Draft 2020 Power System Frequency Risk Review – Stage 1

Consultation Draft – June 2020

A report for the National Electricity Market

Important notice

PURPOSE

AEMO has prepared the Draft 2020 Power System Frequency Risk Review Report – Stage 1 for consultation prior to issuing a final report under clause 5.20A.3 of the National Electricity Rules.

This report is based on information available to AEMO up to 29 May 2020.

DISCLAIMER

Executive summary

AEMO, in consultation with Transmission Network Service Providers (TNSPs), undertakes a Power System Frequency Risk Review (PSFRR) and prepares a PSFRR report for the National Electricity Market (NEM) at least every two years in accordance with rule 5.20A of the National Electricity Rules (NER). AEMO published the last PSFRR report in 2018.

The PSFRR reviews the potential for 'non-credible' power system contingency events to cause frequency swings large enough to initiate uncontrolled plant disconnections, that could in turn result in widespread transmission outages or a black system. AEMO consults with TNSPs and, where relevant, distributors, on the performance of existing emergency frequency control schemes (EFCSs) and other arrangements in place to manage the risks associated with these events. Where AEMO identifies a need for additional or alternative management measures going forward, the PSFRR also assesses feasible options and makes appropriate recommendations for future management.

The 2020 PSFRR considers forecast power system conditions over a five-year outlook period, to 2025.

AEMO is undertaking the PSFRR for 2020 in two stages. Stage 1 of the PSFRR (this report):

- Reviews the status of actions recommended in the 2018 PSFRR.
- Looks back at power system events and changes since the publication of the 2018 PSFRR, including:
  - How the power system in each NEM region has changed in ways that could have adverse impacts on frequency control, including changes in generation mix, level and timing of maximum and minimum demand, interconnector flow patterns, and inertia.
  - The impact of climate conditions in each region on the likelihood, potential consequences, and effective management of non-credible contingency events.
  - A review of non-credible contingency events since the 2018 PSFRR with potential for uncontrolled frequency changes to result in cascading outages or a black system.
  - An initial assessment of the adequacy of current EFCSs and other arrangements available to manage or mitigate the impacts of these events.
- Identifies the non-credible contingency events and associated management arrangements to be prioritised for more detailed assessment and option analysis in Stage 2 of the 2020 PSFRR.
- Highlights **one set of immediate high priority recommendations** for non-credible contingency events that could result in a separation of the South Australia region from the rest of the NEM power system. These recommendations are drawn from ongoing studies that AEMO has been conducting in consultation with ElectraNet, SA Power Networks (SAPN), and the South Australian jurisdictional system security coordinator. As a result of this work, AEMO has identified:
  - A range of recommended options to increase the capability and effectiveness of South Australian under-frequency load shedding (UFLS) schemes, for implementation from late 2020 onwards. These include adding more load to the UFLS scheme and introducing dynamic arming for UFLS circuits in reverse flows.
  - A recommendation for a **new protected event** for the non-credible separation of South Australia, that will initially allow Heywood interconnector flows into the region to be limited in periods when the UFLS schemes in South Australia are not effective enough to prevent cascading failures and a potential black system.

- Interim arrangements to mitigate the cascading failure risk in these periods until a protected event is declared, by modifying existing constraints needed under South Australian regulations.
- That these risks would be more comprehensively and transparently managed under the NER protected event framework; AEMO therefore plans to make a recommendation to the Reliability Panel by Q4 2020.

Stage 2 of the 2020 PSFRR (due for completion in December 2020) will include simulation studies of the priority non-credible contingencies identified in Stage 1, with more detailed assessment of the adequacy of EFCSs and other existing management arrangements, analysis of future management options, and recommended options for EFCS improvement and further protected events if warranted. Stage 1 has identified one possible protected event for further analysis in Stage 2, in connection with a Queensland protection scheme.

AEMO summarises below:

- The key findings of Stage 1 of the PSFRR.
- The consultation process from here on Stage 1 of the 2020 PSFRR.
- The plan and timeline for delivery of Stage 2 of the 2020 PSFRR.

Status of 2018 PSFRR recommendations

This is the second PSFRR for the NEM, following the initial PSFRR report published in June 2018. AEMO made a number of recommendations in 2018 for action by TNSPs or AEMO. The 2018 PSFRR recommendations and their current status are summarised in Table 1.

Table 1 Summary of 2018 PSFRR recommendations and current status

PSFRR recommendation	Action	Status (June 2020)
Implement an upgrade to the recently commissioned System Integrity Protection Scheme (SIPS) in South Australia, to reduce the likelihood that a loss of multiple generators in South Australia will lead to separation and a black system.	ElectraNet	In progress
Amend the existing Central Queensland to Southern Queensland Special Protection Scheme (CQ–SQ SPS), to be effective for higher southerly flows that are anticipated as new generation projects connect in North Queensland.	Powerlink	In progress (the 2020 PSFRR identifies potential for a protected event to mitigate risks in the interim)
Declare a protected event comprising the loss of multiple transmission lines in South Australia during destructive wind conditions.	AEMO	Completed
Commence a joint study between Powerlink and AEMO to evaluate the risk of major supply disruption following the non-credible separation of the Queensland – New South Wales Interconnector (QNI) during high export to New South Wales.	AEMO/Powerlink	Completed

Review of the power system in NEM regions

General observations

- Increasing inverter-based resources (IBR) and reduced operation of traditional synchronous generating systems has continued in all regions, reducing inertia and system strength that support the stable operation of the power system.

- In some areas, the proliferation of distributed photovoltaic (DPV) generation is leading to reduced power flows from upstream substations, and in some cases even reverse power flows. During an under-frequency event, disconnection of such feeders because of UFLS action will reduce the effectiveness of existing UFLS arrangements and potentially exacerbate frequency disturbances.
- Analysis of inertia levels in each region and interconnector transfer between regions highlight the risk of high interconnector transfer during periods of low inertia. This operational scenario could result in high power system frequency excursions following a non-credible contingency event involving the loss of an interconnector.
- As a consequence of the large uptake of IBR in areas of limited transmission capacity, the number of Special Protection Schemes (SPSs) employed to increase the transmission capacity is growing. The system now relies even more on these schemes for managing system security. Further, the operating conditions considered in designing and testing of some existing EFCSs have changed over the last 5-10 years. Some frequency events during 2018-20 highlighted the need to further review the design and operation of EFCSs and SPSs which may impact AEMO's ability to manage frequency stability.

Queensland – potential need for new protected event declaration

As outlined in Table 1, there are increasing risks associated with the existing CQ–SQ SPS in Queensland. Modifications to the existing SPS are required for the scheme to be effective during period of higher southerly flows, which are becoming increasingly frequent as new generation projects come online in north Queensland. AEMO will continue working with Powerlink in Stage 2 of the PSFRR to improve projections of the emerging risks and timing of these changes. This work will help to determine whether a protected event recommendation is warranted to allow AEMO to manage the risk through operational measures ahead of changes to the SPS.

South Australia – UFLS improvements and new protected event declaration

AEMO recently released analysis exploring the management of credible contingencies in low load, high DPV periods in South Australia[1]. report presents complementary analysis that explores the management of non-credible events in low load, high DPV periods, specifically exploring the effectiveness of UFLS in the event of a non-credible separation of South Australia.

