TRANSPOWER

HVDC Cable Discharge Modelling Review

Review of risk and existing mitigations

Version: 1

Date: October 2024

Version	Date	Change
1.0	18/10/24	Approved for industry comment

IMPORTANT

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Contact Details

Address: Transpower New Zealand Ltd
Waikoukou
PO Box 1021
Wellington
New Zealand

Telephone: +64 4 590 7000

Email: system.operator@transpower.co.nz

Website: http://www.transpower.co.nz

Executive summary

Transpower, in its role as System Operator (SO), is required to review the identification, assessment and assignment of potential credible power system events at least once in each five-year period. At the end of 2023 we published the 2024 Credible Event Review Scope report signalling what we would study during the 2024 review, including how events are managed during HVDC cable discharge periods – the subject of this report.

The HVDC link, which includes cables running under the Cook Strait, is a major part of the transmission system which enables the transport of electricity between North and South Islands. The link also enables instantaneous reserves to cover potential power system events to be shared between both islands, and national reserves to be scheduled based on the lowest market prices. However, at times when one of the HVDC cables is reversing polarity, it goes through a discharge period which can restrict reserve sharing at times.

The way instantaneous reserves are handled during HVDC cable discharge periods was established in the 2018 National Market for Instantaneous Reserves Refinements report, specifically how cable discharge is modelled in our dispatch tools. Under certain circumstances, the sharing of instantaneous reserves is restricted during cable discharge due to physical limitations of the HVDC. However Schedule Pricing Dispatch (SPD) currently restricts instantaneous reserve sharing during all instances of cable discharge.

This report reviews the current approach. It contains our assessment of the impact on system frequency of an AC Contingent Event (CE) occurring during periods of HVDC cable discharge while instantaneous reserves are being shared between the North and South Islands. It compares the costs of the current SPD modelling method with the costs of not modelling the instantaneous reserve sharing restrictions, and includes a comparison with a potential improved modelling approach.

The review concludes that the existing SPD approach of modelling the reserves sharing capability limitations during HVDC cable discharge is justified and should be continued as it provides the optimal security outcome for the New Zealand power system. There is potential to improve the SPD modelling approach with an annual cost saving of $25,000, this will be costed against an internal review of the feasibility and related project costs of updating SPD.

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1 Introduction

1.1 Scope and approach for 2024 Credible Event Review

Transpower, in its role as System Operator (SO), is required to identify and review the events deemed credible on the transmission system and to determine if the classification of such events is correct.

At least once in every five-year period, we must review the identification, assessment and classification of potential credible events, publish our assessments and invite comments. We began this process at the end of 2023 when we published the scope for our 2024 review (2024 Scope).

The 2024 Scope set out our approach for the review and the issues for further consideration in our 2024 Review.

This document is one of the reviews we signalled in the 2024 Scope.

1.2 The need for a review of HVDC cable discharge modelling

The HVDC link, which includes cables running under the Cook Strait, is a major part of the transmission system which enables the transport of electricity between North and South Islands. The link also enables instantaneous reserves to cover potential power system events to be shared between both islands, and national reserves to be scheduled based on the lowest market prices.

Whenever the HVDC cables reverse polarity, they require a 5 min discharge time to change direction of power transfer. Depending on how the flows are changing, and how reserves are being procured at the time, this can lead to a spike in reserve cost. In 2018 the System Operator implemented refinements to the national market for instantaneous reserves to remove a ‘sticky point’ phenomenon with the HVDC transfer. This required the introduction of new constraints for the fast instantaneous reserves (FIR) to model different physical limitations of the HVDC. Following the introduction of real time pricing to the New Zealand power system in 2022, it became apparent that further improvements may be possible when modelling FIR during HVDC cable discharge.

This report reviews the current approach. It assesses of the impact on system frequency of an AC Contingent Event (CE) occurring during periods of HVDC cable discharge while instantaneous reserves are being shared between the North and South Islands. It compares the costs of the current modelling method with the costs of not modelling the instantaneous reserve sharing restrictions, and includes a comparison with a potential improved modelling approach.

