HVDC DEVELOPMENT OPTIONS
CABLE CAPACITY
27 June 2005

1.0 Introduction

This paper summarizes the issues which may be relevant when considering the need or otherwise to provide spare submarine cable capacity. Few HVDC transmission systems have provided spare cable capacity, and with the exception of the DC Hybrid upgrade project, the others were very early installations in the history of international HVDC schemes. Several high power monopolar schemes have been, and are being installed, for which long submarine cables are involved without spare cable capacity, but none of these are in key grid roles.

The Benmore-Haywards Link is however, in a special situation as it is an essential element of the New Zealand national grid.

2.0 Basic Issues

The issues relevant to the provision of spare cable capacity are –

a) the need to maintain link capacity throughout the year
b) the difficulty of implementing repairs, and the associated time to completion
c) the risk to the cables of damage due to external causes
d) the cost of providing spare cable capacity
e) the expected cable performance/reliability

3.0 Risk of Damage and Cable Performance/Reliability

Data available from various periodic international reviews, shows very clearly that until the late 1980's most cable faults were due to external causes primarily from maritime activities (i.e. anchoring and fishing). Some cables suffered damage as a result of lengths having been suspended over rocks, and in areas of high water velocities associated with gravel/stone coastal zones, or tidal flows through narrow straits abrasion-corrosion damage has been of concern.

Rigid joints, particularly those made during difficult weather conditions generally proved to be unreliable. Rigid land-sea joints which involved a change of conductor diameter through the joint also provided to be unreliable because of differential conductor expansion associated with cable loading cycles, which led to deformation of the outer cable insulation.

Over the last 15 years or so techniques have been developed to protect against maritime damage by burial below the sea floor, or by monitoring shipping activities near the cables, and installation techniques have been adopted to control cable laying so that cable suspensions are avoided.

In addition, newer cables do not use rigid joints, and avoid any change of conductor cross section. Techniques for repair have been improved and now include jointing within a humidity controlled environment and the use of insulation lapping machines to provide more precise control of insulation tension and overlap. Repair joints are in many ways close to what can be described as a factory re-constitution joint.

4.0 Provision to Date of Spare Cables for the Benmore-Haywards HVDC Transmission Link

There have been two stages of development in the HVDC transmission between the North and South Island.

4.1 The Original 1965 Link

A spare cable was included in the ±250kV 600MW bipolar HVDC link commissioned in 1965. The decision to provide a spare was based on

- the need to maintain link capacity, as it was expected to be, and did become, critical to meeting both North Island peak demand and energy demand as the North Island load increased.

- the likely long time to complete a repair – in excess of 12 months was forecast. This was borne out in the repair of a deep sea fault in 1976/77.

The three gas pressurized cables were laid in 1964 using a specially outfitted freighter. One cable was kinked during laying and failed on test necessitating repair using a rigid repair joint. The repair failed in 1976, and was repaired during 1977 after re-fitting the original freighter.
All shore joints containing a change in conductor diameter, either failed or necessitated repair. (Checks were made on the joint at the apposite end of each cable when a failure occurred to assess the internal state of deterioration and replacements were sometimes adopted to avert impending failure). On average shore joints needed repair roughly every 7 years.

A failure (major gas leak) occurred at a cable suspension point and was repaired in 1982. Investigation identified other potential failure points and considerable cost and effort was applied to stabilizing other suspended lengths to minimize further failures.

By 1993 ROV survey techniques enabled a full examination of all 3 cables which showed the presence of fishing and other anchors lodged in the cable. Subsequently serious abrasion corrosion damage was found on all three cables in the rip zone where gravel trains and high velocity movement of gravel impacted severely on the cables.

One cable was damaged at a mid-span position (30m suspended length) which showed evidence of severe external impact (160m water depth) considered to have been caused by deep trawling.

No failure of virgin (undamaged) cable occurred, and checks on recovered sections, at the time of repair, indicated the basic cable design to be generous and speculation was given to re-joining good lengths of cable to create one good cable and to operate it at 350kV 800Amp. This was too costly to be attractive. In 1997 all three cables were withdrawn from service.

4.2 The 1992 Hybrid Up-grade

The DC Hybrid Link up-grade was based on the purchase of new 560MW thyristor converters to operate with 350kV 500/560MW (continuous/short term rating) cables.

Three 500/560MW cables were installed to provide for long term expectations. At that time it was expected the DC Link would become a 1000/1120MW bipole when the mercury arc converters and 250/270kV cables reached the end of their life – forecast then at around 2005.

The Hybrid configuration utilizing both the mercury arc converters and original cables together with the new thyristor converters and cables, and with the new converters given an overload capacity of 700MW, enabled a 1240MW capacity to cater for the excess South Island energy expected in the early to mid-1990's after the commissioning of Clyde Powerstation.

The specification for the new 350kV cables specifically excluded the use of rigid joints, of any change in conductor cross section between sea and land sections, and required a monitored touch down/laying process through the rock-outcrop areas. In addition counter wound double wire armouring with a heavier, non biodegradable resilient outer serving than applied to the original cables was adopted. The specification also limited suspended lengths to values which would allow a 40 year life.