In conjunction with SAPN and ElectraNet, AEMO has identified an urgent need to implement measures to improve the adequacy of UFLS arrangements in South Australia. Following a non-credible separation, in periods with low load or high DPV generation, the UFLS may not be adequate to arrest frequency decline or prevent cascading failure. This risk is increasing with the ongoing growth in DPV, which reduces the net load available to be disconnected by existing UFLS schemes. DPV also demonstrates under-frequency disconnection behaviour, which further compromises UFLS effectiveness in arresting a frequency decline.

AEMO forecasts that spring 2020 will see more periods where there is insufficient (net) load available for disconnection by UFLS relays. In some cases, UFLS action could even exacerbate the disturbance by disconnecting circuits operating with reverse power flows.

To mitigate the risk, AEMO is presently working with ElectraNet to develop a power system constraint designed to limit imports into South Australia on the Heywood interconnector to the level where there is confidence that cascading failure will be avoided if a non-credible separation event occurs. This will be introduced under regulation 88A of the *Electricity (General) Regulations 2012* (SA), in conjunction with limits advice from ElectraNet, to keep the rate of change of frequency (RoCoF) below 3 hertz per second (Hz/s) for the non-credible trip of both Heywood interconnector circuits. It should be noted that RoCoF would exceed 3 Hz/s once cascading failure starts to occur, so the constraint would be designed to avoid frequency falling to 47 Hz during periods when UFLS schemes are unlikely to be effective.

[1] AEMO, Minimum operational demand thresholds in South Australia – technical report, May 2020, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2020/Minimum-Operational-Demand-Thresholds-in-South-Australia-Review.

Although regulation 88A allows for an interim solution, AEMO considers it preferable to manage the identified risks under the NER protected event framework, because this would:

- Provide greater transparency, and
- Allow consideration of all non-credible contingency events that could cause separation of the South Australia region, and a wider range of options to mitigate this issue.

The PSFRR therefore recommends the declaration of a protected event to appropriately manage the risk of cascading failure and a black system in South Australia.

The extent of any management actions, such as constraints on power flows through the Heywood interconnector, would be a function of the effectiveness of arrangements in place at any point in time to interrupt load and/or increase generation in response to a separation event, to meet the protected event standards.

AEMO intends to prepare a submission to the Reliability Panel requesting declaration of the proposed protected event before the end of 2020.

Identification and review of non-credible contingency events

AEMO has considered selected reviewable operating incidents involving frequency excursions resulting from non-credible contingency events that occurred since the 2018 PSFRR. These have been categorised by reference to the extent of the frequency excursion with respect to the Frequency Operating Standard (FOS):

- Minor event – frequency remained within the applicable normal operating frequency excursion band (49.75-50.25 Hz for the mainland NEM and Tasmania).
- Moderate event – frequency exceeded the applicable normal operating frequency excursion band but remained within the applicable operational frequency tolerance band (49.0-51.0 Hz for the mainland NEM and 48.0-52.0 Hz for Tasmania).
- Major event – frequency exceeded the applicable operational frequency tolerance band, or the contingency resulted in a separation event, involved the operation of EFCSs, or resulted in the power system no longer being in a secure operating state.

Table 2 shows a summary of the outcomes of the review, highlighting that South Australia recorded the highest number of 'Major' events since June 2018, while other regions recorded mostly 'Moderate' or 'Minor' events. Although not all non-credible contingencies had a significant power system frequency impact, in some cases this could be due to favourable power system operational conditions when events occurred.

Table 2 Number and category of relevant non-credible contingency events since 2018 PSFRR

Region	Category (number of occurrences)		
	Major	Moderate	Minor
Queensland	1	0	8
New South Wales	2	1	0
Victoria	3	2	2
South Australia	6	0	2
Tasmania	0	3	1

Identification and review of emergency frequency control schemes and protected events

The EFCSs being used in the NEM to prevent frequency collapse include:

- UFLS schemes, which automatically disconnect consumer load to arrest frequency decline and prevent a black system.
- Over-frequency generation shedding (OFGS) schemes, which co-ordinate the tripping of generators in a pre-determined manner to prevent unco-ordinated cascading tripping of generators leading to a black system.
- Additional schemes to reduce effective contingency sizes, or to respond to specific contingency events to prevent system separation and uncontrolled frequency excursions in the resulting islanded sub-networks.

A detailed review of existing EFCSs and their adequacy will be undertaken as part of Stage 2 PSFRR.

At present there is only one protected event in the NEM, which exists in South Australia and was declared following the recommendations of the 2018 PSFRR. The protected event is:

> *"The loss of multiple transmission elements causing generation disconnection in the South Australia region during periods where destructive wind conditions are forecast by the Bureau of Meteorology"*.

AEMO is currently managing the risks associated with this protected event by limiting the maximum flow into South Australia on the Heywood interconnector to 250 megawatts (MW) during forecast destructive wind conditions.

Consultation process for Stage 1

AEMO is seeking email submissions from all persons interested in the PSFRR. Submissions will contribute to the finalisation of the PSFRR stage 1 report and its recommendations and considerations for the PSFRR Stage 2 report.

If you would like to make a submission, please email it to 2020PSFRR@aemo.com.au. Written submissions will be accepted until 17 July 2020.

Submissions will be published on AEMO's website. Please indicate to AEMO if there are any parts of your submission you would like kept confidential, with reasons why.

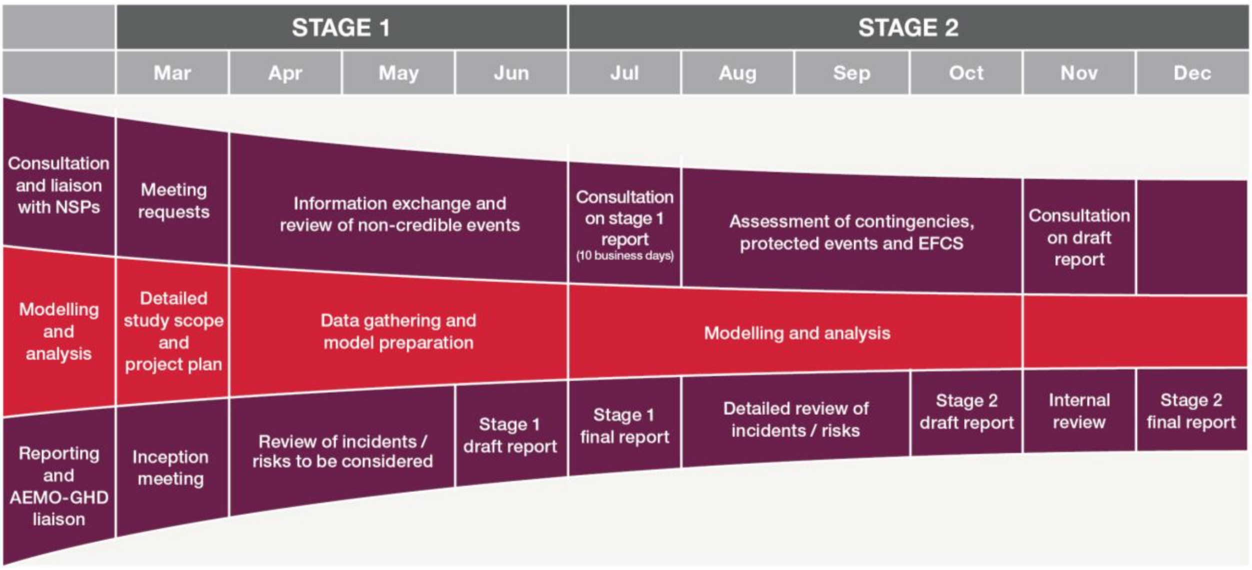
Plan for Stage 2 of 2020 PSFRR

The Stage 2 PSFRR assessment and reporting will build on the reviews undertaken in Stage 1, and will involve:

- Detailed analysis and simulation studies of priority non-credible contingency events which AEMO finds are likely to involve uncontrolled frequency excursions leading to cascading outages or major supply disruption. The non-credible contingency events prioritised for review in Stage 2 are:
  - Loss of double-circuit Queensland – New South Wales Interconnector (QNI), leading to New South Wales and Queensland separation.
  - Loss of multiple single-circuit interconnectors between New South Wales and Victoria, leading to New South Wales and Victoria separation.
  - Loss of double-circuit Heywood interconnector, leading to Victoria and South Australia separation
  - Loss of double-circuit Calvale – Halys transmission line between Central Queensland (CQ) and South Queensland (SQ), leading to a complete separation of CQ from SQ.
- Assessment of the performance and adequacy of existing EFCSs for management of potential frequency risks in the next two years (until the 2022 PSFRR).
- Review of options for future management of such events, which may include new or modified EFCSs, declaration of protected events, network augmentation, and non-network alternatives to augmentation.
- Suggested improvements of the scope and processes associated with the PSFRR and related reports to deliver system security outcomes more efficiently and maximise consumer benefits.

Figure 1 shows the timeline for delivery of Stage 2 and how it relates to Stage 1 assessment.

Figure 1 Timeline for delivery of 2020 PSFRR – Stage 1 and Stage 2



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Acronyms

Acronym	Term
AC	Alternating Current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
APD	Alcoa Portland
BESS	Battery Energy Storage System
CQ	Central Queensland
DC	Direct Current
DER	Distributed Energy Resources
DPV	Distributed Photovoltaic
EAPTS	Emergency Alcoa-Portland Potline Tripping Scheme
EFCS	Emergency Frequency Control Scheme
EMT	Electromagnetic Transient
ESB	Energy Security Board
EV	Electric Vehicle
FCSPS	Frequency Control System Protection Scheme
FOS	Frequency Operating Standard
GPG	Gas Powered Generation
GW	Gigawatt
GWs	Gigawatt seconds
Hz	Hertz
Hz/s	Hertz per second
HVDC	High Voltage Direct Current
IECS	Interconnector Emergency Control Scheme
ISP	Integrated System Plan
JPB	Jurisdictional Planning Body
km	Kilometre
kV	Kilovolt
ms	Milliseconds

Acronym	Term
MI	Major Industrial
MW	Megawatt
MPS	Mortlake Power Station
NEM	National Electricity Market
NER	National Electricity Rules
NQ	Northern Queensland
NSP	Network Service Provider
NTNDP	National Transmission Network Development Plan
NSW	New South Wales
OFGS	Over-Frequency Generation Shedding
PMU	Phase Measurement Unit
PSFRR	Power System Frequency Risk Review
PSS®E	Power System Simulator for Engineering (also written as PSS/E)
PV	Photovoltaic
QLD	Queensland
QNI	Queensland to North South Wales Interconnector
RIS	Renewable Integration Study
RIT-T	Regulatory Investment Test - Transmission
RoCoF	Rate of Change of Frequency
SA	South Australia
SCADA	System Control and Data Acquisition
SIPS	System Integrity Protection Scheme
SMM	Single Mass Model
SPS	Special Protection Scheme
SQ	Southern Queensland
TAPR	Transmission Annual Planning Report
TVGCS	Tamar Valley Generator Contingency Scheme
UFLS	Under-Frequency Load Shedding
VAPR	Victoria Annual Planning Report
VPP	Virtual Power Plant
WAPS	Wide Area Protection Scheme

1. Introduction

1.1 Purpose

The Power System Frequency Risk Review (PSFRR) is an integrated review of power system frequency risks associated with non-credible contingency events in the National Electricity Market (NEM). AEMO undertakes a PSFRR for the NEM at least every two years, in accordance with rule 5.20A of the National Electricity Rules (NER). The review is conducted in consultation with Transmission Network Service Providers (TNSPs), and with Distribution Network Service Providers (DNSPs) and other parties where appropriate.

1.2 Management of frequency

Managing the power system frequency sufficiently close to its nominal value of 50.0 hertz (Hz) is critically important for maintaining the security of the power system and safety of the connected equipment.

Most plant connected to the power system, in particular connected generating plant, is designed to operate most efficiently at the nominal frequency. When connected plant is operated at a frequency significantly outside the nominal operating value, it may mal-operate and is susceptible to damage. Large connected plant, including generating plant, therefore have protection systems to isolate from the grid when the power system frequency falls outside safe operating limits. Uncontrolled tripping of generating plant could lead to either partial or total system collapse.

The specific frequency requirements AEMO must meet under different power system conditions are set out in the **Frequency Operating Standard (FOS)**[2] for the mainland NEM and Tasmania, determined by the Reliability Panel. The FOS includes defined frequency bands and timeframes in which the system frequency should be contained and recover following different types of events, including credible contingency events (such as tripping generation or load, or an unplanned network outage) and non-credible contingency events (such as the loss of multiple generation or network elements or a regional separation event). The FOS requirements inform how AEMO operates the power system, including through applying constraints to the dispatch of generation or enabling frequency control ancillary services (FCAS).

The power system frequency is maintained by the **balance of the generation and load** connected to the power system. Any imbalance will lead to either increase or decrease in frequency, until remedial action is taken to restore the balance. A large imbalance in generation/load could create a very rapid fall or rise of frequency. Therefore, the remedial actions for mitigating such frequency variations require activation of pre-planned actions within a very short time. The pre-planned actions could be activation of additional generation response (for example, FCAS) or activation of load (for example, under-frequency load shedding [UFLS]).

Depending on the type of contingency and the probability of occurrence, AEMO follows different approaches to manage frequency[3]:

- Events which are relatively common and, although unexpected in timing, generally anticipated to occur, are **credible contingency events**, such as the loss of a single generator, a single load, or a single line in the network. AEMO is expected to have sufficient generation or load procured and available to maintain the power system frequency within the 'operational frequency tolerance band; after a credible contingency event, and return the frequency to the 'normal operating frequency band' within a short period of time.

[2] Reliability Panel AEMC, Frequency Operating Standard, Effective 1 January 2020, at https://www.aemc.gov.au/sites/default/files/2019-12/Frequency%20operating%20standard%20-%20effective%201%20January%202020%20-%20TYPO%20corrected%2019DEC2019.PDF.