2 Key concepts

This section introduces key concepts relevant to the assessment of frequency events on the New Zealand power system and explains the issues around the HVDC cable discharge.

2.1 Reserves and reserve sharing

Instantaneous reserve is generating capacity, or interruptible, or controllable load, available to operate automatically in response to a CE or an Extended Contingent Event (ECE). This service is required to meet the required frequency criteria. Transpower as System Operator enters into instantaneous reserve contracts with participants who can offer instantaneous reserve compliant with the System Operator's technical requirements and the Code. Instantaneous reserve is procured on a half-hour clearing market basis.

This instantaneous reserve can be shared between both islands through the HVDC link, enabling national reserves to be scheduled based on the lowest market prices.

2.2 Reserve Management Tool

The Reserve Management Tool (RMT) calculates the quantity of fast instantaneous reserves (FIR) and sustained instantaneous reserves (SIR) required to   process of energy and reserves.

2.3 Schedule Pricing Dispatch

Schedule Pricing Dispatch (SPD) is used to determine dispatch instructions in near real time. The valid offers from the forecast schedule are finally used by the SPD application to provide a dispatch schedule for the current demand conditions. The SPD application runs every five minutes to keep pace with the changing load.

2.4 HVDC cable discharge

The HVDC cables have a five-minute discharge time between blocking and de-blocking whenever a pole's power direction is changed.

Under normal bipole operation the HVDC has roundpower functionality which enables it change power direction without requiring to be shut down. It achieves this by reversing the voltage polarity of each pole separately as the bipole power in one direction reduces towards 0 MW. The first pole is shut down at what is known as the 'bipole-to-monopole-transition-level'. This is usually set at 200 MW and a 10 MW hysteresis is applied meaning that the transition to monopole would occur at 190 MW bipole power and the transition back to bipole operation at 210 MW bipole power.

Once a pole is shut down it must remain idle for 5 minutes before it can be energised in the opposite voltage polarity (which is required for changing the power direction) [1]. This is related to the physical

[1] The consideration of this behaviour is limited to the situation when roundpower is enabled. Roundpower can be disabled for various reasons and reserve sharing is managed differently during those times as the bipole has to shut down completely in order to change direction.

characteristics of the HVDC Cook Strait cables' insulation, and is referred to as the cable discharge period.

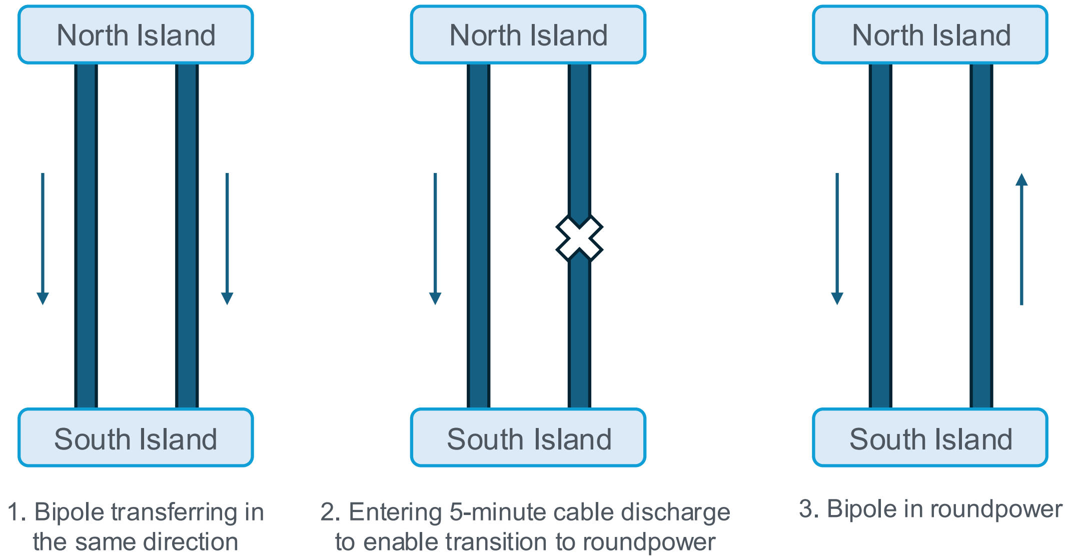

Figure 1 – Example of the bipole transition into roundpower

An example of this transition is shown in Figure 1 where steps 1-3 show the transition through cable discharge into roundpower, these steps would be reversed to transition out of roundpower.