The cable contract called for manufacturing technology (design and manufacture) which has shown long term satisfactory in-service performance, as ‘The Employer’ (i.e. Transpower) did not anticipate replacing the cables within 40 years. The abrasion-corrosion conditions in Cook Strait, now understood better, are such that mechanical deterioration may play a more significant part in life expectancy, and that by around 40 years mechanical handling for repairs may become risky.

In recent years, monitoring of the statutory cable protection zone has been regularly pursued to minimize the possibility of external damage to the cables from maritime activities.

Three cables were included in the contract to provide one cable per pole and one spare for the ultimate 1000MW bipolar development.

The reasons for this decision were the same as in the first (1965) scheme, as the possibility of the subsequent market development were then some years away and not foreseen at that time.

Consideration was given to delaying the provision of a spare 350kV DC cable until sometime in the early 2000’s, but this was shown to be less attractive option.

With the strict specification and subsequent monitoring and survey programmes now followed, the most likely cause of future failures is likely to be failures in virgin cable. Currently a failure rate for virgin cable of 0.02 faults per 100 cable km years is used internationally, which for three 40km lengths over 40 years corresponds to one fault over the life of the installation. The existing installation of three 350kV 500MW cables meets the basic requirement for a 1000MW link with a spare cable to ensure 1000MW bipole capacity can be maintained should a cable fault arise and caters for the low probability that any further failures may occur.

5.0 Provision of Spare Cable Capacity for 1200MW and 1400MW Development Option

Two future development options are being considered. These are provision of 1200MW, or 1400MW capacity.

Consideration is given below for each of these development options.

5.1 Development to 1200MW

If the existing mercury-arc converters are replaced using thyristor plant with identical technical parameters to the pole 2 thyristor plant, the key difference between the two options, as far as converter plant is relevant, is likely to be in the extent to which cooling plant is provided for the converter transformers. If a different set of parameters is used, then the single phase converter transformer units may not be interchangeable with the existing pole 2 units and hence 4 would be necessary at each station.

The converter issues are not discussed any further in this paper as the emphasis is on submarine cable capacity.

The issues relevant to the provision of spare cable capacity for 1200MW link capacity are –

- the need to maintain 1200MW capacity throughout the year
- the cost of providing spare capacity
- the expected reliability of the existing 350kV cables

With three 350kV 500MW cables the 1200MW capacity can be maintained with two cables on pole 2 and one on pole 1. The loss of any one cable would incur a reduction to 1000MW capacity until a repair can be completed.

The failure of cable 6 in October 2004, when the fault position was examined showed a classical over-voltage/impulse breakdown with the breakdown path passing radially outwards. There was no clear indication for this weakness. The cable failure followed a series of polarity reversals at 270kV DC. The cable had been designed and tested for polarity reversal with stand strength in accordance with CIGRE recommendations at 1.4 times 350kV DC. The reasons for the discontinuity/weakness may be the result of handling during installation as the failure was in the length floated ashore under the guidance of divers and close to the shore. The cable was laid correctly in the corridor specified through the rocky outcrops.

While the cause of failure is difficult to establish it is considered unlikely to arise elsewhere. See appendix for a discussion on the possible cause and significance of the fault in Cable 6. Many hundreds of km of paper insulated cable of similar construction have been made in the same factory over a number of years without any failure similar to that on cable 6 being reported. Reporting is included via scheme owners in the annual HVDC returns to CIGRE Study Committee B4.

Therefore in the remaining 26 years of life forecast for the three existing cables, the probability of a further failure is less than one, based on past international performance history.

Although the design and installation requirements, and the maritime monitoring programme, is aimed at continuing to achieve a low probability of cable failure, the situation still remains that a cable fault in deep water will inevitably take a long time to completion of repair. Any associated prolonged reduction in inter-island HVDC link capacity can impact on the electricity market and hence on consumers generally.

In order to continue to fulfill its role as national grid provider, the objective of ensuring inter-island capacity irrespective of any extended cable repair duration, can only be met by providing spare cable capacity for the 1200MW case.

The options for this are –

- provision of a 350kV 250MW cable for around $86m
- provision for a 350kV 500MW cable for around $100m

While there is some apparent cost advantage in providing a 250MW cable instead of a 500MW cable the need for extra spare cable, extra spare terminating porcelains and associated equipment, may erode the apparent advantage.

The benefits of installing a fourth 500MW cable of similar design to the existing arises through the interchangeability of material and minimization of spares. Forecast cable performance does not justify expenditure for the provision of two spare cables.

5.2 Development to 1400MW

For this development, it will be necessary to provide at least one further cable to achieve 1400MW capacity. This can be achieved by installing either a 500MW cable (around $100m) or a 250MW cable (around $86m).

However, for Transpower to maintain 1400MW capacity in the event of having to carry out a deep water cable repair over a prolonged period of time, would necessitate installing two further cables, either of 250MW or 500MW capacity.

While the cost of providing two 500MW cables is likely to exceed that of providing two 250MW cables by around $20m or so, the issues associated with having two sizes of cables would need careful consideration to establish clearly a good economic case for pursuing that option.