[3] Australian Energy Market Commission (AEMC), Fact sheet, "What is a protected event?", at https://www.aemc.gov.au/sites/default/files/content/e5a68389-611d-4e15-b89b-41ee5a74c3c5/Fact-sheet-What-is-a-protected-event-%28FINAL-PUBLISHED-VERSION%29.pdf.

- More rare events may cause a large imbalance in load and generation and could cause significant frequency deviations. These events, which are considered unlikely, are known as **non-credible contingency events**; examples are the simultaneous loss of multiple generators, or multiple transmission circuits. AEMO may use corrective actions such as controlled load or generation shedding, together with any FCAS procured for managing the credible events, to limit the consequences of a non-credible contingency event. The corrective action, including settings for any Emergency Frequency Control Schemes (EFCSs), should be designed to contain frequency within the 'extreme frequency excursion tolerance limits', and progressively return.

Under certain conditions AEMO can also **reclassify a contingency event** from non-credible to credible. AEMO makes a reclassification when a non-credible contingency is more likely to occur due to any abnormal conditions prevailing at the time, such as in the presence of bushfires or increase in lightning strikes near transmission assets.[4]

Non-credible events identified as having high-impact consequences requiring additional management to avoid cascading failure can be declared by the Reliability Panel as **protected events**. To maintain the FOS following the occurrence of a protected event, AEMO may take various measures including purchase of FCAS, constraining generation, or controlled shedding of generation or load[5].

In some areas of the grid, AEMO is seeing the proliferation of inverter-based resources (IBR) reduce the effectiveness of existing backup arrangements which were designed to protect the system against high impact low probability events. This is giving rise to a greater need to review those arrangements and consider declaring protected events as either short-term or long-term measures.

AEMO may propose the declaration of a non-credible event as a protected event if recommended as an outcome of the PSFRR and after considering the options and costs of managing the event. The Reliability Panel determines whether to declare a protected event, having undertaken its own cost-benefit assessment.

1.3 2018 PSFRR

In June 2018, AEMO completed a PSFRR assessing frequency risks in each region of the NEM. Below is a summary of recommendations made as part of the 2018 PSFRR, and their current status:

- Implement an upgrade to the recently commissioned System Integrity Protection Scheme (SIPS) in South Australia, to reduce the likelihood that a loss of multiple generators in South Australia will lead to separation and a black system. AEMO and ElectraNet estimated that the modification could be completed within two years.
  - In collaboration with AEMO, ElectraNet is upgrading the existing SIPS to a Wide Area Protection Scheme (WAPS)[6] in which Phasor Measurement Unit (PMU) technology will be used to develop the enhanced scheme. A pilot scheme has been commissioned to trial the technology and understand its quality and performance as fit for use in a protection scheme. In parallel, a study is also underway to consider the feasibility of development of the WAPS using PMUs, which includes development of a significant number of power system simulations for analysis and development of the WAPS. This feasibility study is expected to be completed by December 2020, after which AEMO and ElectraNet will review and make a decision on implementing the WAPS.
- Amend the existing Central Queensland (CQ) – South Queensland (SQ) Special Protection Scheme (SPS) to be effective for higher southerly flows that are anticipated as several new generation projects connect in

[4] Refer to AEMO's Power System Security Guidelines SO_OP_3715, at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/power-system-operation/power-system-operating-procedures.

[5] AEMC, Information Fact Sheet, 2017, at https://www.aemc.gov.au/sites/default/files/content/e5a68389-611d-4e15-b89b-41ee5a74c3c5/Fact-sheet-What-is-a-protected-event-%28FINAL-PUBLISHED-VERSION%29.pdf.

[6] ElectraNet, South Australia Energy Transformation Regulatory Investment Test – Transmission (RIT-T), May 2019, at https://www.electranet.com.au/wp-content/uploads/projects/2016/11/2019-05-22-SAET-SPS-Report.pdf.

North Queensland. AEMO and Powerlink estimated that the modification could be completed within two years.

  - When amending the SPS for secure operation, Powerlink identified a requirement to trip inverter-based generation ahead of synchronous generation to maintain system strength. However, given the variable nature of such generation (including different cloud cover patterns and transitions from afternoon to evening), implementation is challenging. Powerlink has advised it is planning to deploy the first phase of the new scheme by mid-2021 with around 600 megawatts (MW) of renewable generators along with the existing CQ–SQ SPS, which will continue to trip Callide units.

- Declaration of a protected event in South Australia. Following the 28 September 2016 black system event in South Australia, AEMO initiated an operational action plan to limit flow on the Heywood interconnector during destructive wind conditions in South Australia (under NER 4.3.1(v)). For transparency, and to provide certainty to the market, AEMO recommended that this condition be declared a protected event. If approved by the Reliability Panel, AEMO expected this protected event to be activated approximately twice per year, based on historical weather conditions.
  - After the AEMO submission, on 19 June 2019, the Reliability Panel declared 'the loss of multiple transmission elements causing generation disconnection in the South Australia region during periods where destructive wind conditions are forecast by the Bureau of Meteorology' as a protected event[7].
  - The SIPS being upgraded by AEMO and ElectraNet also assists in managing the protected event.
  - Since the declaration of the protected event, AEMO's records indicate it has occurred twice (on 8 August 2019 and 22 January 2020) for a period of around 24 hours in total.

- AEMO/Powerlink joint study into Queensland over-frequency risk. AEMO's studies showed that Queensland may, in future, be at risk of over-frequency leading to cascading outages following the non-credible trip of the Queensland – New South Wales Interconnector (QNI) during high export to New South Wales. AEMO recommended a joint study between Powerlink and AEMO to evaluate the risk of major supply disruption due to this event. This study should incorporate projections from AEMO's 2018 Integrated System Plan (ISP). AEMO anticipated that an over-frequency generation shedding (OFGS) scheme would be the preferred option to manage this risk.
  - AEMO and Powerlink have completed a joint study which considers the major supply disruptions which could lead to over-frequency events in Queensland. The study concluded that the recommended measures in the AEMO's final report for the 25 August 2018 separation event will mitigate the risk of over-frequency.
  - AEMO's analysis of system behaviour on the 25 August 2018 event demonstrated that a progressive reduction in the provision of primary frequency response (PFR) by the generation fleet over several years has increased the chance of under-frequency load shedding and over-frequency generation shedding following non-credible contingency events.
  - The study recommended NER changes to increase the control of frequency closer to 50.0 Hz. The Australian Energy Market Commission (AEMC) made a final rule effective on 4 June 2020, that will require all capable generating systems to provide PFR within performance parameters set out in primary frequency response requirements (PFRR) established by AEMO.
  - At present, there is no OFGS in Queensland. Over-frequency is currently managed through the FCAS lower markets. For events exceeding the design criteria of the levels procured under FCAS, the frequency will be maintained through the uncoordinated generator over-frequency protection. AEMO and Powerlink plan to review this requirement further as part of the QNI upgrade.

[7] Reliability Panel AEMC, Final report AEMO request for protected event declaration, June 2019, at https://www.aemc.gov.au/sites/default/files/2019-06/Final%20determination%20-%20AEMO%20request%20for%20declaration%20of%20protected%20event.pdf.

