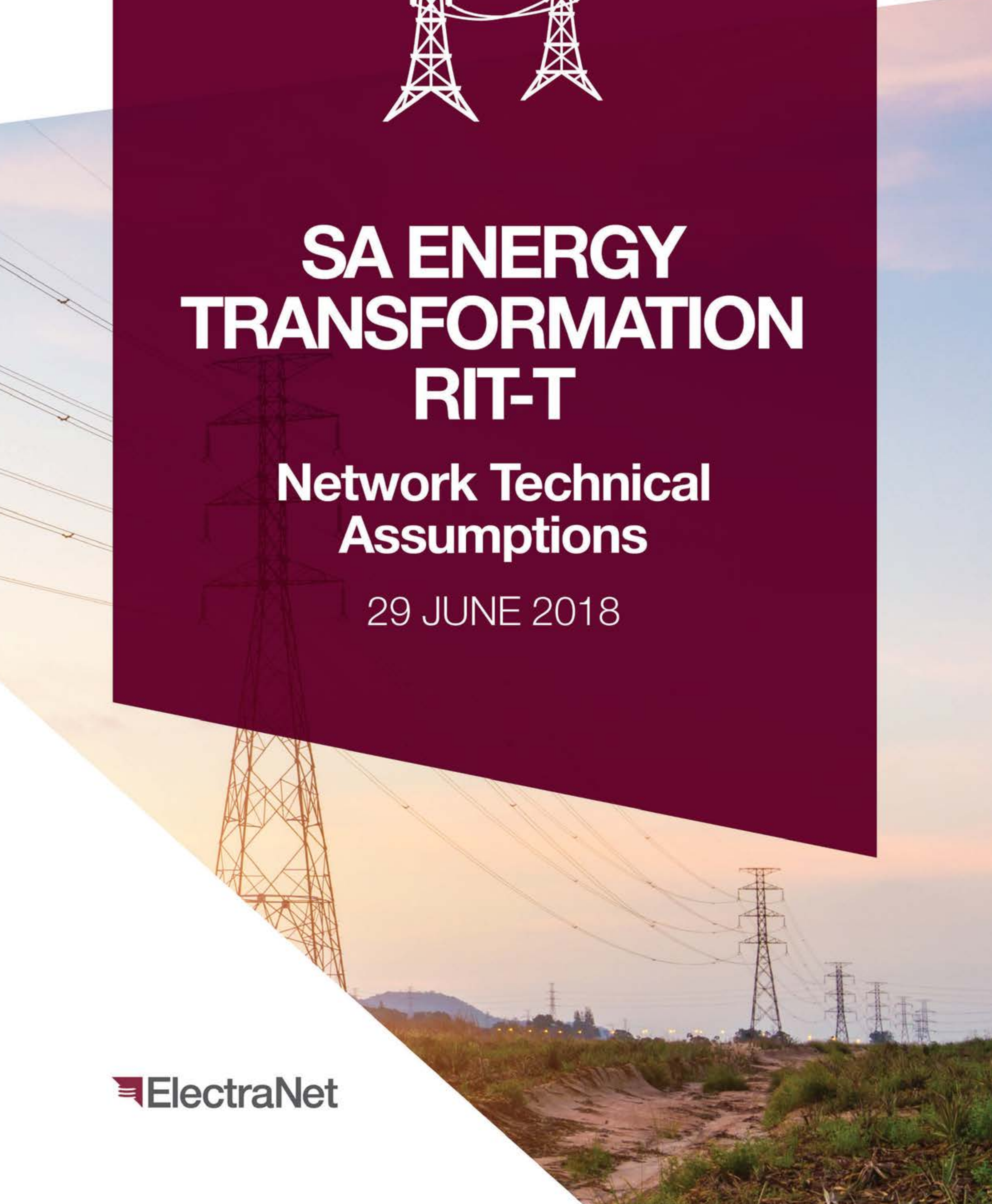
SA ENERGY TRANSFORMATION RIT-T

Network Technical Assumptions

29 JUNE 2018



ElectraNet

Revision Record

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Glossary of Terms

Term	Description
RoCoF	Rate of Change of Frequency
ISP	AEMO's Integrated System Plan
SIPS	System Integrity 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
VSC	Voltage Source Converter
PST	Phase Shift Transformer

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 and non-network options.

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, generally 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 assumptions need to be made regarding modelling constraints and the technical parameters for each option.

This overview document has been prepared to set out these assumptions and to demonstrate that they are well considered, transparent and understood. Adherence to the assumptions contained in this document will ensure consistency across studies, help in discussion and agreement on these assumptions with internal and external stakeholders.

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

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

[1] South Australia Government Gazette dated 12 October 2016

3. Transient 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 Integrity Protection Schemes (SIPS).
- Requirements for combined interconnector flow 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 based on the premise that a system black event should not eventuate under the "non-credible" loss of the Heywood Interconnector[2] (Heywood) representing a non-credible contingency[3]. Load and generation shedding will likely be required but should be minimised. For all interconnector solutions, in the event of the non-credible loss of either the existing or new interconnector, the remaining interconnector should remain in operation, making use of reasonable load or generation shedding (including under frequency load shedding (UFLS) and over frequency generation shedding OFGS) to maintain system stability and connection with the NEM.

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.

In the first stage, credible contingencies are assessed and necessary reactive plant to achieve the nominal transfer capacity of each of the proposed options is determined.

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

[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

These studies have been undertaken in PSSE. Transient and Voltage stability was assessed for the options for both single credible contingencies and also for non-credible loss of one interconnector. As described above, an identified level of maximum load shedding/ generation support was included to understand the implications of the above events. Where required, additional reactive power plant was included to manage voltage related problems. The intention being to limit the transfer capability by transient stability and not voltage stability which can be easily alleviated by adding low cost reactive plant.

