SA ENERGY TRANSFORMATION RIT-T

Network Technical Assumptions Report

13 FEBRUARY 2019

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Revision Record

Date	Version	Description	Author	Checked By	Approved By
13 February 2019	1.0	Issued with PACR	Vinod Dayal	Brad Harrison	Hugo Klingenberg

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Glossary of Terms

Term	Description
RoCoF	Rate of Change of Frequency
ISP	AEMO's Integrated System Plan
SPS	System Protection Scheme
RIT-T	Regulatory Investment Test for Transmission
SVC	Static Var Compensator
NEM	National Electricity Market
NEFR	National Electricity Forecast Report
NTNDP	National Transmission Network Development Plan
HVDC	High Voltage Direct Current
HVAC	High Voltage Alternating Current
VSC	Voltage Source Converter
PACR	Project Assessment Completion Report
PST	Phase Shifting Transformer

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1.   Introduction

The South Australian Energy Transformation (SAET) Regulatory Investment Test for Transmission (RIT-T) process involves undertaking a cost benefit assessment of various options that can meet the identified need, including both new interconnectors between South Australia and other states in the NEM as well as a non-interconnector option.

Detailed market modelling is required to assess the market benefits of the various options over a range of possible future scenarios. The scenarios considered for the assessment is shown below.

High Scenario	Central Scenario	Low Scenario
Intended to represent the upper end of the potential range of realistic net benefits from the options	Reflects the best estimate of the evolution of the market going forward, and is aligned with AEMO's 2018 ISP neutral scenario	Intended to represent the lower end of the potential range of realistic net benefits associated with the various options

A number of technical and design assumptions are made regarding the technical parameters and network and system constraints that needs to be represented for each option.

This overview document has been prepared to set out these assumptions and to demonstrate that they are well considered, transparent and easy to understand. Applying the assumptions contained in this document enables consistency across studies.

This document presents the assumptions used in technical studies to derive the scope of each option and constraints for economic modelling. The document also describes the constraints and key parameters of those constraints that were used in the economic modelling conducted as part of the RIT-T. The major SAET RIT-T system limitations being examined in the economic modelling are:

- System Strength limitations identified by AEMO in the 2016 National Transmission Network Development Plan (NTNDP) as a result of significant penetration of non-synchronous generation in SA, leading to a confirmed forecast 'Network Support and Control Ancillary Services (NSCAS) Gap' in South Australia' in September 2017 and updated in March 2018.

- Rate of change of frequency (RoCoF) constraints to limit RoCoF to at or below 3 Hz per second in South Australia to prevent the loss of synchronism with the NEM, as required by the South Australian government[1].

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[1]   South Australia Government Gazette dated 12 October 2016

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- Transient and Voltage stability limits for the non-credible loss of Heywood interconnector or the new interconnector (where applicable), particularly at times of high utilisation.

Items covered in this document include:

- System strength requirements and benefits calculations.

- Assumed levels of acceptable load shedding and generation support for the System Protection Scheme (SPS).

- Requirements for combined interconnector transfer limits.

- Generator projects included in technical studies that are not yet operational.

- Network Option description along with transmission line parameters.

1.1 SAET Technical study basis

The SAET technical studies are premised on a design that for a loss of the Heywood Interconnector[2] (Heywood) representing a non-credible contingency[3], the South Australian system will remain in a secure operating state. Load or generation shedding is allowed to manage non-credible contingencies under the NER.

The technical assessment takes a pragmatic approach on the quantum of load shedding and tries to minimise the amount of generation or load shedding, to ensure consequential issues such as high system voltages do not jeopardize the security of the system. For all new interconnector options, the premise is that for a non-credible loss of either existing or new interconnector, the remaining interconnector will continue to operate with the South Australian power system in a secure state, with reasonable load or generation shedding.

With HVAC interconnections, frequency change will not be expected as it is connected to the larger NEM power system and therefore SPS with alternative triggering mechanisms will be used to trigger the response.

The circumstances under which a new or existing interconnector are lost is assumed to be starting from a secure operating state. That is, the loss of an interconnector is assumed not to be preceded by any other event.

1.2 Assessment Methodology

The technical assessment of each option considered is based on two stages of study.

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[2] South Australian Energy Transformation (SAET) RIT-T Project Specification Consultation Report (PSCR)

[3] A contingency event is an event that affects the power system in a way which would likely to involve the failure or sudden and unexpected removal from operational service of a generating unit or transmission element

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In the first stage, credible contingencies were assessed and required reactive plant to achieve the nominal transfer capacity of each option was determined.

In the second stage, non-credible contingencies of interconnectors into SA are considered, and a SPS that can shed no more than a maximum predefined threshold of load or generation along with injections from batteries is incorporated into the studies.

These studies have been undertaken using PSS/E software. Transient and Voltage stability was assessed for the options for both single credible contingencies and also for non-credible loss of either interconnector.

As described above, an identified level of maximum load or generation shedding and support from operational BESS was included to understand the implications of the above events. Where required, additional reactive power plant was included to manage voltage stability related issues. The intention being to limit the transfer capability by transient and not voltage stability, as voltage stability can be easily alleviated by adding low cost reactive plant.

1.3   Overview of Options considered for the PACR

The economic models consider all thermal network limits (as applied by ElectraNet) and many dynamic limits. At any point in time, the model will determine transfer limits across various interfaces based on the system configuration including generation dispatch, loads and network topology. Hence, in the models (and in practice) the limits on either Heywood or a new interconnector options will vary dynamically.

Table 1 identifies the notional maximum capability of interconnectors – both the Heywood interconnector and a new interconnector (for different options) – in the economic modelling for the PACR.

These values should be used as a guide on the maximum possible power transfer capability of the interconnector under favourable operating conditions.

Table 1 : Notional individual interconnector thermal limits with and without upgrades

Option	Notional Maximum Capability (MW)	
	Heywood[4]	New Interconnector
Base case	650	-
Option A: non-interconnector	650	-
Option B: Davenport-Western Downs HVDC	750	700

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[4]   Increase of the notional capacity of the Heywood interconnector to 750 MW is due to improvement to existing stability limits with the parallel interconnectors in place. This capability will not always be achievable.

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Option	Notional Maximum Capability (MW)	
	Heywood[4]	New Interconnector
Option C.3: 330 kV line from Robertstown SA to Wagga Wagga NSW, via Buronga	750	800
Option C.3ii: 330 kV from Robertstown SA to Wagga via Northern Victoria	750	800
Option C.3iii: Multi-Terminal HVDC link from Robertstown SA to Wagga with mid terminal at Buronga	750	800
Option D: 275 kV line from central SA to Victoria	750	650

2.   Base case

This section describes the base case assumptions for a range of key system security considerations.

2.1   System strength

AEMO identified a NSCAS Gap for system strength in the SA region.[5] [6] AEMO has declared a fault level short fall of 620 MVA at Davenport.[7]

AEMC Rule changes for "Managing power system fault levels"[8] have been assumed, in the SAET RIT-T modelling, to extend the timeframe of the NSCAS Gap.

On 29 June 2018, AEMO published the required minimum three phase fault levels at three *fault level nodes* for South Australia (collectively representing system strength requirements) and concluded that a fault level shortfall currently exists in South Australia at Para and Robertstown in addition to Davenport[9].