1.4 Scope of 2020 PSFRR

In accordance with NER clause 5.20A.1, the scope of the 2020 PSFRR includes:

- Identification and review of priority non-credible contingency events which AEMO expects are likely to involve uncontrolled frequency changes leading to cascading outages or major supply disruption.
- Review and assessment of current arrangements for managing such non-credible contingency events, including the performance of existing EFCSs.
- Identification and assessment of technically and economically feasible options for future management of such events, which may include new or modified EFCSs, declaration of the event as a protected event, network augmentation, and non-network alternatives to augmentation.
- Assessment of the adequacy and costs of managing existing protected events, including consideration of whether to recommend revocation.

1.5 Acknowledgements

AEMO would like to acknowledge and thank Powerlink, TransGrid, ElectraNet, TasNetworks, and AusNet Services for their input to the development of the 2020 PSFRR stage 1 report, as well as SA Power Networks (SAPN) in relation to emerging issues with UFLS in South Australia. Acknowledging the impact of DPV on UFLS schemes as well as increases in large-scale generation connections to distribution networks, AEMO plans to further engage with DNSPs as part of the development of the Stage 2 report.

AEMO would also like to thank engineering consultants GHD who assisted with the review.

2. Approach

2.1 Approach for 2020 PSFRR

AEMO is undertaking the PSFRR for 2020 in two stages. Stage 1 of the PSFRR (this report):

- Looks back at power system events and changes since the publication of the 2018 PSFRR, including:
  - How the power system in each NEM region has changed in ways that could have adverse impacts on frequency control, including changes in generation mix, maximum and minimum demand levels with their expected timing, interconnector flow patterns, and inertia.
  - The impact of climate conditions in each region on the likelihood, potential consequences, and effective management of non-credible contingency events.
  - A review of non-credible contingency events since the 2018 PSFRR with potential for uncontrolled frequency changes to result in cascading outages or a black system.
  - An initial assessment of the adequacy of current EFCSs and other arrangements available to manage or mitigate the impacts of these events.
- Identifies the non-credible contingency events and associated management arrangements to be prioritised for more detailed assessment and option analysis in Stage 2 of the 2020 PSFRR.
- Highlights one set of immediate high priority recommendations for non-credible contingency events that could result in separation of the South Australia region from the rest of the NEM power system. These recommendations are drawn from ongoing studies that AEMO has been conducting, in consultation with ElectraNet, SAPN, and the South Australian jurisdictional system security coordinator. As a result of this work, AEMO has identified:
  - A range of recommended options to increase the capability and effectiveness of South Australian UFLS schemes, for implementation from late 2020 onwards. These include adding more load to the UFLS scheme and introducing dynamic arming for UFLS circuits in reverse flows.
  - A recommendation for a new protected event for the non-credible separation of South Australia, that will initially allow Heywood interconnector flows into the region to be limited in periods when the UFLS schemes in South Australia are not effective enough to prevent cascading failures and a potential black system.
  - Interim arrangements to mitigate the cascading failure risk in these periods until a protected event is declared, by modifying existing constraints needed under South Australian regulations, although these cannot cover all potential separation events.
  - That these risks would be more comprehensively and transparently managed under the NER protected event framework; AEMO therefore plans to make a recommendation to the Reliability Panel by Q4 2020.

Stage 2 of the PSFRR (due in December 2020), will include a more detailed review based on PSS®E simulation studies of the priority non-credible contingencies identified in Stage 1, and the adequacy of EFCSs for managing the impact of such events. Specifically, AEMO plans to undertake the following activities in consultation with TNSPs as part of Stage 2:

- Detailed analysis and simulation studies of priority non-credible contingency events which AEMO expects would be likely to involve uncontrolled frequency excursions leading to cascading outages or major supply disruption.
- Assessment of the performance and adequacy of existing EFCSs for management of potential frequency risks in the next two years (until the next PSFRR in 2022).

- Review of options for future management of such events, which may include new or modified EFCSs, declaration of a protected event, network augmentation, and non-network alternatives to augmentation.

2.2 Collaboration with TNSPs

AEMO consults with TNSPs in all NEM regions (Powerlink, TransGrid, AusNet Services, ElectraNet, and TasNetworks) to identify non-credible contingencies and EFCSs to be included in the 2020 PSFRR.

As part of the Stage 1 review, AEMO sought and obtained feedback from all TNSPs on the EFCSs presently available and planned, potential non-credible contingency events appropriate for consideration in the PSFRR, TNSP experience on the impact of climate change and extreme weather-related contingency events on frequency risks, and the impact on frequency risks of distributed photovoltaic (DPV) generation and generation/load inter-trip schemes.

Further consultation with TNSPs, relevant DNSPs, and other key stakeholders is planned for Stage 2.

2.3 Criteria for assessment

As required by the NER (clause 5.20A.1(a)(1)), the PSFRR must identify and review:

> *'non-credible contingency events, the occurrence of which AEMO expects would be likely to involve uncontrolled increases or decreases in frequency (alone or in combination) leading to cascading outages, or major supply disruptions'.*

The criteria for selection of non-credible contingency events to be prioritised as part of the review include:

- Whether the event fits the definition quoted above under clause 5.20A.1(a)(1) of the NER.
- The likely power system security outcomes if the event occurs.
- The likelihood of the event occurring.
- Whether, in AEMO's opinion, it is reasonably likely there are technically and economically feasible options to manage the event.

As part of the Stage 1 PSFRR, AEMO undertook a review of selected reviewable operating incidents involving frequency excursions resulting from non-credible contingency events that occurred since the 2018 PSFRR. For the purpose of assessment and reporting, the non-credible contingency events have been categorised in terms of the frequency excursion with respect to the FOS:

- Minor event – frequency remained within the applicable normal operating frequency excursion band (49.75-50.25 Hz for the mainland NEM and Tasmania).
- Moderate event – frequency exceeded the applicable normal operating frequency excursion band but remained within the applicable operational frequency tolerance band (49.0-51.0 Hz for the mainland NEM and 48.0-52.0 Hz for Tasmania).
- Major event – frequency exceeded the applicable operational frequency tolerance band, or the contingency resulted in a separation event, or the operation of EFCSs, or the power system not being in a secure operating state.