1.3 Overview of Options considered

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 status. Hence, in the models (and in practice) the limits on either Heywood or a new interconnector options may fluctuate.

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

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
Option C.1: New DC link from Riverland SA to NSW ("Murraylink2")	750	300
Option C.2: 275 kV line from mid-north SA to Wagga Wagga NSW, via Buronga	750	600
Option C.3: 330 kV line from mid-north SA to Wagga Wagga NSW, via Buronga	750	800

4 Increase to 750 MW for the Heywood interconnector is due to improvement to existing voltage stability limits with the parallel interconnectors in place. This capability will not always be achievable.

Option	Notional Maximum Capability (MW)	
	Heywood[4]	New Interconnector
Option C.3i:330 kV line from mid-north SA to Wagga Wagga NSW, via Buronga, plus series compensation (or similar)	750	800
Option C.4: 330 kV line from mid-north SA to Wagga Wagga NSW, via Darlington Point	750	800
Option C.5: 500 kV line from Northern SA to east NSW	750	1000
Option D: 275 kV line from central SA to Victoria	750	650
Option Di: 275 kV line from central SA to Victoria plus series compensation (or similar)	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 NSCAS Gap.

The following solution is assumed to provide system strength in South Australia sufficient to meet the identified NSCAS Gap:

1. Six synchronous condensers, two each located at Davenport, Robertstown and in the Adelaide Metropolitan area to provide fault level support. The specifications of these machines are still to be determined. The primary role

[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

of these machines will be to support the fault level requirement at Davenport of 620 MVA.

2. As the Davenport NSCAS gap requirement of 620 MVA will be met with the synchronous condensers, it is assumed that there will not be any additional fault level contribution required from synchronous machines.

3. Non-synchronous generator dispatch will be limited to the maximum threshold as defined by AEMO in their latest limit advice (non-synchronous cap). Generation dispatch beyond the non-synchronous cap will be subject to optimisation with synchronous support. Sufficient fault level will be provided by the synchronous condensers to ensure the cap is no lower than 1,295 MW[9].

The system strength requirement will be represented in the market modelling with a constraint to represent the non-synchronous cap based on AEMO's limit advice in March 2018[10]. This advice describes Low and High combinations of synchronous generation. For the low combinations, a 1295 MW non-synchronous generation cap will be applied. For the high combination, it is formulated as an equation shown in the next section.

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[11]. The non-synchronous cap is set at (1870 – Vic to SA transfer) MW of non-synchronous generation.

2.1.2 Non-synchronous cap formulation

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

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 all new interconnector options considered.

[9] http://www.aemo.com.au/Media-Centre/South-Australia-System-Strength-Assessment
[10] Transfer Limit Advice – South Australia System Strength – March 2018
[11] AEMO, *Update to the 2016 NTNDP*, 2017

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, 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 tests a 1 Hz/s RoCoF limit. This level 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 2) provided by online generators where G_i is on/off status) and the inertia provided by the grid (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 the inertia constraint when online.

As six Synchronous Condensers are assumed in the base case to meet the NSCAS gap, the inertia of these condensers needs to be offset in the above equation. Based on the medium inertia condensers currently proposed 2400 MW.s will be used as an offset to the above equation.

Table 2 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]
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 (6*synchronous condenser)	2400
Pumped Hydro[12]	~ 1000
Solar thermal[13]	~ 500
Each additional synchronous condenser	400

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

2.2.1 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, therefore the RoCoF constraint is removed for all new AC interconnector options.

2.2.2 HVDC links and RoCoF requirements

It has been assumed that with a new HVDC interconnector, fast frequency response (FFR) can be implemented to cover the loss of the Heywood Interconnector. FFR for frequency control may be able to be optimised with inertia requirements if action can occur fast enough. FFR is not expected to eliminate the need for other system strength requirements in the SA region, so it is expected the need for synchronous plant or condensers will still be required for an HVDC option. For this reason, for the HVDC option, the requirement for the current RoCoF constraint has been removed based on this FFR response. This allows HVDC options to be studied on a consistent basis with the AC

[12] Submission to the SAET RIT-T
[13] Submission to the SAET RIT-T

interconnector options when calculating benefits, but it is acknowledged this assumption will need to be further verified.[14]

Specifically, HVDC response to frequency changes are noted as being a mature technology[15], 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 required inertia in the SA system will not be designed in detail until this option is the preferred option in the RIT-T.

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 FCAS providers:

- Pelican Point
- Torrens Island A
- Torrens Island B
- Osborne
- Quarantine 5

The additional cost of procuring sufficient FCAS, and ensuring it is available at all times will be considered in the cost-benefit analysis.

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.

[14] 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. This can be provided by existing generators provided they do not retire and will require some time to come online.

[15] 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

Whilst the methodology for determining the minimum levels of inertia is unknown at this stage it is expected that South Australia will be nominated as a sub-region and that a short fall will be determined (this Rule change was initiated by the South Australian government). Options being investigated, such as investment in additional synchronous paths (i.e. a second interconnector) between South Australia and the eastern states, would alleviate this short fall. It is appropriate that this possibility be considered and valued by the SAET RIT-T, as the need for investment to meet established minimum levels of inertia may not be material for AC interconnector options.

3. Transient stability limits

As per the study basis identified in section 1.1, non-credible contingencies of both Heywood and a potential new interconnector were considered as part of the system security assessments, as transient stability becomes the limiting factor in maintaining system security, for such contingencies.