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[5]   AEMO, *Second update to the 2016 NTNDP*, 2017

[6]   AEMO, *Update to the 2016 NTNDP*, 2017

[7]   AEMO, *NSCAS Gap for System Strength Services in South Australia*, 2017

[8]   AEMC, *Managing power system fault levels*, 2017

[9]   AEMO, *System Strength Requirements Methodology – System Strength Requirements & Fault Level Shortfalls*, 29 June 2018. Available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Requirements_Methodology_PUBLISHED.pdf.

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For the purposes of the SAET RIT-T assessment the following solution was assumed to provide sufficient system strength in South Australia to meet the identified NSCAS Gap:

- Two synchronous condensers located at Davenport each rated at 100 MVA and providing inertia of 650 MWs each. To fully meet the system strength gap, it was further assumed that two large synchronous generators to be online in South Australia in the base case[10]. For this technical assessment, it was assumed that a minimum of two TIPS-B units are operational at all times at its technical minimum output of 40 MW each. For higher demand conditions, other synchronous generators will be dispatched as required.

- On the basis of the above, the total minimum physical inertia in the South Australian system in the base case will be 3100 MWs.

- Non-synchronous generator dispatch will be limited in the base case to the high non-synchronous generator cap, as described in sections 2.1.1 and 2.1.2.

The system strength requirement will be represented in the market modelling with a constraint to represent the high non-synchronous cap based on AEMO's advice [11].

2.1.1 Non-synchronous generator cap

The 'non-synchronous cap' will limit non-synchronous generation. AEMO identified "high non-synchronous penetration levels" as driving weak system strength[12]. For number of synchronous generators online below a certain threshold, a 1295 MW cap will apply, as at the time the study was initiated. Beyond that threshold, the non-synchronous cap is set at (1870 – Vic to SA transfer) MW of non-synchronous generation.

2.1.2 Non-synchronous cap formulation

On the assumption that the 1295 MW cap threshold is met with the synchronous condensers and synchronous plant in the base case, the formulation of the non-synchronous cap in the economic models is as follows:

$$\sum_N G_n \leq 1870 - (Vic\ to\ SA\ flow)$$

Equation 1: non-synchronous cap.

Where N is the set of non-synchronous generators in SA

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[10] ElectraNet is addressing the declared system strength gap outside of this RIT-T process. Since the SAET RIT-T technical assessment ElectraNet has recommended to AEMO that the installation of four large synchronous condensers will meet the system strength gap. The proposed system strength solution will enable the South Australian power system to be operated without directing synchronous generators on for system strength purposes.

[11] Transfer Limit Advice – South Australia System Strength – March 2018

[12] AEMO, *Update to the 2016 NTNDP*, 2017

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G_n is the Generation dispatched from non-synchronous generators in MW.

The above constraint will be applied consistently across the base case in all considered scenarios capturing a range of key system security considerations and appropriately removed for new interconnector options.

2.2   Rate of Change of Frequency

The loss of synchronism and separation from the eastern seaboard – referred to as 'Islanding' requires South Australia to source inertia to manage RoCoF from within South Australia in the event of a loss of the Heywood Interconnector (Heywood).

The South Australian government has required that RoCoF under the loss of Heywood does not exceed 3 Hz/s. Flows on Heywood are managed to ensure that, in the event of a non-credible loss of Heywood interconnector, the RoCoF level will not exceed this threshold. The amount of inertia provided by conventional generators online effectively determines the limits on flows on Heywood.

Future limits on inertia in South Australia could be more onerous than exist today. The 'High' scenario modelled in the Project Assessment Draft Report tested a 1 Hz/s RoCoF limit. For the Project Assessment Conclusions Report (PACR) the less onerous 3 Hz/s RoCoF limit has been included. A level of 1 Hz/s is currently required by AEMO during outages of elements of the existing interconnector (i.e. when the likelihood of islanding is greater than normal) and are applied internationally. For example, Ireland is a jurisdiction that is matching South Australia on many metrics for the installation of non-synchronous generators and uses 1 Hz/s RoCoF limit.

The equation governing the trade-off between the size of the contingency (ΔP which becomes the limit on flows on Heywood), inertia from generators (γ_i in Table 3) provided by online generators where G_i is on/off status) and the inertia provided by the isolated power system (H_{Enet}) is shown in the equation below.

$$\frac{f_0}{2\,RoCoF}\Delta P - \sum_I \gamma\,G_i \leq H_{Enet}$$

Equation 2: Rate of change of frequency for loss of Heywood interconnector

Table 2 below identifies the contribution of existing generators in South Australia to inertia when online.

As two synchronous condensers are assumed in the base case to assist with the NSCAS gap, the inertia of these synchronous condensers needs to be offset in the above equation. Based on the assumed synchronous condensers 1,300 MWs will be used as an offset to the above equation. In addition, the minimum synchronous generation contribution of 1800 MWs and the contribution from Hornsdale and Dalrymple batteries of a further 380 MWs of equivalent inertia via

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Fast Frequency Response was considered in the base case. This amounts to 3480 MWs of <u>minimum</u> system inertia available at all times.

Table 3 identifies assumed contributions of new entrant generators to inertia or synchronous condensers.

Table 2: Existing generator contributions to inertia

Generator (G_i)	Inertia (MW.s) [γ from Equation 2 above]
Torrens Island B1-B4	900
Torrens Island A1-A2	795
Pelican Point (all units)	4,769
Osborne (all units)	1,512
Quarantine 1-4	89
Quarantine 5	1,030
Dry Creek 1-3	526
Hallett (all units)	598

Table 3: New generator or network contributions to inertia constraint

Generator / Network augmentation	Inertia (MW.s)
Base case (2*synchronous condensers)	1300
Pumped Hydro[13]	~ 1000
Solar thermal[14]	~ 500
Each additional synchronous condenser	650
100 MW Battery (assumed response time 250 ms)	380

The inertia contribution from pumped hydro is available at all times. The contribution from solar thermal plant occurs only when generating.

The effectiveness of synthetic inertia from batteries was described in detail in the Supplementary Information Paper. For the purposes of the economic models, the batteries are assumed to be at half load and provide half the capacity to support imports and half to provide exports.

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[13] Submission to the SAET RIT-T

[14] Submission to the SAET RIT-T

2.2.1 Base case inertia summary

Generator / Network augmentation	Minimum System Inertia (MW.s)
Base case (2*synchronous condenser)	1300
Base case (FFR from BESS)	380
Minimum conventional plant inertia based on 2 x TIPS B units (this will vary depending on dispatch)	1800
Total	**3480**

2.2.2 Option A inertia summary

Table below includes relevant Option A assumptions.

Generator / Network augmentation	Minimum System Inertia (MW.s)
300 MW Battery (assumed response time 250 ms)	1,140
Pumped Hydro	1,000
Solar Thermal	500
Base case (2*synchronous condenser)	1300
Base case (FFR from BESS)	380
Total	**4320**

2.2.3 AC links and RoCoF requirements

For the SAET studies, the new AC interconnection is assumed to be engineered and operated to withstand the non-credible loss of Heywood (no islanding of South Australian system), therefore the RoCoF constraint is removed for all new AC interconnector options.

2.2.4 HVDC links and RoCoF requirements

It is assumed that HVDC VSC based interconnector can be configured to provide both fast frequency response (FFR) and system strength (up to its rating) to cover the loss of the Heywood Interconnector. This allows HVDC options to be studied on a consistent basis with the AC interconnector options when calculating benefits, but it is acknowledged this assumption will need to be further verified.[15]

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[15] There will be a requirement for inertia in South Australia in the event of the loss of the Heywood interconnector to operate as an island. See section 2.4.