6.0 Summary

In order that Transpower can continue to maintain the inter-island link as a key element of the national grid, especially in view of the particular difficulties and long time durations possible for a deep water cable repair, in the difficult and highly variable Cook Strait environment, spare cable capacity for the three future HVDC link options are:

a) 1,000MW DC Link
- the current installation of three 350kV 500MW DC cables provides for one cable per pole plus one spare, which is considered adequate

b) 1200MW DC Link
- a further cable is necessary (either 250MW or 500MW capacity) to provide for any one cable (either 250MW or 500MW) to be spare

c) 1400MW DC link
- two further cables (in addition to the existing three) will be necessary (either 250MW or 500MW) for any one cable to be spare

The complications of having two different cable sizes would need to be carefully evaluated, as the apparent cost savings may be eroded by factors such as provision of spares (particularly spare cable and repair joints) and flexibility of terminal interconnections, etc. At this stage it is appropriate to assume further cables would be 500MW cables until a smaller size can be thoroughly evaluated.

7.0 Conclusion

The inter-island HVDC link is in a unique role as a component of a national grid, when compared to the roles of many overseas HVDC links. Long repair durations must be allowed for in case failures occur in the deep and difficult part of Cook Strait. Transpower's aim of giving priority to maintaining link capacity, even though the statistical probability of failure may be low, can only be met by providing spare cable capacity for all optional expansion capacities.

Although the expected cost of providing 250MW cables is lower than that of providing 500MW cables, careful evaluation of the advantages and disadvantages may identify some overall benefit in ensuring interchangeability if cables similar to those already installed are obtained. The forecast failure rates based on international statistics do not provide any economic justification for considering more than one spare cable for any of the development options.

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APPENDIX

Cable 6 Fault – October 2004

When cable 6 repair was carried out in late 2004 and early 2005, an essential part of the exercise was to retrieve a length of cable containing the fault position for dissection and examination for any indication of the nature of the breakdown and possible cause of failure.

Unfortunately the damage within the cable, caused by the fault and the 'thumper' discharges from the fault locator, was such that a conclusion on the likely cause of failure was not possible.

Sufficient indication remained, of imprint patterns of the stress control screens to eliminate, with a reasonable degree of confidence, any manufacturing defect. The manufacturing logs do not record any 'non conformity' arising at this position during manufacture of the cables. (Every 'non conformity' which occurs during manufacture is recorded, and the action taken to ensure full quality controlled restoration of the cable to production specification is recorded in detail).

The report of the ABB staff who were involved in the cable dissection and examination, contains a simple error which may hold the clue to a possible failure cause. The report stated the distance of the fault from the cable terminating end as 350m and associated this with the position of the 'Skagerrak' when the end of cable 6 was floated ashore. The Skagerrak was in fact approximately 350m from shore or 550m from the cable sealing end. The ABB report suggests that incorrect bending during floating of the cable from ship to shore may have been a possible cause, probably because this part of the installation process of any power cable is regarded as the most difficult and is when the risk of laying damage is greatest.

It is known (e.g. from the laying of Fennoskan cable) that when there is a long length of cable on floats between the cable laying vessel and shore and tension is removed from the cable there is a risk of over-bending the cable should the firmly held portion of the cable going out over the vessel laying sleeve be bent downward by a lowering of the vessel stern at that time. A situation occurs briefly of perhaps some minutes during floating the cable-end to shore, when the cable-end reaches shore and the tension on the pulling wire is released to allow the cable-end to be settled onto the powered cable rollers in the trench across the beach to the terminal building. Once on the powered rollers, cable landing progress resumes and tension is restored to the cable. It is impossible for tight bends to be introduced into the floating length of cable because of the exceptionally high stiffness (normally requiring power to force bending).

One hypothesis for the cause of cable 6 failure therefore, is that in the brief period when the cable-end reached shore, and progress paused, an unexpected downward movement of the stern of Skagerrak occurred, over-bending cable 6, before tension was restored. The over-bending may have compressed a short section of cable insulation sufficient to leave a weakness which resulted in the over-voltage failure associated with the line fault polarity reversal incidents. Damage within the cable during breakdown and subsequent fault location has obliterated any evidence to validate this hypothesis.

While not improbable, a failure based on this hypothesis can be regarded as a 'one-off' event. Modification to the HVDC control to minimize the severity of possible polarity reversal stresses associated with line protection operations are being pursued separately as the 'weakness' was only brought to light under such conditions.

A second hypothesis is that the cause of the failure is entirely unknown.

Whichever of the above is relevant to the failure, the world wide performance history of HVDC submarine cables remains as an indication that failures in apparently undamaged cable are rare, and hence the accepted figure of 0.02 faults/100 km/year is the only basis to use to assess the likelihood of further risks.
Had evidence been uncovered to indicate the possibility of weaknesses at other locations of any of the three 350kV cables, the probable costs of dealing with only a small number of deep

water repairs could raise the prospect of early replacement of the existing cables, both from a cost/risk and reliability standpoint.

It should be noted that the repair involved quality control developments to improve on an already established repair arrangement which had given proven long term performance.