3.1 Load shedding assumptions

Load-shedding is an action that can assist in ensuring the South Australian power system remains intact following non-credible contingencies that pose the risk of 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. However, there are limits to the amount of load-shedding action that can be realistically undertaken (and hence assumed in the model), without jeopardising the security of the system. Excess amounts of load-shedding can itself lead to voltage swings in turn leading to cascading failures, particularly under low system strength conditions.

For the SAET studies, a conservative limit of 300 MW of post-contingent load-shedding has been set as the upper limit as available to SIPS. 300 MW is 10% of peak demand and is assumed reasonable to manage security and avoid other security risks such as cascading failures. It also aligns with the current maximum generator contingency in South Australia that can be satisfactorily managed. It may also be noted that, with the existing average system demand of 1,400 MW, 300 MW is a significant proportion of the system demand. Load-shedding above 300 MW would require careful co-ordination and detailed studies prior to enabling.

It may be a challenge for an SIPS to always have 300 MW of loads available to trip. As load continues to decline it is almost certain that 300 MW of load may not exist with current forecasts suggesting zero grid demand by mid 2020s in South Australia. This assumption influences the combined import capability of the Heywood and new interconnector. Hence, 300 MW of load can reasonably be assumed will be available under high import conditions. Under low demand conditions, where 300 MW of load shedding may not be available, the need to import power at the combined interconnector limits would be less likely.

It has also been assumed that as well as load-shedding, triggering a high-speed MW response from large batteries can be utilised. It is assumed that 100 MW response from the 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.

3.2 Combined Interconnector Limits

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

Murraylink, as a DC interconnector is not considered to influence the management of the non-credible transient stability limit.[16]

3.3 Combined limits for AC interconnector options

In the event of the non-credible loss of a double circuit interconnector, the remaining interconnector would need to sustain the increased flow it is subjected to without any risk of cascade failure, islanding and potentially blacking out of the SA system.

Transient stability for a loss of the existing Heywood interconnector is sets the limit on imports into SA, due to the relatively high transfer impedance of the new AC interconnector flow paths. For such contingencies, rapid load shedding and battery injection will increase the overall combined transfer limits.

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[17]. This still remains the case when considering the loss of any new interconnector.

For a situation with 650 MW import on the Heywood interconnector, and 650 MW import on a new interconnector, study results highlight that load needs to be shed in the SA system post contingency by the following amount:

- Total pre-contingent import into SA = 650+650=1300 MW
- Maximum allowable post-contingent flow=950 MW
- 1300-950=350 MW of load would need to be shed.

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

[16] 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).

[17] ElectraNet, *Network studies*, 2017

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.

3.4 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.

300 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 Queensland 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. An additional 250 MW post-contingency capacity has been considered for the SA-QLD HVDC option in recognition of this capability.

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.1: Murraylink2	800	900
Option C.2: Robertstown – Buronga-Wagga 275 kV	800	950
Option C.3: Robertstown-Buronga-Darlington Pt 330 kV	1150	1300

Option C.4: Robertstown-Darlington Point 330 kV	1000	1150
Option C.5: Davenport – Mt Piper 500 kV	1300	1300
Option D: Tungkillo – Horsham 275 kV	950	1200

*Murraylink option is limited by its size and loss of Heywood Interconnector

Table 5 : N-2 transient stability limits with 50% series compensation included

Option	Combined Import limits (MW) (Heywood improvement)	Combined Export limits (MW) (Heywood improvement)
Option C.3i: Robertstown-Buronga-Darlington Pt 330 kV	1300	1450
Option Di: Tungkillo – Horsham 275 kV	1100	1350

3.5 Sensitivity Studies

Considering the uncertainties around the technologies that will be available in the future, a sensitivity assessment will be undertaken by removing the combined limits for all options, applying only thermal N-1 thermal constraints.

Further, a sensitivity, which will push the redundancy limits close to 'N' limits, will also be assessed. It is assumed that 80% of N capacity is used, to allow for some margin.

3.6 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 should remain operational, i.e. not also trip and island the SA system from the NEM.
- SIPS 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 SIPS including load shedding will be included in all additional interconnector 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.

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

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.

New generation

- SA Government emergency generation
- Hornsdale 3
- Lincoln Gap Wind Farm
- Willogoleche Wind Farm
- Barkers inlet reciprocating engine
- Bungala (stage 1 and Stage 2)

New Batteries

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

Retirements

- Liddell (2022)

5. Option Modelling

5.1 Option B: Davenport-Western Downs

- New VSC Bipole from Davenport 275 kV to Western Downs 275 kV, including converters, DC lines and HVAC transformers.

5.1.1 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 X Rdc * I^2

Transformer impedances

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

5.1.2 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

<u>QNI Transient Limit</u>

Powerlink's analysis of the QSA interconnector option has included an assessment of the increase in the QNI transient stability limits.

With the HVDC link's ability to rapidly inject or draw up to 250 MW (within 200 ms) along QSA following a contingency in Queensland, there are material increases to the transient stability limits which improves both northerly and southerly QNI limits.

The analysis has considered, the southerly transient limits set by the Armidale fault and the Boyne Island potline trip; and the northerly transient limit set by the Kogan Creek generator trip. Average improvements are listed in Table 6.

Table 6 - Approximate increase to QNI transient limits due to post contingent action on QSA

Direction	Limit Increase	Required post contingent action
South	340 MW	250 MW from QLD to SA within 200ms
North	410 MW	250 MW from SA to QLD within 200ms

QNI Voltage Stability and Thermal Limits

The active power post-contingency control action is not required to be as fast for voltage and thermal constraints. This is because these limits are predominantly caused by high post-contingent flows which the control action is relieving. Conservatively, we would expect at least a 1:1 increase in these limits for the level of power involved in the post contingent action. We therefore recommend that QNI voltage limits be offset by 250MW and (given modelling constraints) QNI associated thermal limits be removed (these are typically NSW intra-regional limits of 330 kV feeders in the Hunter Valley around Bayswater and Liddell).