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Specifically, HVDC response to frequency changes are noted as being a mature application[16], but the exact nature of the FFR response (ramp up/ramp down, or a dynamic response such as the Basslink Frequency Controller) and final level of contribution to inertia in the SA system will only be specified if any HVDC option becomes the preferred option.

2.3   Frequency Control Ancillary Services

For South Australia to survive a non-credible loss of the Heywood interconnector, sufficient FCAS must be sourced from within South Australia to firstly assist in managing the contingency and then to continue providing FCAS regulation and contingency services to manage and enable islanded operation of the South Australian power system.

The following generators are registered FCAS providers:

- Pelican Point

- Torrens Island A

- Torrens Island B

- Osborne

- Quarantine 5

- Hornsdale wind farm and battery

2.4   Inertia

On 19 September 2017 AEMC finalised the Rule Change 'Managing rate of change of power system frequency. This Rule requires AEMO to

- nominate sub-networks of the NEM that must be able to operate independently as an island,

- determine the minimum required levels of inertia and

- assess whether a shortfall exists.

If a shortfall exists, a Transmission Network Service Provider (TNSP) must make available a minimum level of inertia as determined by AEMO. TNSPs can either invest in inertia, FFR or contract with third parties for the provision of these services.

At the time of this technical assessment, AEMO had not declared an inertia shortfall. In the 2018 NTNDP, published on 22 December 2018, AEMO declared an inertia shortfall in South Australia[17].

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[16]   See http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf

[17]   See http://www.aemo.com.au//media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2018/2018-NTNDP.pdf

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ElectraNet will address this declared inertia shortfall outside of this RIT-T. This requirement is only applicable when South Australia is at a credible risk of islanding, or islanded already. As such, this new requirement is not expected to affect interconnector operation at other times.

3. Transient stability limits

As per the study basis identified in section 1.1, non-credible contingencies of both Heywood and new interconnector were considered as part of the system security assessments, as transient stability becomes the limiting factor in maintaining system security. This dictates the limit of power transferred across both interconnectors, with load shedding relief as discussed in the next section.

3.1 Load and Generation shedding assumptions

Load or Generation shedding is an action that can assist in ensuring the South Australian power system remains in a stable condition following non-credible contingencies that pose the risk of overloading, system insecurity and possible separation from the NEM. One of the identified needs required of the SAET is to reduce the risk of a system black condition.

While the Rules allow up to 60% of operational demand to be shed for non-credible contingency events, a more pragmatic approach is adopted for the amount of load-shedding action that is triggered during such events, in order to ensure that the security of the system with other consequential risks such as over voltages is not jeopardized.

Excessive amounts of load-shedding can itself lead to power and voltage swings in turn leading to cascading failures, particularly under low system strength conditions.

A limit of 400 MW of post-contingent load -shedding has been set as the upper limit for the SPS, which is about 15% of peak demand and about 30% of average demand in South Australia and has been assessed as a manageable amount of load shedding, to avoid risks associated with excessive load shedding.

Though it may be a challenge for an SPS to always have 400 MW of loads available to trip due to declining load profiles, the larger amount of load shedding is required during very high import which in turn is associated with higher demand periods. This assumption dictates the combined import capability of the Heywood and new interconnector.

It has also been assumed that as well as load-shedding, triggering a high-speed MW response from grid-scale batteries can be utilised. It is assumed that 100 MW response from the operational Hornsdale and Dalrymple battery is available, providing an additional relief of 100 MW. For HVDC options it is assumed that fast injection from the HVDC link can be used to offset some or all load shedding.

Up to 500 MW of generation trip is assumed to be triggered for loss of interconnector under high SA export conditions.

The SPS scheme for both import and export conditions will be triggered by detecting changes to network topology or equivalent detection methods.

3.2 Combined Interconnector Limits

The following sections describe the combined limits that are imposed to manage transient stability limits across Heywood and the new interconnector.

Murraylink, as a HVDC interconnector, is not considered to influence the management of the non-credible transient stability limit.[18]

3.2.1 Combined limits for AC interconnector options

As noted before, the premise of the combined interconnector transfer limit is the ability to securely survive the non-credible loss of either interconnector, with the remaining interconnector remaining intact and connected to the NEM.

Transient stability for a loss of the existing Heywood interconnector sets the limit on imports into SA, due to the relatively high transfer impedance of the new AC interconnector flow paths. As discussed in the previous section, rapid load shedding and battery injection will be initiated with a SPS and the maximum acceptable post-event transfer will determine the overall combined transfer limits. Therefore, the maximum combined transfer capacity of all AC interconnectors will be set on the maximum allowable amount of post-contingent action to maintain transient stability on the Heywood interconnector, and vice versa.

For the existing Heywood Interconnector, transient stability limits for flows into SA currently require post contingent flow to be maintained at or below approximately 950 MW[19]. This still remains the case when considering the loss of any new interconnector.

The maximum transfer capability in MW of any new interconnector will be limited by the transient stability limit for loss of the Heywood interconnector, and amount of post -contingency event action available. The exception to this is the 500 kV and HVDC (Queensland and NSW) options, where loss of the new interconnector becomes the limiting contingency, as the existing interconnector will have a lower transfer capacity for such an event.

3.2.2 Combined transfer limits

Studies are showing that for a loss of the Heywood Interconnector, transient stability limits are generally lower than the 950 MW Heywood transient limit. As this limit depends on the interconnector impedances, it is different for the various options. As noted previously, there are some exceptions where the Heywood transfer capacity of 950 MW becomes the limiting factor. Results from studies are summarised in Table 4.

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[18] Murraylink has not been considered as a solution to this transient stability issue due to uncertainties in the headroom available to increase flow by (e.g. capabilities of network to which it is connected).

[19] ElectraNet, *Network studies*, 2017

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400 MW load-shedding and 100 MW contribution from battery storage has been assumed for the studies resulting in the interconnector transient limits shown in Table 4.

The total combined import limit (Heywood + new AC option) is set by the amount of allowable load-shedding, battery injection, and transient limits for the new interconnector for loss of the Heywood interconnector, except for the 500 kV and HVDC options.

Similarly, the total combined export limit (Heywood + new AC option) is set by the amount of available generation for tripping, and transient limits for the new interconnector for loss of the Heywood interconnector. Results for combined export limits are presented for 500 MW of non-synchronous generation available for tripping.

Although the HVDC options do not result in any transient stability issues following the (N-2) loss of the Heywood interconnector, Heywood stability limits are still applicable when considering the loss of the HVDC link itself.

HVDC links will be able to respond to the reduction in frequency that would occur following the loss of the Heywood interconnector, and reduce load-shedding requirements by increasing output. This is recognised in determining the transfer capacity for HVDC options.

Table 4 : N-2 transient stability limits

Option	Combined Import limits (MW) (400+ MW load relief)	Combined Export limits (MW) (500 MW Generation trip)
Option B: Davenport to Western Downs HVDC Bipole	1300	1300
Option C.3: Robertstown-Buronga-Darlington Pt 330 kV	1300	1450
Option C.3ii Robertstown-Buronga-Kerang-Darlington Point 330 kV	1300	1450
Option C.3.iii Robertstown-Buronga-Darlington Pt HVDC option	1300	1300
Option D: Tungkillo – Horsham 275 kV	1,100	1,350

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3.3   Summary

- The technical assessment is based on meeting the requirement that, following any non-credible contingency, especially loss of any double circuit interconnector, the remaining interconnector remain operational, i.e. not also trip and island the SA system from the NEM.