The non-credible contingency events which have been prioritised for review in Stage 2 are:

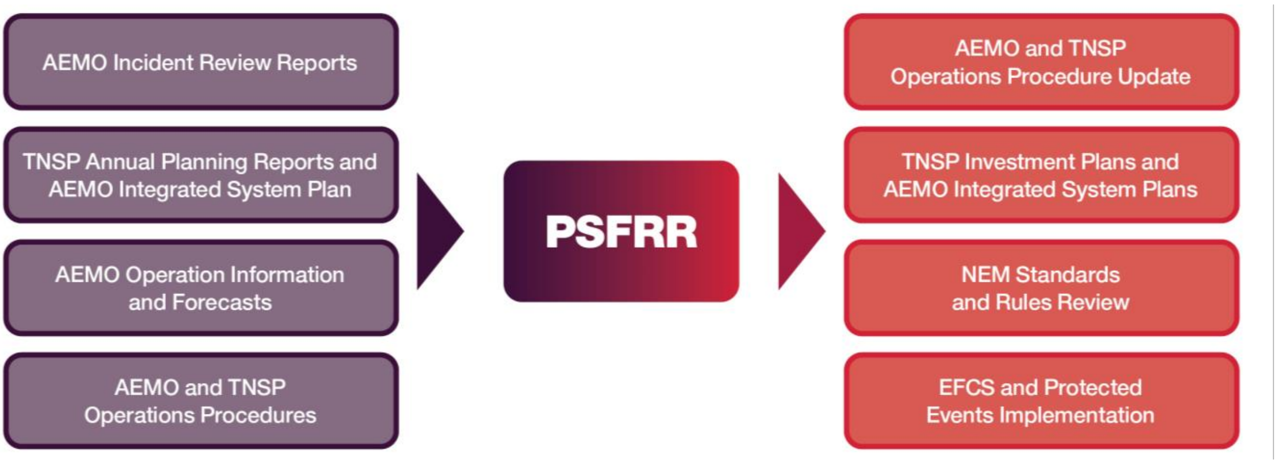
1. Loss of double-circuit QNI, leading to New South Wales and Queensland separation.
2. Loss of multiple single-circuit interconnectors between New South Wales and Victoria, leading to New South Wales and Victoria separation.
3. Loss of double-circuit Heywood interconnector, leading to Victoria and South Australia separation.
4. Loss of double circuit Calvale – Halys transmission line between Central Queensland (CQ) and South Queensland (SQ), leading to a complete separation of CQ from SQ.

2.4 PSFRR relationship with other reports

The PSFRR draws inputs from a number of related reports and processes, and informs and underpins several reports and processes owned by AEMO and TNSPs. Figure 2 shows this inter-relationship.

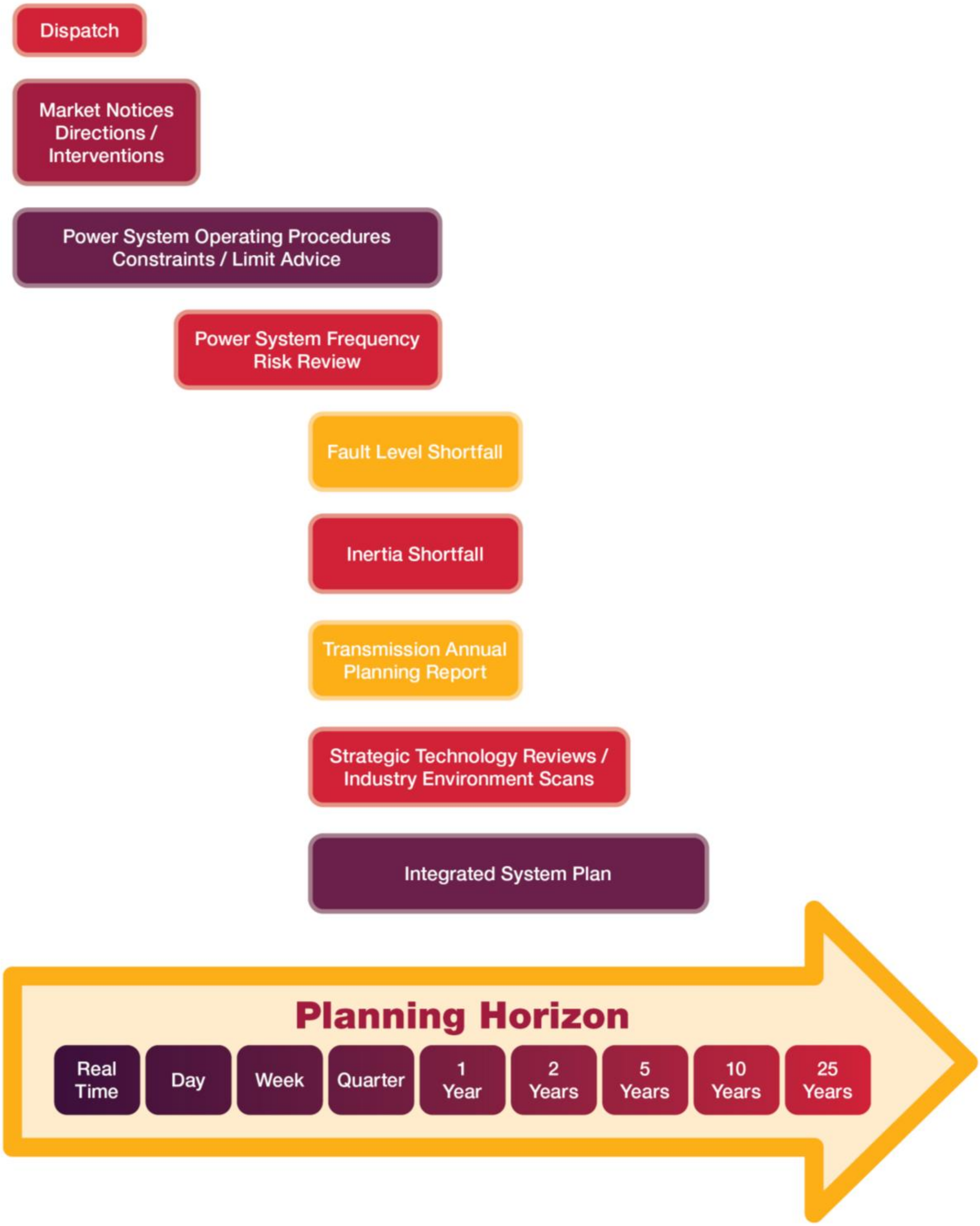
The PSFRR assesses the adequacy of existing arrangements and potential risks associated with the management of power system frequency. For this purpose, the review considers past incidents, the operating conditions during the incident, trends observed in generation and demand, and generation and demand forecasts. The PSFRR then extrapolates this information to assess potential future risks (approximately within next two to five years) and determines suitable risk mitigation measures. Mitigation measures may be in the forms of review and revision of TNSP and AEMO operating procedures, future investments by TNSPs, network investments consistent with AEMO's ISP, review and revision of EFCSs, or protected events. AEMO may also recommend that a previously declared protected event be revoked based on a review of the adequacy and costs of the arrangements for managing the event.

Figure 2 Inputs to and outcomes of the PSFRR



The PSFRR is one of a suite of documents periodically published by AEMO to inform the market on the state of the power system and potential risks. Figure 3 shows the PSFRR in relation to other key AEMO documents and processes.

Figure 3 Relationship of PSFRR with other AEMO documents and processes



The recent Renewable Integration Study – Stage 1 report[8] is an example of the key Strategic Technology Reviews and Industry Environment Scan documents published by AEMO.

[8] At https://aemo.com.au/en/energy-systems/major-publications/renewable-integration-study-ris.