Table 7- 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

Table 8 - 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

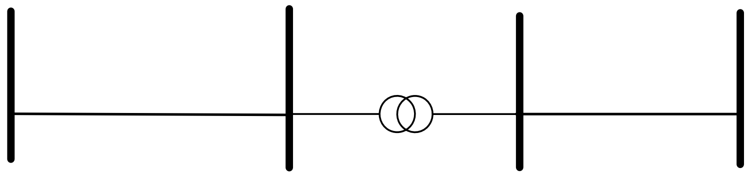
QNI Oscillatory stability limit

The QNI oscillatory stability limit is currently set at a conservative 1,200 MW in the southerly direction. There has been no incentive in increasing this limit since at this magnitude it's always limited, during system normal conditions, by the transient stability limits. With increases in transient limits, we would be able to increase this limit to theoretical levels of >1,400 MW. Further, the VSC-HVDC could be fitted with power oscillation damping controls providing higher oscillatory stability limits**.**

It is therefore recommended that QNI oscillatory stability limits not be modelled in the QSA option.

5.2 Option C.1 - Murraylink 2 upgrade

Removal of the Murraylink transmission constraint in South Australia



The first stage would reinforce the connection between Murraylink and the Electranet transmission system.

A new double circuit 275 kV transmission line between Robertstown and Berri, would initially be strung on one side. This line would link ElectraNet's substation at Robertstown to a single 275/132 kV transformer substation located near Berri, with a 132 kV connection to Murraylink's western terminal at Monash.

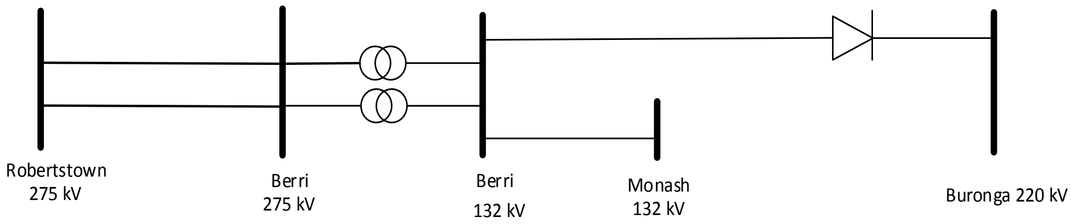
(Based on 150 km, twin Mango)

Parameters ROB-BERRI 275kV	pu
Resistance(R)	0.008545
Reactance (X)	0.071673
Susceptance (B)	0.327241
Rating	700 MVA

Parameters BERRI-MON 132kV	pu
Resistance(R)	Use parameters of existing line
Reactance (X)	
Susceptance (B)	
Rating	

Transformer
10% impedance on 300 MVA base

Duplication of Murraylink



Both circuits of the Robertstown – Berri 275 kV line would connect to an expanded two transformer substation at Berri. From there, a new DC link (Murraylink 2) with cable and overhead sections would connect between Berri and Buronga in NSW, thereby bypassing the constrained Victorian transmission network.

Murraylink 2 would provide about 300 MW of additional interconnection capacity for export from South Australia and would operate in parallel to the existing link. It would also provide additional import capability to South Australia from NSW and increase the level of support to the regional transmission networks.

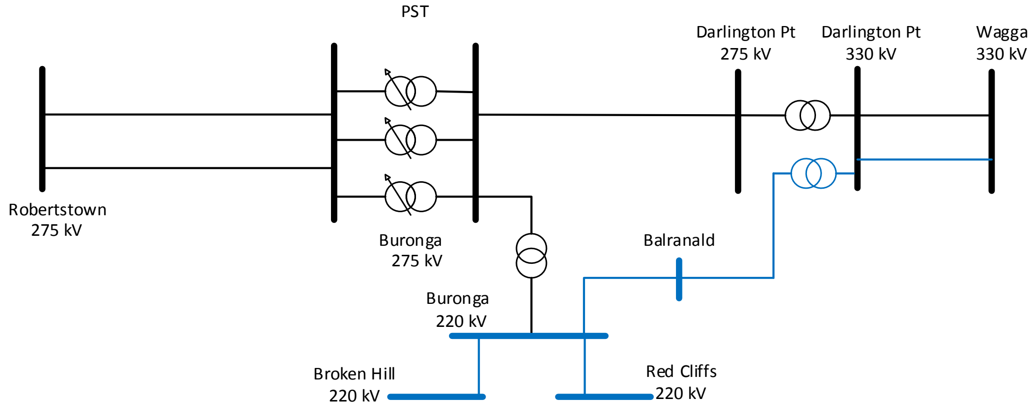
Parameter (for each 275 kV circuit)	pu
Resistance(R)	0.008545
Reactance (X)	0.071673
Susceptance (B)	0.327241
Rating	700 MVA

Transformer
10% impedance on 300 MVA base

HVDC Line	
R	Use same as existing Murraylink
Rating	300 MW

5.3 Option C.2: Robertstown-Buronga-Darlington Point 275 kV

This option includes:



*Existing circuits shown in blue

<u>Overview</u>

- New 275 kV double circuit from Robertstown to Buronga
- New additional 275 kV single circuit from Buronga to Darlington Point
- Existing 220 kV circuit between Buronga and Darlington Point via Balranald to remain at 220 kV (can be uprated to 275 kV if required)
- New additional 330 kV single circuit line from Darlington Point to Wagga
- Three new phase shift transformers at Buronga 275 kV
- New 275/220 kV transformer at Buronga
- New 330/275 kV transformer at Darlington Pt