- SPS including load shedding will be required for all options (AC, HVDC, non-network) to be able to cater for the non-credible loss of either the Heywood interconnector at high import levels, or any new interconnector itself. Costs for SPS including load shedding will be included in all options.

- The maximum capacity of any new interconnector is set by the maximum allowable amount of post-contingent action (load or generator shedding) required to maintain transient stability on the Heywood interconnector for the loss of the new interconnector.

- Total import (Heywood + new AC Interconnector) is set by the amount of allowable load-shedding, and transient limits on the new interconnector for loss of the Heywood interconnector to not over load the new interconnector and vice versa.

- Total import (Heywood + new HVDC Interconnector) is set by the amount of allowable load-shedding, and short-term thermal limits on the new HVDC interconnector for loss of the Heywood interconnector. However, in this the limitation will be due to loss of HVDC link, as the Heywood Interconnector power transfer will be the limiting factor.

- Total export (Heywood + new AC Interconnectors) is set by the amount of allowable generator-shedding, and transient limits on the new interconnector to allow continued operation of the new interconnector on loss of the Heywood interconnector.

- Total export (Heywood + new HVDC Interconnectors) is set by the amount of allowable generator-shedding, and short term thermal limits on the new interconnector to allow continued operation of the new interconnector on loss of the Heywood interconnector.

- Batteries can be utilised to offset load-shedding, and improve combined interconnector limits.

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4. Projects included as part of the base case technical studies

The following developments have been assumed in the base case for the calculation of network limits in the PACR.

New generation

- SA Government emergency generation
- Lincoln Gap Wind Farm
- Willogoleche Wind Farm
- Barker Inlet reciprocating engines
- Bungala Solar Farm Stage 2

New Batteries

- Hornsdale 100 MW Battery, 129 MWh
- Dalrymple 30 MW Battery, 8 MWh

Retirements

- Liddell (2022)

The following network projects or reconfigurations have been assumed in the base case for the calculation of network limits in the PACR.

- Western Victoria Renewable integration:
  - 2 x 500 kV Sydenham – Ballarat
  - 2 x 500/220 kV transformers at Ballarat
  - 2 x 220 kV Ballarat – Ararat
  - 1 x 220 kV Red Cliffs – Buronga

- 220 kV Buronga – Balranald – Darlington Point to remain intact for all options (possible overloads managed via control schemes)

Note that the assumptions in the technical studies and the economic studies may diverge. The economic studies have examined a broader range of futures than the technical studies.

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5.   Network Option Modelling

Note that all the conductor type used for all the options in the modelling is indicative and it will be optimised during detailed design. Also, the line lengths in this report were used to derive line impedances. The final line lengths may vary due to line route optimisation.

5.1   Option B – Davenport-Western Downs HVDC

Davenport 275 kV   Broken Hill   Western Downs 275 kV
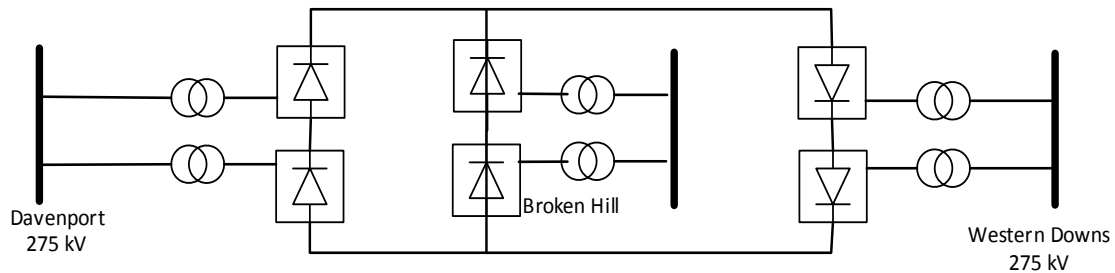
Scope of work
HVDC VSC Bipole converter stations at Davenport, Broken Hill and Western Downs
HVDC line between the three terminals (total distance of 1450 km)
2 x Converter transformers of appropriate voltages for the three HVDC terminals
Substation works at Davenport, Broken Hill and Western Down to connect the HVDC terminals
Turn in the existing Robertstown to Para 275 kV line into Tungkillo
SPS to manage interconnector trip

5.1.1   Updates since the publication of the PADR

Aspect	Description	Reason	Comments
Additional terminal (multi-terminal)	A new HVDC terminal is considered based on PADR feedback	To collect the renewables in the line corridor	Assumed at Broken Hill to capture wind and solar potential
SA Augmentations	Turn Robertstown to Para 275 kV line into Tungkillo	Low cost provide thermal/transient benefits	
Victorian Projects	2 x 500 kV lines between Ballarat and Sydenham
2 x 500/220 kV transformers at Ballarat
2 x 220 kV lines between Ararat and Ballarat	As per ISP	

Aspect	Description	Reason	Comments
Vic-NSW Project	A new double circuit Buronga to Red Cliffs 220 kV line strung on one side	As per ISP	Same line parameters as existing line

5.1.2 Impedances

DC load flow modelling parameters and DC link losses

- Preliminary Loss Model (for 700 MW) with twin sulphur conductors

- No load losses 3.2%,

- Full load losses 10% (varies with load squared), overall average losses ~ 10%

Line parameters for each line (noting there are two lines)

- Rdc – 40 ohm (twin Sulphur,1450 km) – 0.039pu (320 kV, 100 MVA base)

- HVDC line losses will be based on the formula $2 \times Rdc * I^2$

Transformer impedances

- Assumed 10% impedance (500 MVA base), two units at each converter station.

5.1.3 Impact on inter-regional limits

Additional interconnector capacity for SA-VIC, VIC-NSW, NSW-QLD making use of the post contingent controls available with VSC-HVDC.

QNI Voltage Stability and Thermal Limits

ElectraNet expect a 1:1 increase in these limits for the level of power involved in the post contingent action. QNI limits have been offset by 250MW.

The improvement is in addition to the improvements assumed in the base to the Queensland to New South Wales interconnector due to the ISP and the expected development of QNI Option 3 and Option 5 (as per the ISP).[20]

Table 5- Recommended increase to QNI voltage limits due to post contingent action on QSA

Direction	Limit Increase	Required post contingent transfer
South	250 MW	250 MW from QLD to SA
North	250 MW	250 MW from SA to QLD

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[20] Powerlink and Transgrid, Expanding NSW-QLD Transmission Transfer Capacity RIT-T, 2018

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Table 6 - Updated thermal constraints

Contingency	Overload	Max Overload	Min Overload
Armidale - Dumaresq	20070_2ARM_S1_330_21250_2DMQ330A_330_1_CKT	1307 + 250 = 1557	-1406 - 250 = -1656
Armidale - Tamworth	20070_2ARM_S1_330_21770_2TAM330A_330_1_CKT	1002 +250 =1252	-1002- 250 = -1252