Cable discharge can occur multiple times a day and usually does not restrict the sharing of instantaneous reserves in either direction. There are however a set of circumstances where cable discharge can restrict the sharing of instantaneous reserves in the reverse direction (the opposite direction to the bipole power flow), this is referred to as a 'cable discharge risk period' in this report. An important distinction is that while instantaneous reserve sharing capability is only physically restricted during cable discharge risk periods, the current SPD logic restricts instantaneous reserve sharing during all instances of cable discharge. This disparity will be the focus of the following analysis.

The cable discharge risk period occurs when all the following criteria are met:

1. Both poles were transferring in the same direction before cable discharge,
2. One pole is in cable discharge, which is detected as:
   a. The bipole was dispatched above 190 MW before cable discharge[2],
   b. The bipole was dispatched to below 190 MW during cable discharge, and
3. Sharing of instantaneous reserves is planned in the reverse direction.

When all the above criteria have been met, the system frequency on the HVDC sending island (for an AC event on that island) can be impacted if the reserve sharing limit is not applied and more reserves are procured on the HVDC receiving island than can be shared.

The significance of criteria 1 is due to a pole's ability to re-energise during a cable discharge in the direction it was previously transferring. This means if the bipole was previously operating in

[2] The 190 MW figure relates to the normal operation with the transition level set at 200 MW. The transition level can be set higher (typically 350 MW to retain the HVDC link in monopole operation for AC voltage control) – this is excluded from the analysis as the single pole in service has sufficient capacity for reserve sharing in both directions at the higher transition level.

roundpower, where the poles were transferring in opposite direction, the discharging pole can re-energise and the bipole can return from monopole to roundpower, enabling instantaneous reserve sharing in either direction. If both poles were transferring south before the cable discharge, the discharging cable would only be able to re-energise in the south direction if cable discharge had not completed, enabling sharing of significant instantaneous reserves south, but limiting the amount that could be shared north.

Criteria 2a and 2b together are used to determine that a pole has gone into cable discharge which is the trigger for instantaneous reserve sharing being limited in the real time dispatch schedule.

When criteria 1-3 have been met, instantaneous reserves can only be shared in the reverse direction by reducing the power transfer of the active pole (P). This is further restricted by the pole's minimum power level (Pmin) of 35 MW and the Frequency Keeping Control Modulation Risk (MR) of 30 MW, therefore the reverse instantaneous reserve sharing capacity (IR) in this instance would be:

$$IR = P - Pmin - MR$$

or

$$IR = P - 65$$

The HVDC (both bipole and monopole) is normally operated with a ramp rate of 25 MW/min. This means the power on the active pole can reduce by up to 125 MW during the five-minute cable discharge of the other pole. In the worst case, if the active pole was at 190 MW when the other pole entered cable discharge and proceeded to reduce its transfer by 25 MW/min, then the power transfer of the active pole would approach 65 MW towards the end of the cable discharge period. Given the 65 MW required by Pmin and MR, this would reduce available reverse reserve sharing capacity to zero just at the end of the five-minute window. This example is demonstrated in Figure 2 below.