Detailed scope of works
Build NSW section (140 km), 275 kV transmission line between Robertstown substation in SA and Buronga substation in NSW with double-circuit towers.
String above transmission line on both sides with twin ACSR Mango conductor for 85 Deg C standard design temperature. This gives a normal rating of about 700 MVA per circuit.
Installation of 330 kV 3 x 300 MVA new phase shifting transformers on Robertstown – Buronga line at Buronga substation. The transformers will have ±60 degrees phase shifting and automatic on-load MW control capability.
New 275 kV single circuit line from Buronga to Darlington Point (existing 220 kV line via Buronga remain)
New single circuit 330 kV line from Darlington Point to Wagga
1 x 275/220 kV interconnecting transformer with 400 MVA capacity at Buronga substation to interface with the existing 220 kV connections.
1 x 400 MVA 330/275 kV transformer at Darlington Point
Installation of approx. ±100 MVAr new SVC at Buronga 275 kV bus
Installation of approx. ±50 MVAr new SVC at Balranald 220 kV bus
Installation of approx. ±100 MVAr new SVC at Darlington Point 330 kV bus
Installation of shunt capacitor banks and shunt reactors at Buronga, Balranald and Darlington Point
Substation works at Wagga
275 kV works at Robertstown substation
Build 230 km of 275 kV line from Robertstown to the border, as per above configuration
100 MVAr 330 kV shunt capacitor
2 x 50 MVAr 275 kV line shunt reactors at Robertstown
SIPS to manage interconnector trip

5.3.1 Impedances

Buronga - Robertstown 275 kV double circuit line:

275kV double-circuit steel tower**,** twin Mango phase conductor, 330 km

Parameter (for each circuit)	**pu**
Resistance(R)	0.01880
Reactance (X)	0.15768
Susceptance (B)	0.71993
Rating	700 MVA

With addition of 50% series compensation

Parameters with series compensation.

Transmission Line	R1	X1	B1	Rating MVA
Buronga - Robertstown 275 kV double circuit line	0.01880	0.07884	0.71993	700

Buronga – Darlington Point 275 kV single circuit line:

275kV single-circuit steel tower**,** twin Mango phase conductor, 398 km

Parameter (for each circuit)	pu
Resistance (R)	0.02199
Reactance (X)	0.18449
Susceptance (B)	0.84232
Rating	700 MVA

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

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

Parameter (for each circuit)	pu
Resistance (R)	0.006082
Reactance (X)	0.04678
Susceptance (B)	0.57310
Rating (MVA)	915

Buronga Phase shift transformer (three items)
275 kV
10% impedance on 300 MVA base
60 degree phase shift angle

Buronga 275/220 kV tie-transformer
275/220 kV, 500 MVA
10% impedance on 500 MVA base

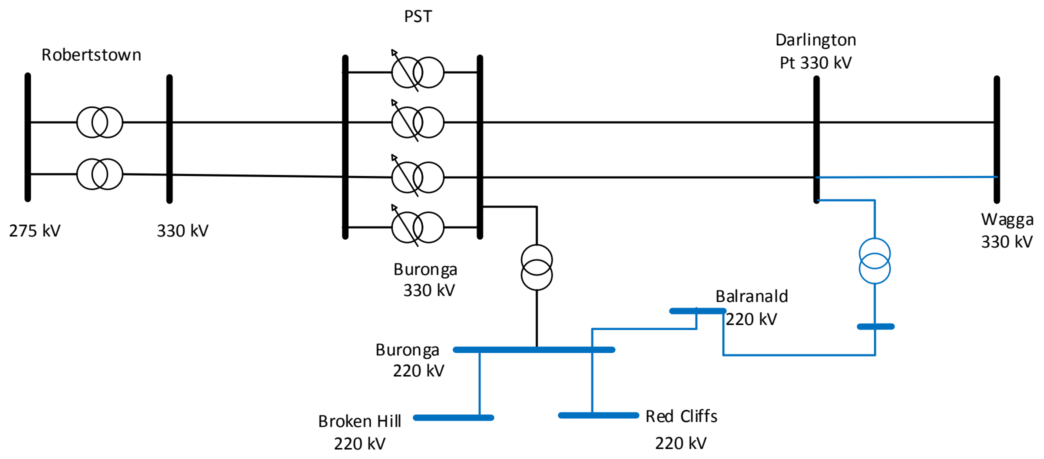
Darlington Point 330/275 kV tie-transformer
330/275 kV, 500 MVA
10% impedance on 500 MVA base

5.3.2 Impact on inter-regional limits

The thermal capability of this option is given below:

Export capability NSW end (MW)	Export capability NSW end (MW) - if VIC contribution is limited to 200 MW	Import capability NSW end (MW)	Import capability NSW end (MW) - if VIC contribution is limited to 200 MW
750	600	900	800

5.4 Option C.3 : Robertstown-Buronga-Wagga 330 kV



*Existing circuits shown in blue

Overview

- New 275/330 kV transformers at Robertstown
- New 330 kV double circuit line from Robertstown 330 kV to Buronga 330 kV
- 4 new Phase Shift Transformers at Buronga 330 kV
- New 330/220 kV transformer at Buronga
- New 330 kV double circuit lines from Buronga to Darlington Point
- New additional 330 kV line from Darlington Point to Wagga 330 kV