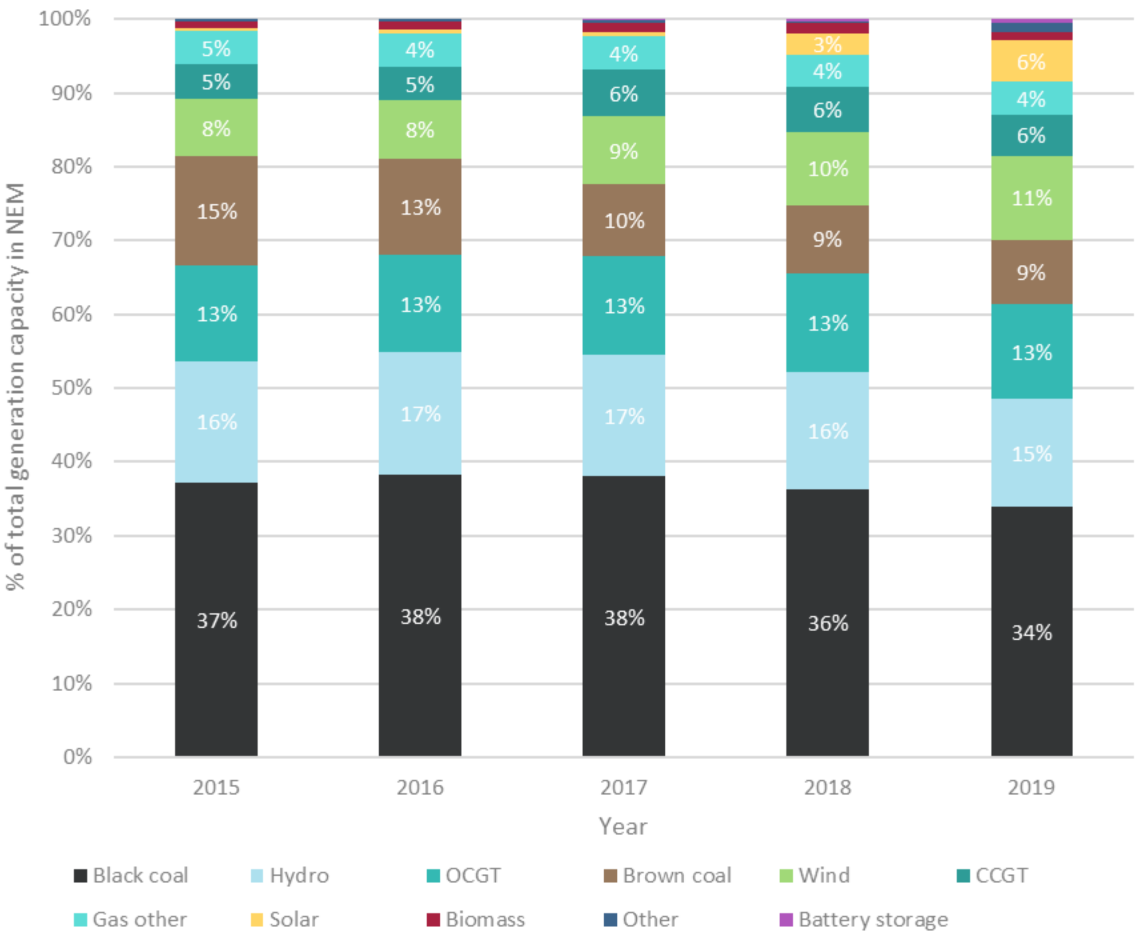
3. Industry in transition

3.1 Past and forecast future change in energy mix

Australia's electricity needs were historically met by generation from synchronous machines using hydro power, coal, or gas as their primary energy sources. Over the last decade, a significant uptake of renewable (mainly wind and solar) generation has occurred, and several ageing coal-fired generating plants have been retired and decommissioned. More recently, several large-scale Battery Energy Storage System (BESS) projects have been implemented, and significantly more BESS capacity is planned for connection to the NEM.

Figure 4 shows recent changes in the energy mix of large grid-connected generation plants in the NEM[9].

Figure 4 NEM generation mix changes, 2015-19



In addition, an unprecedented change has also occurred in the connection and use of small distributed generation, mainly in the form of DPV, along with a small uptake of distributed small battery storage systems.

A number of grid-connected energy storage projects, mainly battery energy storage and pumped hydro energy storage projects, are also being planned and proposed. Generation using stored energy is likely to

[9] AEMO, Generation Information, at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information. Data used in this chart has been taken from the final update each year.

become vital for managing intermittency of the availability of renewable sources, as the generation mix moves from the presently available and dispatchable generation to variable renewable generation.

To date, BESS have been shown to respond rapidly to power system frequency changes and are contributing positively to maintain the frequency closer to the nominal value, following power system disturbances[10]. Although operating flexibility and economic efficiencies may be gained by connecting pumped hydro generation via inverters, such an approach is likely to increase the risks associated with managing power system frequency, by reducing available system inertia (discussed further in Section 3.6).

3.2 AEMO operational reviews

AEMO undertakes a NEM-wide summer review that outlines the preparations undertaken by AEMO and NEM participants prior to summer and considers the effectiveness of these preparations in minimising disruptions. The report reviews the operational measures for risk mitigation, availability of generation, performance of transmission assets, frequency management, and the impacts of climate changes. The Summer 2019-20 NEM Operations review was published on 22 June 2020[11].

3.3 Distributed energy resources and composition of load

The characteristics and composition of loads in the NEM have also significantly changed over the last decade.

In the past, most household loads and industrial processes responded to voltage and frequency disturbances in a manner that lessened the impact of those disturbances, where the power consumed by the loads was reduced with a reduction in voltage or frequency. These quick reductions in consumed power reduced the stress on the power system during disturbances, aiding recovery from disturbances.

Many modern household consumer appliances, including lighting, are now supplied through some form of power conditioning system (for example, a switch mode power supply) embedded in those appliances. Similarly, the power supply to many industrial rotating machines is now conditioned to improve their efficiency and performance, using some form of electronic motor drive systems. Because of these conditioning systems, the power consumed by these devices is less susceptible to disturbances in supply voltage or frequency. While the power conditioning is beneficial because it makes the devices, and therefore their outputs, less susceptible to power system disturbances, it (comparatively) increases the stress on the power system during disturbances.

The composition of load as seen from the grid has also significantly changed, driven by two major factors:

- The move of industry from a heavy manufacturing industry base to a value added service-oriented industry base, and the closure and reduction of large industrial loads, such as metal smelters.
- The proliferation of distributed energy resources (DER) meeting at least part of the load at consumer premises.

3.4 NEM-wide UFLS review

The levels of DER, in particular DPV, have resulted in some distribution feeders operating as a net source of power to the transmission system under some operating conditions. As existing distribution network UFLS relays operate at the feeder level, and do not distinguish between downstream load and generation connected within the feeder, the effectiveness of such schemes is greatly reduced and may even exacerbate

[10] AEMO, Initial operation of the Hornsdale Power Reserve BESS, April 2018, at https://www.aemo.com.au/-/media/Files/Media_Centre/2018/Initial-operation-of-the-Hornsdale-Power-Reserve.pdf.

[11] At https://www.aemo.com.au/-/media/files/electricity/nem/system-operations/summer-operations/2019-20/summer-2019-20-nem-operations-review.pdf?la=en.

frequency disturbances. This is particularly evident in SA where there are emerging UFLS adequacy issues given high rates of DPV growth.