5.2 Option C.3 – Robertstown-Buronga-Darlington Point-Wagga 330 kV
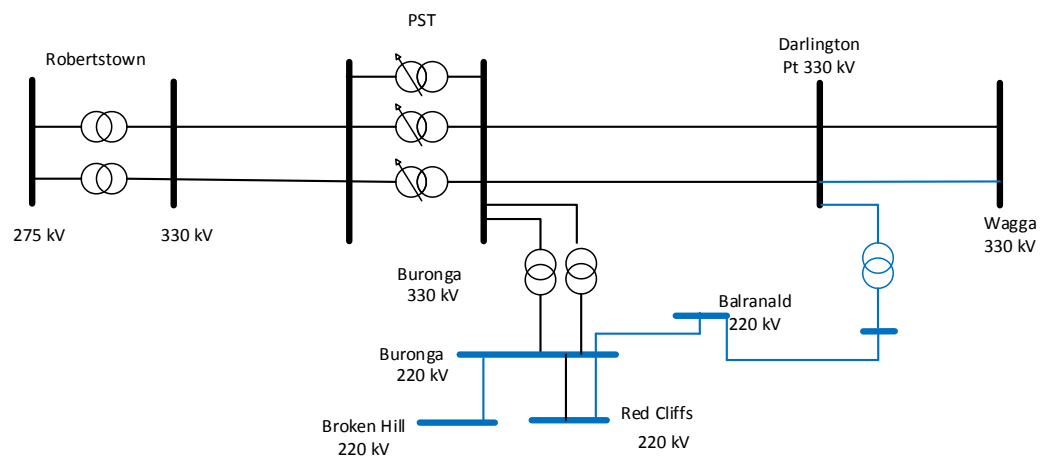
*Existing circuits shown in blue

Scope of work
330 kV double circuit twin Mango conductor transmission line between Robertstown substation in SA and Buronga substation in NSW.
330 kV double circuit twin Mango conductor transmission line between Buronga and Darlington Point.
330 kV single circuit line between Darlington Point and Wagga of same conductor size as existing line
220 kV double circuit line between Buronga in NSW and Red Cliffs in Victoria of same conductor size as existing line, strung on one side
330 kV 3 x 400 MVA new phase shifting transformers on Robertstown – Buronga line at Buronga substation. Rated to ±40 degrees phase shifting and automatic on-load MW control capability.
330 kV switchyard at Robertstown with 2 x 330/275 kV transformers
330 kV switchyard at Buronga substation
Substation works at Wagga to connect the new line
2 x 330/220 kV transformer with 400 MVA capacity at Buronga substation to interface with the existing 220 kV connections to Broken Hill and Red Cliffs substations.
2 x 100 MVAr new synchronous condenser at Buronga 330 kV bus.
Shunt capacitor banks 2x50 MVAr at Buronga 330 kV bus and 2x50 MVAr 330 kV reactors.
2 x 100 MVAr synchronous condenser at Darlington Point 330 kV bus
Shunt capacitor (2 x 50 MVAr) banks and line shunt reactors (2 x 60 MVAr) at Darlington Point
275 kV works at Robertstown substation to connect to the new 330 kV yard
100 MVAr 275 kV shunt capacitor at Robertstown
2 x 60 MVAr 330 kV line shunt reactors at Robertstown
Turn in Existing Robertstown to para 275 kV line into Tungkillo
SPS to manage interconnector trip

5.2.1 Updates since the publication of the PADR

Aspect	Description	Reason	Comments
Preferred option	Use the transmission line parameters for option **C.3**	Series capacitors <u>are removed</u> to avoid risk of connection of new generation and line cut-ins due to potential risks due to SSR/SSCI, but transfer capacity will be retained. Transfer capacity same as the previously series compensated option with some additional load shedding	Twin Mango 330 kV conductors @~1200 MVA per circuit

Aspect	Description	Reason	Comments
SA Augmentations	Turn Robertstown to Para 275 kV line into Tungkillo	Low cost provide thermal/transient benefits	
Victorian Projects	2 x 500 kV lines between Ballarat and Sydenham 2 x 500/220 kV transformers at Ballarat 2 x 220 kV lines between Ararat and Ballarat	As per ISP	
Vic-NSW Project	A new double circuit Buronga to Red Cliffs 220 kV line strung on one side	As per ISP	Same line parameters as existing line

5.2.2 Impedances

All impedance parameters are in pu on 330 kV and 100 MVA base.

<u>Buronga - Robertstown 330 kV double circuit line:</u>

330 kV double-circuit steel tower, twin Mango phase conductor, 340 km

Line Parameters (for each circuit)	pu
Resistance(R)	0.01305
Reactance (X)	0.10950
Susceptance (B)	1.03670
Rating (MVA)	1180

<u>Buronga – Darlington Point 330 kV double circuit line:</u>

330 kV double-circuit steel tower, twin Mango phase conductor, 400 km

Line Parameter (for each circuit)	pu
Resistance (R)	0.01582
Reactance (X)	0.13273
Susceptance (B)	1.25661
Rating (MVA)	1180

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Darlington Point – Wagga 330 kV single circuit line (same as the existing line):

330 kV single-circuit steel tower, twin Mango phase conductor, 152 km

Line Parameters (for each circuit)	pu
Resistance (R)	0.00608
Reactance (X)	0.04678
Susceptance (B)	0.5731
Rating (MVA)	915

Buronga Phase shift transformer (three)
330 kV
10% impedance on 400 MVA base
30 degree phase shift angle

Buronga 330/220 kV tie-transformer
330/220 kV, 400 MVA
10% impedance on 400 MVA base

Robertstown 330/275 kV tie-transformers
330/275 kV, 1000 MVA
10% impedance on 1000 MVA base

Buronga – Red Cliffs 220 kV (double circuit strung on one side):

Line parameters as per existing line

5.2.3 NSW-SA interconnector power transfer capability

The notional maximum power import and export capacity of the interconnector is about 800 MW, which is determined by the N-1 system security requirement in a credible contingency of one of 330 kV lines tripping between Robertstown and Wagga.

Buronga (NSW) - Red Cliffs (Victoria) 220 kV line will be augmented with a double circuit strung on one side of similar conductor and rating to the existing circuit.

5.2.4 Impact on inter-regional limits

Intra-regional issues in NSW do not specifically affect the NSW to Robertstown thermal capability.

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Preliminary view of any significant impacts on other interconnector capability

- The QNI transfer levels are presently limited due to voltage and transient stability requirements, with the critical contingencies being local to the QNI for NSW import and tripping of the largest QLD generator for NSW export. It is unlikely that the present QNI transfer levels are affected by the new NSW-SA interconnector because of the distance and the network impedance involved. NSW-SA interconnector flow may be limited by the NSW-VIC and VIC-SA transfer limits under certain system conditions

- NSW-VIC and VIC-SA transfer is unlikely to be limited due to trip of one circuit of NSW – SA interconnector.