Detailed scope of work
330 kV transmission line between Robertstown substation in SA and Buronga substation in NSW with double-circuit towers. String above transmission line on both sides with twin ACSR Mango conductor for 85 Deg C standard design temperature. This gives a normal rating of 800 MVA per circuit.
Installation of 330 kV 4 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.
Installation of a new 1 x 330/220 kV interconnecting transformer 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.. ±200 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.
Additional intra-regional upgrades
New double circuit 330 kV next to existing Buronga to Darlington Point single circuit 220 kV line
Build 330 kV new single circuit 330 kV line between Darlington Point to Wagga
Installation of approx.. ±200 MVAr new synchronous condenser 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
275 kV works at Robertstown substation
New 330 kV substation at Robertstown with 2 x 275 kV transformers
100 MVAr 330 kV shunt capacitor
2 x 60 MVAr 330 kV line shunt reactors at Robertstown
SIPS to manage interconnector trip

5.4.1 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, 330 km

Parameter (for each circuit)	pu	With 50% SC
Resistance(R)	0.013054	
Reactance (X)	0.109503	0.05475
Susceptance (B)	1.036696	
Rating (MVA)	800	

Buronga – Darlington Point 330 kV double circuit line:

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

Parameter (for each circuit)	pu	With 50% SC
Resistance (R)	0.015273	
Reactance (X)	0.128118	0.064056
Susceptance (B)	1.212935	
Rating (MVA)	800	

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

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

Parameter (for each circuit)	pu
Resistance (R)	0.006082
Reactance (X)	0.04678
Susceptance (B)	0.5731
Rating (MVA)	800

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

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

5.4.2 NSW-SA interconnector power transfer capability

The notional maximum power import and export capacity of the interconnector is ~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.

The 220 kV interconnection between Buronga (NSW) and Red Cliffs (VIC) is unlikely to restrict the notional capacity below 800 MW, due to an inter-trip scheme that will manage the overloads. It is noted that, during maximum power import / export conditions across NSW-SA and VIC-SA AC interconnectors, the flow across Buronga - Red Cliffs line (to or from NSW) does not exceed the historic flow levels.

To manage a non-credible contingency of the Heywood interconnector, the post contingency power transfer limit across the NSW-SA interconnector is identified by technical studies as approximately 800 MW for Option C3.

5.4.3 Impact on inter-regional limits

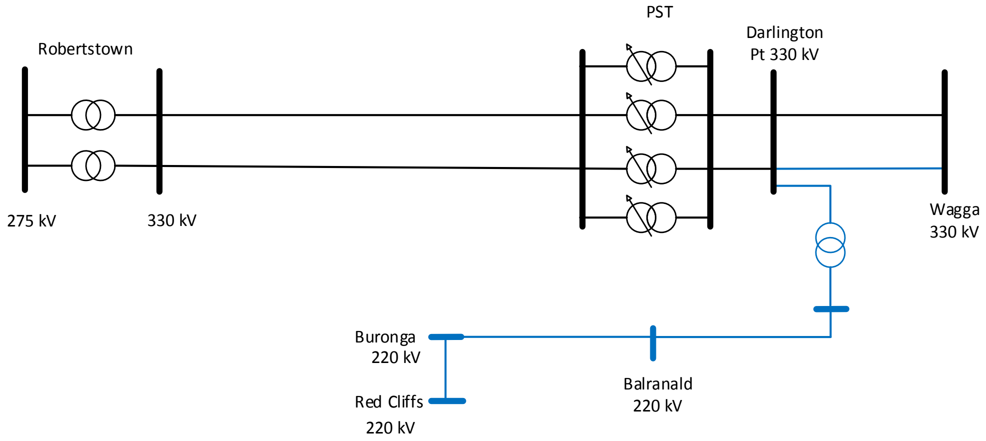
Intra-regional issues in NSW do not specifically affect the NSW to Robertstown thermal capability.

Option	Export capability NSW end (MW)	Export capability NSW end (MW) - if VIC contribution is limited to 200 MW	Import capability NSW end (MW)	Import capability NSW end (MW) - if VIC contribution is limited to 200 MW
B – at Buronga	800	750	800	800
C – at Darlington Point	800	N/A	800	N/A

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.

5.5 Option C.4 : Robertstown – Wagga 330 kV (bypassing Buronga)



*Existing circuits shown in blue

Overview

- New 275/330 kV transformers at Robertstown
- New Robertstown-Darlington Point 330 kV double circuit lines
- New Phase Shift Transformers at Darlington Point
- Additional Darlington Point-Wagga 330 kV line

Detailed scope of works
330 kV transmission line between Robertstown substation in SA and Darlington Point substation in NSW with double-circuit towers. String above transmission line on both sides with twin ACSR Mango conductor for 85 Deg C standard design temperature. This gives a normal rating of 800 MVA per circuit.
Installation of 330 kV 4 x 400 MVA new phase shifting transformers on Robertstown – Darlington Point line at Darlington Point substation. The transformers will have ±40 degrees phase shifting and automatic on-load MW control capability.
Darlington Point Busbar extension and line switch bays
Installation of approx. ±300 MVAr new SVC at Darlington Point 330 kV bus.
Installation of 2x50 MVAr 330 kV line shunt reactors at Darlington Point
Installation of shunt capacitor banks of approx. 2x50 MVAr at Darlington Point 330 kV bus
Additional Intra-regional upgrades
New single circuit 330 kV line from Darlington Point to Wagga
Substation works at Wagga
275 kV works at Robertstown substation
New 330 kV substation at Robertstown with 2 x 275 kV transformers
100 MVAr 330 kV shunt capacitor
2 x 50 MVAr 330 kV line shunt reactors at Robertstown
SIPS to manage interconnector trip

5.5.1 Impedances

Darlington Point - Robertstown 330 kV double circuit line:

330 kV double-circuit steel tower**,** twin Mango phase conductor, 728 km

Parameter (for each circuit)	pu
Resistance(R)	0.027951
Reactance (X)	0.234465
Susceptance (B)	2.21975
Rating	800 MVA

With addition of 50% series compensation

Parameters with series compensation.