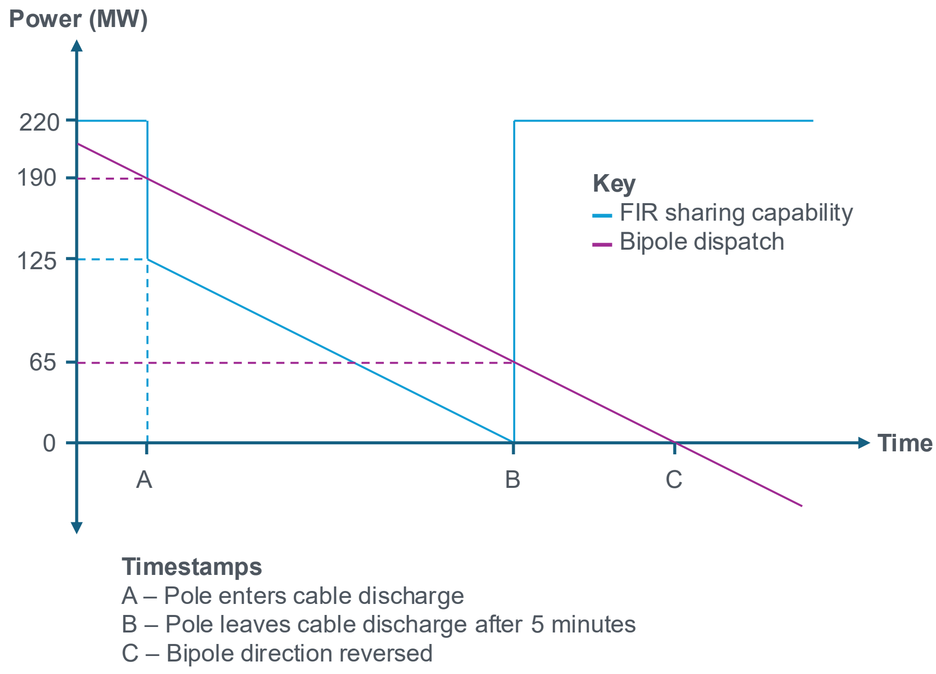

Figure 2 – Example FIR sharing capability during cable discharge

3 Analysis

This section compares the costs of the current SPD modelling method with the costs of not modelling the instantaneous reserve sharing restrictions, and includes a comparison with a potential improved modelling approach. The costs associated with the different SPD modelling methods are annualised costs based on historical data from 2023 following the introduction of real time pricing to the New Zealand power system. The cost of not modelling cable discharge in SPD is a 'per significant event' cost due to the difficulty of classifying the probability of a significant event occurring. These are two different factors, however given past experience our expectation is that at least one significant event will occur each year, making the costs somewhat comparable.

3.1 Assumptions

The following assumptions have been made for this analysis:

- Only FIR reserve sharing is impacted during the cable discharge risk period, SIR is applied over a fifteen-minute period so will always be available outside the five-minute cable discharge period, and no limit is presently applied for SIR sharing related to cable discharge,
- Reserve sharing is always available in the SPD dispatch if reserves are available,
- Loads during cable discharge will be 50% of winter 2027 expected Island peaks to accommodate for cable discharge happening only when HVDC bipole dispatch is low,
- A significant event in this analysis is defined as 'an ACCE risk event large enough to trip one AUFLS block only when planned instantaneous reserves are unavailable',
- The possibility of an ACECE risk event tripping more AUFLS load than it otherwise would have has not been included due to the low probability of an ACECE risk being the binding risk and also not requiring all of the available AUFLS,
- The value of lost load is $32,700 per MWh, this is based on the value specified in the Code in Q4 of 2004 adjusted for inflation,
- The time to restore one block of AUFLS lost load is 2 hours,
- Any instantaneous reserve shortfall will trip the first block of AUFLS,
- The transition to the four block AUFLS scheme in the North Island is complete,
- The first AUFLS block size is exactly 10% of load in the North Island and 16% of load in the South Island, and
- Cable discharge and events requiring instantaneous reserve (CE or ECE) are independent.

3.2 Cable discharge risk period statistics

Five years' of HVDC cable discharge data (2019-2023) was analysed at one minute resolution to determine the probability of cable discharge risk periods occurring at any given minute. Figure 3 below details some key results from that study:

Total	2019	2020	2021	2022	2023	Average
Minutes of risk	*1397*	*1451*	*1968*	*2196*	*1421*	*1687*
Probability of reverse sharing restriction (%)	*0.266%*	*0.276%*	*0.374%*	*0.418%*	*0.27%*	*0.32%*
Average shortfall in reserve sharing (MW)	*88.3*	*87.7*	*88.9*	*90.2*	*92.9*	*89.6*

