves and converter transformers is well advanced with a desktop study commissioned with the original equipment suppliers, ABB.

3.3.2 Submarine Cable Survey and Route Investigation

The 2005 GUP proposal [2] assessed three bipole options; 1000 MW, 1200 MW, and 1400 MW. The 1000 MW could be transmitted using two cables with the third being a spare. For a 1200 MW link all three 500 MW cables would need to be in service and there would be no spare. If there is a cable fault, the bipole capacity would be reduced to 1000 MW until the cable is repaired which could be up to 17 months. A 1400 MW link would need an additional cable to transmit the 1400 MW and in the event of a cable fault, the bipole capacity would also be limited to 1200 MW until the cable is repaired.

Although the original estimates for deep water cable repairs were up to 12 months, in reality a deep water repair could take 17 months or more to complete as there is a limited weather window (February / March) in the Cook Strait to undertake cable repairs, and there are presently only three purpose built submarine power cable repair vessels in the world.

The three energized cables (cables 4, 5 and 6) and the three more disused power cables from 1965 (cables 1, 2 and 3) presently occupy the cable protection zone (CPZ). In case where one or two new cables are required to be installed the possibility of installing this within the CPZ needs to be evaluated. Understanding the sea floor will help reduce the risk of installation difficulties associated with rock outcrop areas and suspensions that could damage the cables. Accordingly, a bathymetric survey of the CPZ within Cook Strait has recently been completed and a desktop study commissioned to identify likely cable routes and likely problem areas.

3.3.3 Engineering Feasibility Studies

Engineering feasibility studies presently underway are:

- Condition assessment of synchronous condensers at Haywards;
- Preferred configurations to connect synchronous condensers via 100kV or 220kV;
- Detailed noise assessments at the converter stations, particularly Haywards;
- Seismic design issues at the converter stations and cable terminal stations;
- Switchyard layouts and transition staging plans;
- Civil work investigations for location of additional equipment;
- Conceptual civil design for high level cost estimates;

- AC equipment assessment to confirm suitable ratings of existing equipment; and
- Functional specifications.

Following completion of this work, further IGE funding will be required to produce consolidated performance and equipment specifications necessary for project implementation.

3.4 Environmental Investigations

The Pole 1 replacement solution under consideration within the IGE works will ultimately involve physical works at Benmore substation, Haywards substation, Fighting Bay terminal station, Oteranga terminal station and installation of additional Cook Strait cable/s.

Therefore, environment investigations will be carried out to ensure all necessary environmental issues are adequately addressed. This work will ultimately include:

- status confirmation in terms of the regional plans;
- confirming suitable approaches with councils;
- consultation with affected parties; and
- preparation of applications for resource consents and assessments of effects on the environment.

4 Summary

The existing inter-island HVDC Pole 1 was originally planned to be decommissioned in 2010. However, it is now envisaged that Pole 1 operation will be required until 2012 by which time Pole 1's primary equipment will be over 47 years old and its control systems over 20 years old. Retirement plans for Pole 1 are being developed to identify measures to extend operation of Pole 1 through to 2012 and to identify necessary contingency plans. At the same time, normal maintenance continues to ensure the best possible performance of Pole 1. However, major works for life extension of Pole 1 beyond 2012 are not planned.

In parallel with the development of the Pole 1 retirement plan, Transpower is carrying out detailed planning and engineering studies to evaluate the impact of increased HVDC transfer capacity on AC network development, reactive power requirements, power quality, system stability and equipment ratings. The results of these detailed studies will provide key inputs into the development of the performance and equipment specifications that are necessary for project implementation.

References

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