5.3 Option C.3ii – Robertstown-Buronga-Kerang-Darlington Point-Wagga 330 kV
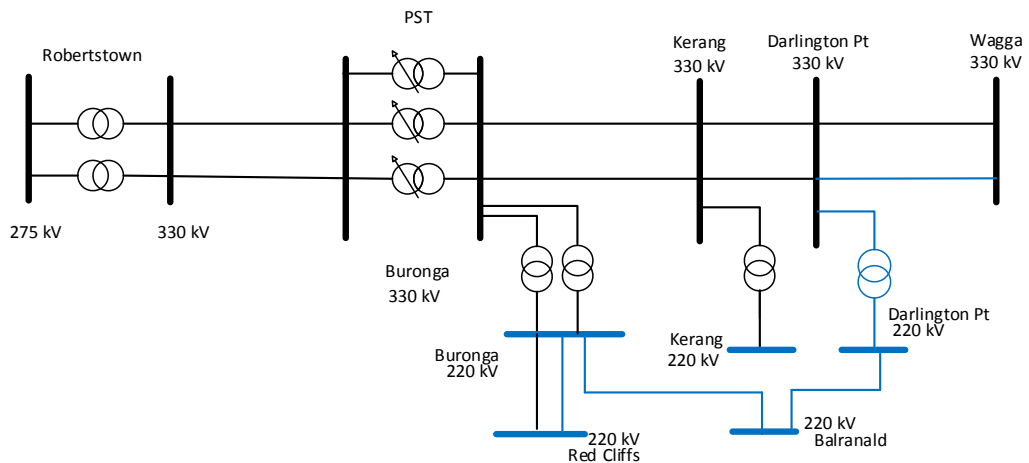
*Existing circuits shown in blue

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Scope of work
330 kV double circuit transmission line with twin Mango conductors between Robertstown substation in SA and Buronga substation in NSW, providing a rating of 1180 MVA per circuit.
330 kV double circuit transmission line with twin Mango conductors between Buronga substation in NSW and Kerang substation in Victoria, providing a rating of 1180 MVA per circuit
330 kV double circuit transmission line with twin Mango conductors between Kerang substation in SA and Darlington Point substation in NSW, providing a rating of 1180 MVA per circuit
Build 330 kV new single circuit 330 kV line between Darlington Point to Wagga
Installation of 330 kV 3 x 400 MVA new phase shifting transformers on Robertstown – Buronga line at Buronga substation. The transformers will have ±40 degrees phase shifting and automatic on-load MW control capability.
Installation of a new 330 kV switchyard at Buronga substation with 2 x 330/220 kV interconnecting transformers with 400 MVA capacity at Buronga substation to interface with the existing 220 kV connections to Broken Hill and Red Cliffs substations
Installation of approx. 2 x 100 MVAr new synchronous condenser at Buronga 330 kV bus.
Installation of shunt capacitor banks of approx. 2x50 MVAr at Buronga 330 kV bus and 2x50 MVAr 330 kV reactors.
Installation of a new 330 kV switchyard at Kerang substation, with a 330/220 kV transformer
Installation of 2 x 100 MVAr synchronous condensers at Kerang
Installation of 100 MVAr shunt capacitor bank at Kerang
New double circuit 220 kV line next to existing Buronga to Red Cliffs single circuit 220 kV line with similar conductors and ratings as existing line
Installation of 2 x 100 MVAr new synchronous condensers at Darlington Point 330 kV bus
Installation of shunt capacitor (2 x 50 MVAr) banks and line shunt reactors (2 x 60 MVAr at Darlington Point
Substation works at Wagga to connect the new line
275 kV works at Robertstown substation to connect to new 330 kV substation
New 330 kV substation at Robertstown with 2 x 275 kV transformers
100 MVAr 330 kV shunt capacitor at Robertstown
2 x 60 MVAr 330 kV line shunt reactors at Robertstown
Turn the existing Robertstown to Para 275 kV line into Tungkillo
SPS to manage interconnector trip

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5.3.1   Updates since the publication of the PADR

Aspect	Description	Reason	Comments
SA Augmentations	Turn Robertstown to Para 275 kV line into Tungkillo	Low cost provide thermal/transient benefits	
Victorian Projects	2 x 500 kV lines between Ballarat and Sydenham 2 x 500/220 kV transformers at Ballarat 2 x 220 kV lines between Ararat and Ballarat	As per ISP	
Vic-NSW Project	A new double circuit Buronga to Red Cliffs 220 kV line strung on one side	As per ISP	Same line parameters as existing line

5.3.2   Impedances

All impedance parameters are in pu on 330 kV and 100 MVA base.

Buronga - Robertstown 330 kV double circuit line:

330 kV double-circuit steel tower, twin Mango phase conductor, 340 km

Line Parameters (for each circuit)	pu
Resistance(R)	0.01305
Reactance (X)	0.10950
Susceptance (B)	1.03670
Rating (MVA)	1180

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Buronga – Kerang 330 kV double circuit line:

330 kV double-circuit steel tower, twin Mango phase conductor 260 km

Line Parameter (for each circuit)	pu
Resistance (R)	00.01021
Reactance (X)	0.08561
Susceptance (B)	0.81051
Rating (MVA)	1180

Kerang – Darlington Point 330 kV double circuit line:

330 kV double-circuit steel tower, twin Mango phase conductor, 240 km

Line Parameter (for each circuit)	pu
Resistance (R)	0.00910
Reactance (X)	0.07632
Susceptance (B)	0.72255
Rating (MVA)	900

Darlington Point – Wagga 330 kV single circuit line (same conductor and design as the existing line):

330 kV single-circuit steel tower, twin Mango phase conductor, 152 km

Line Parameters (for each circuit)	pu
Resistance (R)	0.00608
Reactance (X)	0.04678
Susceptance (B)	0.5731
Rating (MVA)	915

Buronga Phase shift transformer (four items)
330 kV
10% impedance on 400 MVA base
30 degree phase shift angle

Buronga 330/220 kV tie-transformer
330/220 kV, 400 MVA
10% impedance on 400 MVA base

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Red Cliffs 330/220 kV tie-transformer
330/220 kV, 400 MVA
10% impedance on 400 MVA base

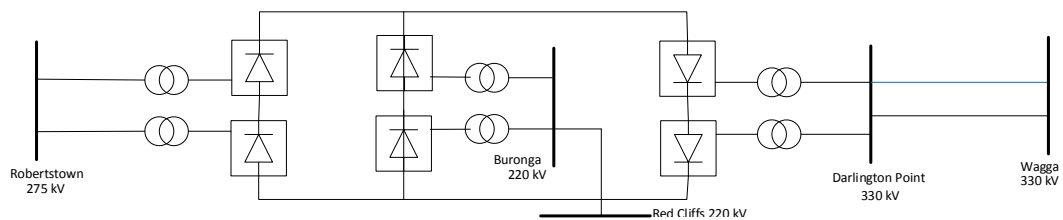| Kerang 330/220 kV tie-transformer |
|---|
| 330/220 kV, 400 MVA |
| 10% impedance on 400 MVA base |

Robertstown 330/275 kV tie-transformers
330/275 kV, 1000 MVA
10% impedance on 1000 MVA base

Buronga – Red Cliffs 220 kV (double circuit strung on one side):

Line parameters as per existing line

5.4   Option C3iii – SA-NSW HVDC

*Existing circuits shown in blue

Scope of work
HVDC VSC Bipole converter stations at Robertstown, Buronga and Darlington Point
HVDC line between the three terminals
2 x Converter transformers of appropriate voltages for the three HVDC terminals
Substation works at Robertstown, Buronga and Darlington Point to connect the HVDC terminals
Turn in the existing Robertstown to Para 275 kV line into Tungkillo
SPS to manage interconnector trip

5.4.1 Updates since the publication of the PADR

Aspect	Description	Reason	Comments
SA Augmentations	Turn Robertstown to Para 275 kV line into Tungkillo	Low cost provide thermal/transient benefits	
Victorian Projects	2 x 500 kV lines between Ballarat and Sydenham 2 x 500/220 kV transformers at Ballarat 2 x 220 kV lines between Ararat and Ballarat	As per ISP	
Vic-NSW Project	A new double circuit Buronga to Red Cliffs 220 kV line strung on one side	As per ISP	Same line parameters as existing line

5.4.2 Impedances

DC load flow modelling parameters and DC link losses

- Preliminary Loss Model (for 700 MW) with twin sulphur conductors

- No load losses 3.2%,

- Full load losses 10% (varies with load squared), overall average losses ~ 10%

Line parameters for each line (noting there are two lines)

- R'Town to Buronga Rdc – 9.2 ohm (twin Sulphur,340 km) – 0.0075pu (350 kV, 100 MVA base)

- Buronga to Darlington Point – 10.53 ohm (twin sulphur 400 km) – 0.0086 pu (350 kV, 100 MVA base)

- HVDC line losses will be based on the formula $2 \times Rdc * I^2$

Transformer impedances

- Assumed 10% impedance (500 MVA base), two units at each end of the link.