South flow	2019	2020	2021	2022	2023	Average
Minutes of risk to North Island	*105*	*161*	*410*	*415*	*286*	*275*
Probability of reverse sharing restriction (%)	*0.02%*	*0.0306%*	*0.078%*	*0.079%*	*0.0544%*	*0.0524%*
Average shortfall in reserve sharing (MW)	*93.3*	*84.3*	*90.3*	*93.3*	*95.7*	*91.4*

North flow	2019	2020	2021	2022	2023	Average
Minutes of risk to South Island:	*1292*	*1290*	*1558*	*1781*	*1135*	*1411*
Probability of reverse sharing restriction (%)	*0.246%*	*0.245%*	*0.296%*	*0.339%*	*0.216%*	*0.2685%*
Average shortfall in reserve sharing (MW)	*87.9*	*88.2*	*88.5*	*89.5*	*92.2*	*89.2*

Figure 3 – Summary of cable discharge data from 2019 - 2023

3.3 Cost assessment of cable discharge modelling

The cost of modelling cable discharge in SPD is the additional cost of procuring extra reserves on the HVDC sending island (compared to procuring on the HVDC receiving island) to cover the shortfall in reverse reserve sharing capability during the five-minute discharge period.

Currently SPD restricts instantaneous reserve sharing during all instances of HVDC cable discharge, this can result in dispatch reserve price spikes if instantaneous reserves were cheaper on the receiving island and being shared to the sending island. These price spikes are visible through the Electricity Authority's website from November 2022 onwards, when real time pricing was introduced to the New Zealand power system.

For this study, periods of cable discharge during 2023 were cross referenced with FIR dispatch reserve price spikes to identify instances of SPD impacting prices. The weighted FIR price for the trading period was recorded and a theoretical price was calculated assuming the price spike had not occurred, the difference in these prices is the impact of restricting reserve sharing during all cable discharges in SPD.

For each affected trading period, the cleared FIR was multiplied with the difference between the real and theoretical FIR prices, giving the current cost of modelling all cable discharge periods in SPD. The results are as follows with further data available in Appendix A.

- **Annual cost of modelling all cable discharge periods in SPD (current approach): $30,500.**
  In 2023, 4% of all cable discharge periods impacted the price of instantaneous reserves, this percentage was then applied to the number of cable discharge risk periods to determine the cost of only modelling cable discharge periods identified as risk periods:

- **Annual cost of only modelling cable discharge risk periods in SPD: $5,600.** These values are subject to sensitivities in the market offers, availability and frequency of HVDC cable discharges.

3.4 Cost assessment of not modelling cable discharge

The cost of not modelling cable discharge in SPD is the cost and risk of tripping an AUFLS block in either the North Island or South Island depending on the direction of HVDC dispatch at the time for the ACCE risk that would otherwise not trip an AUFLS block.

These costs were calculated using the AUFLS lost load cost. Based on the assumptions and statistics above, the cost of tripping the first AUFLS block in each island is as follows with further data available in Appendix B.

- Cost (lost load) of tripping the first AUFLS block in the North Island: $18,500,000,
- Cost (lost load) of tripping the first AUFLS block in the South Island: $13,400,000.

When the probability of instantaneous reserve sharing being restricted is factored in, the cost per significant event is as follows:

- Cost in the North Island of not modelling cable discharge in SPD: $9,700,
- Cost in the South Island of not modelling cable discharge in SPD: $35,900.

Note, these costs are 'per significant event'. Depending on the frequency of these events the annual cost could be higher.

Our analysis considers the direct economic value of load shedding due to AUFLS. There are other costs associated with AUFLS events, including reputational and loss of confidence in New Zealand's power system for consumers and investors. These more qualitative costs are not considered here but are significant considerations.

4 Recommendation

Based on the analysis, the cost of modelling cable discharge in SPD ($5,600 or $30,500 per year depending on SPD implementation) is comparable with the cost of not modelling cable discharge in SPD ($9,700 in the North Island and $35,900 in the South Island per significant event). From these figures, the cost of modelling or not modelling cable discharge in SPD are comparable while offering different security outcomes for the New Zealand power system.

This report recommends maintaining the existing approach of modelling the FIR sharing capability limitations during HVDC cable discharge.