Transmission Line	R1	X1	B1	Rating MVA
Darlington Point - Robertstown 330 kV double circuit line	0.027951	0.11723	2.21975	800

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

Parameter (for each circuit)	pu
Resistance (R)	0.006082
Reactance (X)	0.04678
Susceptance (B)	0.5731
Rating	915 MVA

Darlington Point Phase shift transformer (four items)
330 kV
10% impedance on 400 MVA base
40 degree phase shift angle

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

5.5.2 Impact on inter-regional limits

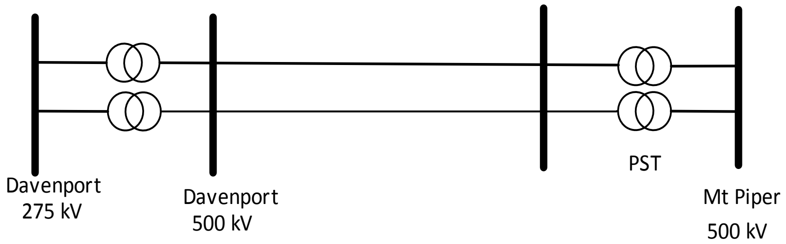
Intra-regional issues in NSW do not specifically affect the NSW to Robertstown thermal capability.

Option	Export capability NSW end (MW)	Export capability NSW end (MW) - if VIC contribution is limited to 200 MW	Import capability NSW end (MW)	Import capability NSW end (MW) - if VIC contribution is limited to 200 MW
B – at Buronga	900	750	1200	900
C – at Darlington Point	900	N/A	800	N/A

Preliminary view of any significant impacts on other interconnector capability

- Unlikely to impact on QNI transfer capacity
- NSW-SA interconnector flow may be limited by the NSW-VIC and VIC-SA transfer limits under certain conditions
- NSW-VIC and VIC-SA transfer will need to consider the trip of one circuit of NSW – SA interconnector.

5.6 Option C.5 - 500 kV Davenport to Mt Piper



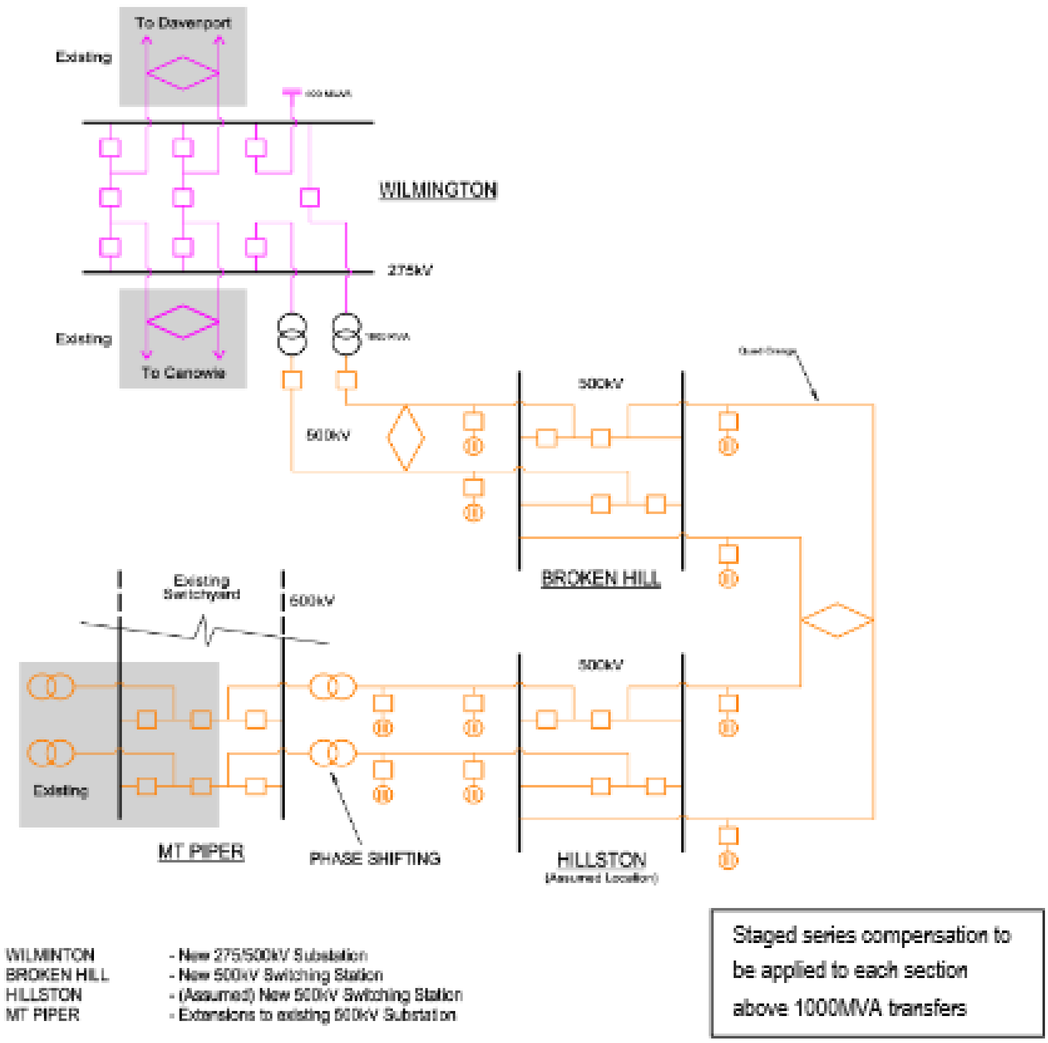
500 kV double circuit quad Orange conductor from Davenport to Mt Piper.