AC line parameters

- Darlington Point – Wagga 330 kV single circuit line (same as the existing line): 330 kV single-circuit steel tower, twin Mango, 152 km. Resistance (R) = 0.00608 pu, Reactance (X) = 0.04678 pu, Susceptance (B) = 0.5731 pu, Rating = 915 MVA

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Buronga – Red Cliffs 220 kV (double circuit strung on one side):

- Line parameters as per existing line

5.5   Option D – Tungkillo-Horsham 275 kV
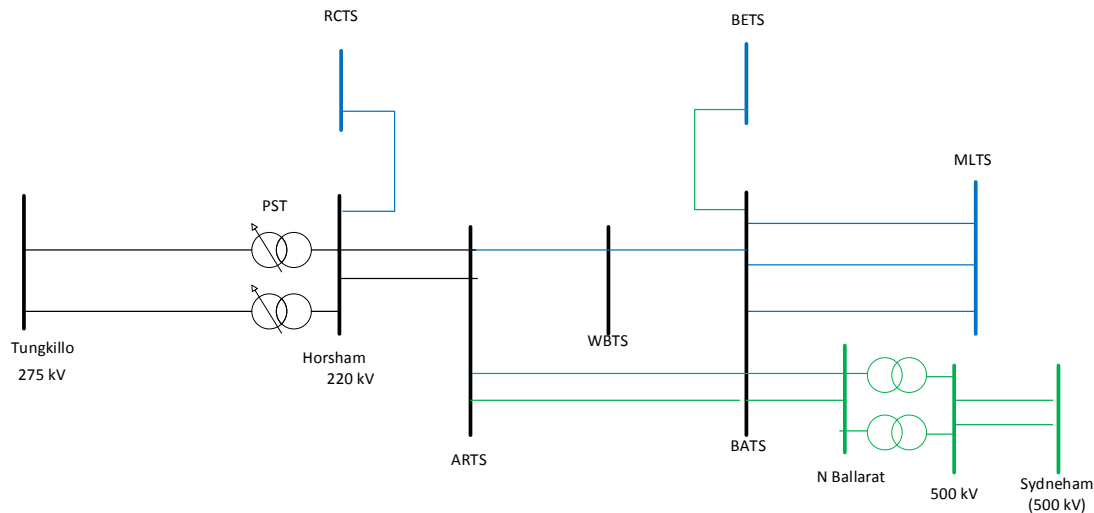
*Existing circuits shown in blue
**Western Victoria RIT-t scope shown in green

Scope of work
275 kV double circuit twin conductor transmission line between Robertstown substation in SA and Horsham in Victoria
Rebuild line between Horsham to Ararat as double circuit line
220 kV double circuit line between Buronga in NSW and Red Cliffs in Victoria of same conductor size as existing line
2 x 275/220 kV Phase shifting transformers at Horsham with phase angle of +/-60 degrees
Substation works at Horsham and Ararat to connect the new lines
2 x 100 MVAr new synchronous condenser at Horsham.
Shunt capacitor banks 2x50 MVAr at Horsham and 2x50 MVAr 275 kV reactors.
275 kV works at Tungkillo substation to connect to the new lines
100 MVAr 275 kV shunt capacitor at Tungkillo
2 x 50 MVAr 275 kV line shunt reactors at Tungkillo
2 x 100 MVAr synchronous condensers at Tailem Bend
Turn in Existing Robertstown to Para 275 kV line into Tungkillo
SPS to manage interconnector trip

5.5.1 Updates since the publication of the PADR

Aspect	Description	Reason	Comments
SA Augmentations	Turn Robertstown to Para 275 kV line into Tungkillo	Low cost provide thermal/transient benefits	
Victorian Projects	2 x 500 kV lines between Ballarat and Sydenham 2 x 500/220 kV transformers at Ballarat 2 x 220 kV lines between Ararat and Ballarat	As per ISP	
Vic-NSW Project	A new double circuit Buronga to Red Cliffs 220 kV line strung on one side	As per ISP	Same line parameters as existing line

5.5.2 Impedances

Transmission Line	Length km	R1	X1	B1	Rating (MVA)
275 kV Heywood to South East*					628
275 kV Tungkillo-Horsham (twin Mango)	412	0.02393	0.20068	0.91627	700
220 kV Horsham – Ararat double circuit	90	0.01522	0.0643	0.18498	290

Victorian intra-regional new transformer parameters

2 x phase shifting transformers at Horsham 275 kV bus

- 700 MVA rating
- ±60° phase angle
- 8% impedance on rating base

5.5.3 ISP assumptions

The following Victorian network augmentations have been assumed in the base case:

- New 500kV double circuit from Sydenham to North Ballarat

- Two new 500/220kV transformers at North Ballarat

- New 220kV double circuit from North Ballarat to Ballarat

- Retires the old single circuit Ballarat-Bendigo 220kV and puts a new single circuit in its place

- New 220kV double circuit from North Ballarat to Ararat.

- Leaves the old Ararat-Waubra-Ballarat 220kV single circuit in-situ.

5.5.4 Impacts on inter-regional limits

The following preliminary views were based on analysis of the AEMO's 2015 constraint report (published June 2016) and recent assessment carried out by AEMO on impact of Horsham link.

Basslink

- Import to Vic transfer is mainly limited in accordance with the constraint equations for the South Morang F2 transformer overload (V>>V_NIL_2A_R and V>>V_NIL_2B_R and V>>V_NIL_2_P) or the transient over-voltage at George Town (T^V_NIL_BL_6).

- Export to Tas transfer is limited by the transient stability limit for a fault and trip of a Hazelwood to South Morang line (V::N_NILxxx and outage cases),

  Horsham link option D is not expected to significantly affect the TAS - Vic transfer limits in either direction.

Vic – NSW

- Import to Vic is mainly limited by voltage collapse in Southern NSW arising from loss of the largest Victorian generator (N^^V_NIL_1), or thermal overload limits on the Murray to Dederang 330 kV lines (V>>V_NIL_1B).

  Option D is not expected to affect the import limit to Vic significantly as it will not significantly improve the above voltage stability and thermal limitations.

- Export to NSW is mainly limited by a number of thermal limitations and transient stability limitation for a fault and trip of a Hazelwood to South Morang line (V::N_NILxxx and outage cases). The thermal limitations which bound frequently in 2015 are:

  − the South Morang F2 transformer (V>>V_NIL_2A_R and V>>V_NIL_2B_R and V>>V_NIL_2_P),

  − the South Morang to Dederang 330 kV line (V>>V_NIL1A_R),

  − the Ballarat to Bendigo 220 kV line (V>>SML_NIL_8), or

  − the Ballarat to Moorabool No.1 220 kV line (V>>SML_NIL_1).