There is potential to improve the SPD modelling approach to restrict sharing of instantaneous reserves only during HVDC cable discharge risk periods. This would provide an annual cost saving of $25,000 which will be costed against an internal review of the feasibility and related project costs of updating SPD.

Appendix 1: COST CALCULATIONS OF SPD MODELLING METHODS

2023	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	
Occurences of cable discharge	193	249	128	87	52	21	280	220	264	58	97	241	1892	
Cable discharge risk periods	29	46	19	10	8	5	56	47	40	22	17	51	350	
Occurences of limiting reserve sharing	10	7	2	0	1	0	20	8	9	2	3	13	75	
Annual cost of limiting reserve sharing	$ 4,950	$ 3,100	$ 1,272	$ -	$ 307	$ -	$ 5,529	$ 3,871	$ 4,000	$ 6,184	$ 4	$ 1,316	$ 30,533	*

** This is the current cost with SPD limiting sharing during every cable discharge*

Results		
Percentage of cable discharges that qualify as a cable discharge risk period	4%	
Average cost of limiting reserve sharing	$ 407	
Annual cost of only limiting reserve sharing during cable discharge risk periods	**$ 5,648**	**

*** This is the cost of limiting sharing during every cable discharge risk period*

Appendix 2: COST CALCULATIONS OF NOT MODELLING IN SPD

North Island Risk (Bipole South Flow)

Inputs		Winter 2027	Notes
Minutes per year		*525,600*	
Minutes reverse reserve sharing is limited per year		*275*	
Probability of at least 90 MW shortfall in reserve sharing		*55%*	
NI load		*2824*	*Half peak load*
Size of 1 block of AUFLS		*10%*	*assume transition complete*
AC IR events considered		*1*	
Cost of lost load	*$*	*32,700*	*per MWh*
Hours to restore 1 block of AUFLS		*2*	

Probability of reserve sharing being limited

Minutes per year	*525,600*
Minutes reverse reserve sharing is limited per year	*275*
Probability at any given minute of reserve sharing being limited by cable discharge	**0.0524%**

Cost of tripping 1 block of AUFLS

NI load		*2824*	
Size of 1 block of AUFLS		*10%*	
MW of lost load		*282*	
Hours to restore 1 block of AUFLS		*2*	
MW Hours of lost load		*565*	
Cost of lost load	*$*	*32,700*	*per MWh*
Cost in dollars of lost load	**$**	**18,468,960**	

Cost to model cable discharge as an ECE risk

Probabilty of reverse sharing restriction resulting in AUFLS trip		*0.052%*
Cost in dollars of lost load	*$*	*18,468,960*
Cost per significant event of not limiting reserve sharing during cable discharge risk periods	**$**	**9,677**

South Island Risk (Bipole North Flow)

Inputs		Winter 2027	Notes
Minutes per year		*525,600*	
Minutes reverse reserve sharing is limited per year		*1,411*	
Probability of at least 90 MW shortfall in reserve sharing		*46%*	
SI load		*1278*	*Half peak load*
Size of 1 block of AUFLS		*16%*	
AC IR events considered		*1*	
Cost of lost load	*$*	*32,700*	*per MWh*
Hours to restore 1 block of AUFLS		*2*	

Probability of reserve sharing being limited	
Minutes per year	*525,600*
Minutes reverse reserve sharing is limited per year	*1,411*
Probability at any given minute of reserve sharing being limited by cable discharge	**0.268%**

Cost of tripping 1 block of AUFLS			
SI load		*1278*	
Size of 1 block of AUFLS		*16%*	
MW of lost load		*204.48*	
Hours to restore 1 block of AUFLS		*2*	
MW Hours of lost load		*408.96*	
Cost of lost load	*$*	*32,700*	*per MWh*
Cost in dollars of lost load	**$**	**13,372,992**	

Cost to model cable discharge as an ECE risk		
Probabilty of reverse sharing restriction resulting in AUFLS trip		*0.268%*
Cost in dollars of lost load	*$*	*13,372,992*
Cost per significant event of not limiting reserve sharing during cable discharge risk periods	**$**	**35,906**

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