- Intermediate switching stations as shown in the drawing below
- 2 x 275/500 kV transformers at Davenport
- 2 x 500/500 kV PSTs at Mt Piper

Parameter (for each 500 kV circuit)	pu
Resistance(R)	0.00864
Reactance (X)	0.12396
Susceptance (B)	13.068
Rating	2000 MVA

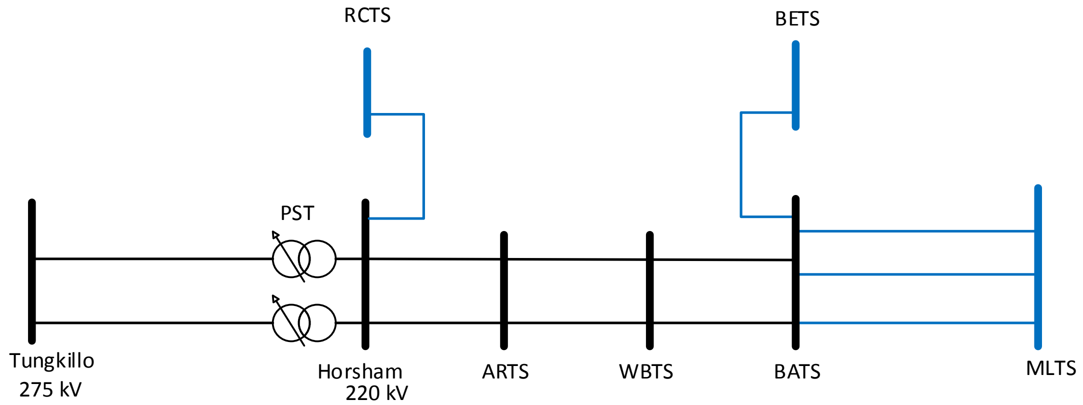
Transformers (275/500 kV and PST)
10% impedance on 1000 MVA base

PST range +/-30



Previous Joint Feasibility Study technical description

5.7 Option D : Tungkillo – Horsham 275 kV



*Existing circuits shown in blue

Overview

- New double circuit 275 kV line from Tungkillo to Horsham
- New 275/220 Phase shifting transformers at Horsham (275 kV)
- Replace existing Horsham-WBTS-ARTS-BATS single circuit 220 kV line with a double circuit line.
- Replace BATS-BETS 220 kV single circuit line with a new higher rated single circuit line (only if required).

A maximum transfer capacity of 650 MW has been assumed.

5.7.1 Impedances

Transmission Line	Length km	R1	X1	B1	Rating MVA
275 kV Heywood to South East*					628
275 kV Tungkillo-Horsham (twin Mango)	420	0.0239	0.20068	0.9162745	700

* Ratings upgrade following NCIPAP project

Victorian intra-regional new transformer parameters

2xphase shifting transformers at Horsham 275 kV bus

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

Victorian intra-regional line augmentation parameters

Transmission Line	Length km	R1	X1	B1	Rating MVA
220kV Ballarat-Bendigo**	96	0.010767	0.080213	0.138953	413
220kV Ballarat-Waubra No.1	38	0.006	0.024	0.070	450
220kV Ballarat-Waubra No.2	38	0.006	0.024	0.070	450
220kV Ararat-Waubra No.1	51	0.008	0.032	0.093	450
220kV Ararat-Waubra No.2	51	0.008	0.032	0.093	450
220kV Ararat-Horsham No.1	90	0.014	0.056	0.164	450
220kV Ararat-Horsham No.2	90	0.014	0.056	0.164	450

** Augmentation likely not required as per the current thinking for the Western Victoria RIT-t.

Note:

Where the need for 220kV network augmentation is identified, the lines are assumed to be replaced with either a single or double Lemon conductor, with a design temperature of 82°C, which is a standard conductor used in Victoria.

Intra-regional augmentations required to facilitate 650 MW across Horsham Link (without VRET):

- New single circuit line parallel to existing Ballarat (BATS) – Waubra (WBTS) – Ararat (ARTS) – Horsham (HOTS) 220 kV line, or replace existing line with new double circuit with rating of at least 826 MVA. Assuming a double circuit Lemon conductor, this line will still have an N-1 overload of approximately 120%, but this can be managed using generation tripping, or a similar control scheme.
- Replace existing BATS – Bendigo (BETS) 220 kV line with new single circuit Lemon conductor, or a line with similar rating. Note that this line congestion will be relieved or even removed if VRET goes ahead, due to the solar generation likely to be connected to the network around Red Cliffs (RCTS), Wemen (WETS) and Kerang (KGTS).

Detailed analysis will be required to determine the optimal timing, need, and option for augmentation, which may include a combination of network, non-network, and operational solutions, including constraining the interconnector flow.

With addition of 50% series compensation

Parameters with series compensation.

Transmission Line	Length km	R1	X1	B1	Rating MVA
275 kV Tungkillo-Horsham (twin Mango)	420	0.0239	0.10034	0.9162745	700

5.7.2 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.

1. 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. However, this augmentation tends to increase flow on the South Morang F2 transformer and is expected to increase the binding hours of the associated constraint equations.

2. 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:

- 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.

1. **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.

1. 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).

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.