  Option D tends to increase the export limits to NSW:

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- A study indicated that the above transient stability limit will be increased under certain operating conditions.

- the thermal limitations will be relieved with potential augmentations in North West Vic as part of Option D

However, it is expected that the increase in export limits will be quite small due to small changes in the network impedances, insufficient to avoid an increase in the binding hours of the constraint equations associated with the above transient stability and thermal limitations due to increased flow as a result of option D.

Heywood interconnector (V-SA)

- Following the Heywood upgrade, the export to SA is now most often restricted by the transient stability limit for loss of the largest South Australian generator (V::S_NIL_MAXG_xxx).

  Option D may increase the Vic to SA transfer limit, as it tends to improve transient stability by reducing the impedance in the transfer path.

  Option D tends to reduce the binding hours of the constraint equations associated with the transient stability limitation, as it may reduce the transfer levels on Heywood interconnector together with an increase in transient stability limit.

- The import from SA to Vic is mainly restricted by the thermal overload limitation on the South Morang F2 transformer (V>>V_NIL_2A_R and V>>V_NIL_2B_R and V>>V_NIL_2_P). Option D is not expected to significantly affect the SA to Vic transfer limit, as it has no impact on the South Morang F2 transformer thermal limitation. This option may increase the binding hours of these thermal constraint equations as it tends to increase the flow on South Morang F2 transformer.

Murraylink

- Transfers from South Australia to Victoria on Murraylink are limited by thermal limitations on the:

  - Robertstown to Monash 132 kV lines (S>V_NIL_NIL_RBNW) and

  - Dederang to Murray 330 kV lines (V>>V_NIL_1B).

  Option D is not expected to affect the SA to Vic transfer limit on Murraylink, as it has no impact on the above two thermal limitations.

  The binding hours of the Dederang to Murray 330 kV limitation may be increased by Option D, as the flow on the Dederang to Murray 330 kV lines may increase following the implementation of Option D.

- Transfers from Victoria to South Australia on Murraylink are mainly limited by a number of thermal overloads or the voltage collapse limitation for loss of the Darlington Point to Buronga (X5) 220 kV line (V^SML_NSWRB_2).

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The thermal limitations are:

- South Morang F2 transformer (V>>V_NIL_2B_R and V>>V_NIL_2_P).

- Ballarat North to Buangor 66 kV line (V>>SML_NIL_7A).

- South Morang to Dederang 330 kV line (V>>V_NIL1A_R).
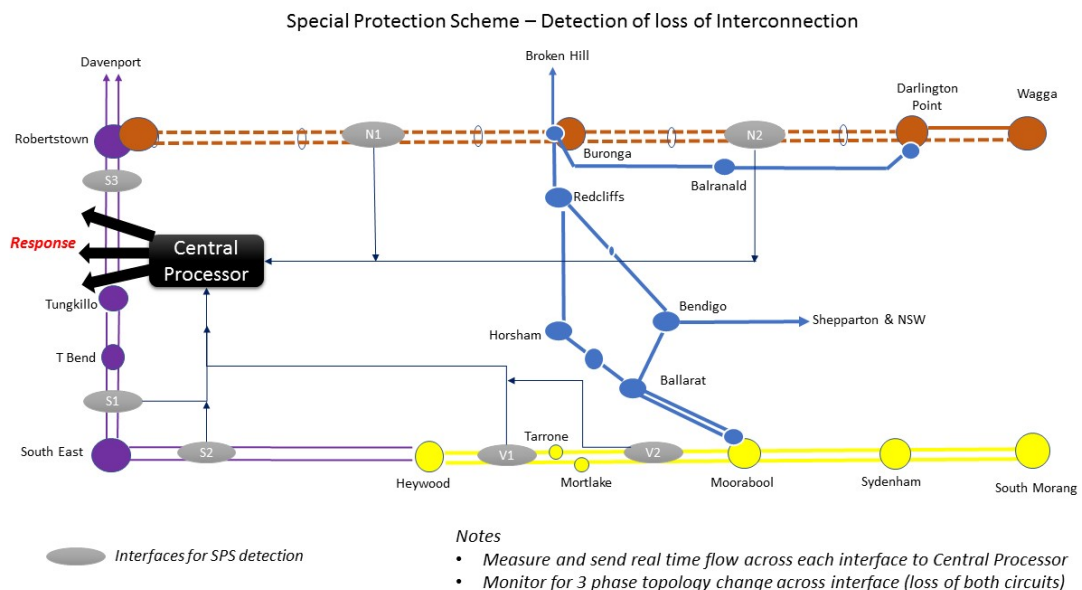
- Ballarat to Bendigo 220 kV line (V>>SML_NIL_8).

Option D may increase the transfer limits from Vic to SA:

- Due to increased thermal transfer limit if potential augmentations in Vic 220kV line go ahead.

- Due to increased voltage collapse limit if new reactive plant is added to the regional Vic area as part of Option D

Option D may increase the binding hours of the constraint equations associated with the thermal and voltage collapse limitations, as the increase in limits may be insufficient to offset the increase in transfer levels.

6. Special Protection Scheme

As noted above, all options require a Special Protection Scheme to provide adequate response to maintain system security following either the non-credible loss of either the existing or new interconnector or a credible contingency following an outage on the interconnector flow path. While importing, the response will be to discharge batteries and perform limited load shedding (~400 MW maximum). While exporting the action will be trip generation in SA. The schematic below illustrates the scheme for option C.3.

Special Protection Scheme – Detection of loss of Interconnection

Notes
- *Measure and send real time flow across each interface to Central Processor*
- *Monitor for 3 phase topology change across interface (loss of both circuits)*

The scheme will require topology based signals along with power flows across each interface to be continuously transmitted to the central processor for real time pre-processing.

When an event occurs, rapid and appropriate response will ensure that the system returns to a new secure state without any risk of cascade tripping of the remaining interconnector. This scheme will utilise the available communication network and dedicated hardware to detect and process the response. It may be noted that for HVDC options, the link will self-manage and the only aspect that needs to be managed is the loss of the HVDC link itself.

It may also be noted that the overview of the scheme is indicative and is subject to change following detailed design.

7.   Base Case assumption changes

Aspect	Description	Reason
To meet the System Strength gap	In addition to two synchronous condensers at Davenport it was assumed that two large synchronous generators will be online in South Australia in the base case	In consultation with AEMO
RoCoF constraint	Assume 100 MW FFR with 250 msec response time from Hornsdale BESS. Equivalent to 380 MWs of physical inertia.	From Hornsdale and Dalrymple BESS

8.   Integrated System Plan

Detailed technical assumptions based on AEMO's ISP can be found in the SAET RIT-T – PACR Modelling assumptions spreadsheet.

Projects assumed in the calculation of network limits are listed in the QNI Augmentations worksheet in the Market Modelling Assumptions Data Book.

For the calculation of market benefits, all group 1 projects have been included in the base case.

The Group 2 project Snowy North has not been included.

Group 3 projects have not been included except where PACR modelling has resulted in transmission augmentation decisions being undertaken by the model. Those decisions have been translated into network augmentations for inclusion in the time sequential modelling. The details of which have been published in the Modelling assumptions spreadsheet and identified as group 3 projects.

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