Preliminary study findings and recommendations relating to the SA UFLS have informed the recommendations for managing non-credible separation of SA in Stage 1 of the PFSRR, and are presented in detail in the report at Appendix A1. AEMO is commencing investigation of the extent to which similar issues may start to impact UFLS adequacy in other regions. Any initial findings will be summarised in the Stage 2 PSFRR report.

It should be noted that NSPs and AEMO have ongoing responsibilities to respectively maintain and review the capability of UFLS to respond to significant non-credible contingency events, and to cooperate on the development and review of EFCS settings where necessary, regardless of the PSFRR process.

The regulatory frameworks in the NER never envisioned a power system supplied primarily by distributed generation at individual customer sites, and do not provide a clear or adequate basis for investment in the optimal solutions for the long term. Review is required. AEMO is preparing concepts for a possible rule change proposal.

In the future, an increased uptake in electric vehicles (EVs) would change the characteristics and composition of the load connected to the grid further. An increased uptake of EVs is also likely to result in a reduction in battery costs, making small-scale BESS more economical and affordable for household, commercial, and industrial use. With such changes, at any given time, the capacity of grid-connected BESS either charging or ready to be discharged would be significant. AEMO is presently investigating the potential avenues for using this resource for better controlling and managing frequency.

3.5 Events causing power system disturbances

A contingency is an event affecting the power system which AEMO expects is likely to involve the failure, or removal from operational service, of one or more generating units and/or transmission elements. A contingency event is a structural element defined in the NER which has been applied by AEMO for managing power system security, effectively and efficiently, since the start of the NEM.

The NER presently define the events which cause power system disturbances in three categories:

- Credible contingency events.
- Non-credible contingency events.
- Protected events.

However, with changes in the electricity generation mix, load composition and climate, an increasing number and type of events could cause a wider range of disturbances in the power system, and the power system's capability to respond to and recover from severe or widespread events is also changing.

This includes the effectiveness of existing backup arrangements to safeguard against unforeseen events. The number of small generators dispersed throughout the system is forecast to keep rising, together with household DPV and batteries, with controlled variable output depending on weather conditions. This means there can be more rapid and unexpected changes in generation, causing frequency disturbances which need to be managed.

In December 2019 the AEMC completed a review on mechanisms to enhance resilience in the power system[12], under terms of reference focused on systemic issues that caused the black system event in South Australia in 2016 or affected the response. This review proposes changes to the regulatory framework to recognise two types of events – 'distinct' and 'indistinct' – which could lead to system security risks, including management of system frequency. Distinct risks involve events causing the sudden unexpected failure of specific generating systems or network elements. Indistinct risks may be associated with distributed events, such as those arising from weather conditions, which act to reduce the capacity of multiple generation or network

[12] See https://www.aemc.gov.au/markets-reviews-advice/review-of-the-system-black-event-in-south-australi.

assets in an affected area. Exactly how this distinction will change the contingency event framework, and AEMO's management of power system security, will be determined after consultation by the AEMC on the rule change proposal recently submitted by the COAG Energy Council[13].

3.6 Impact on system frequency

The changes mentioned in Sections 3.1 to 3.5 have significantly impacted the performance of the power system, in particular its behaviour during system disturbances and its ability to recover following a disturbance.

As described previously, the ability of the power system to recover following a major disturbance is significantly influenced by the ability of the power system to contain the frequency variations within the extreme frequency excursion tolerance band. This is in turn determined by the controls available to AEMO to maintain the balance of generation and load, and the ability of AEMO or network service providers to predict and plan actions necessary to manage that balance in advance, within the operational timeframes (hours) and the planning timeframes (years).

The operating characteristics and parameters of the power system which have been significantly impacted by the changing generating mix are described below.

System inertia

The mechanical inertia of rotating machines connected to the power system provides a resistance to sudden changes in the rotating speed of the machines and therefore the frequency of the power system. A large proportion of the mechanical inertia of the NEM power system comes from connected synchronous machines.

Solar generating units do not contain any rotating mechanical mass and therefore cannot contribute to the mechanical inertia of the power system. While wind turbine generating units constitute of rotating mechanical masses, most modern wind generating units are connected to the power system through inverters, which mask any influence of inertia on the power output of the generating units and therefore do not influence the power system frequency.

The reduction in system inertia[14] associated with the transforming generation mix has reduced the ability for the power system to resist changes in frequency, increasing the susceptibility to more rapid changes. The higher the rate of change of frequency (RoCoF), the less time there is for remedial actions (such as FCAS) to arrest frequency changes before the frequency moves outside the frequency tolerance band of the connected generators. This in turn increases risks associated with managing power system frequency and requires monitoring and implementation of risk mitigation actions.

System strength

System strength defines the ability to maintain the voltage magnitude and phase angle of a given node in the power system following a disturbance as much as possible closer to its pre disturbance values[15].

The stronger the power system, the better the ability of the connected generating plants (both synchronous and inverter-based) to operate stably and remain connected to the power system following a disturbance.

Rotating synchronous plants significantly contribute to power system strength. The current fleet of inverter-based generators does not contribute to system strength, rather it relies on system strength being above a certain minimum level to stably operate.

[13] See https://www.aemc.gov.au/rule-changes/enhancing-operational-resilience-relation-indistinct-events.

[14] AEMO, Renewable Integration Study Stage 1 report – Appendix B, Figure 1, at https://aemo.com.au/energy-systems/major-publications/renewable-integration-study-ris.

[15] AEMO, System Strength, March 2020, at https://aemo.com.au/-/media/files/electricity/nem/system-strength-explained.pdf?la=en.

As the generation mix has changed, with traditional synchronous generation increasingly displaced by inverter-based renewable generation and some ageing synchronous generating plants have retired or are nearing the end of their economic life:

- The capacity of the rotating synchronous plants dispatch in the power system at any given point in time has been gradually decreasing.
- The gradual reduction in system strength makes the connected generating plants more susceptible to instability following system disturbances, particularly non-credible events outside the relevant generator performance standards.
- The risk of generating plants tripping following a large disturbance in the power system, resulting in a large frequency deviation, is therefore increased.
- There is also a greater risk of cascading events occurring following non-credible loss of synchronous machines (or loss of transmission lines connecting sources of system strength to remote inverter-based generation).

Load relief

The sensitivity of connected load to power system frequency has been an important factor assisting management of system frequency following system disturbances. During under-frequency events, the rotating loads directly connected to the power system reduce their power consumption, complementing the use of other under-frequency control ancillary services to restore the generation/load balance during the events. This reduction in consumption is generally referred to as load relief.

As a result of the changing characteristics of connected loads (described in Section 3.3), the sensitivity of power consumption to system frequency is significantly reducing. This reduction in load relief makes the power system more susceptible to wider variations in power system frequency and requires implementation of other measures such as procurement of additional FCAS for managing the potential security risks.

Availability of UFLS

The changes in load composition are also reducing the load that can be accessed and curtailed to manage the fall of frequency during an under-frequency event with the current architecture of UFLS schemes.

The proliferation of DER including DPV is in some cases resulting in greater generation than load at customer premises, causing reversal of power flow over some of the high voltage feeders. During an under-frequency event, disconnection of a feeder in reverse flow will further deteriorate the generation/load balance and negate other actions taken by AEMO to restore frequency.

The variability of the power flow in both directions (from network to consumers and from consumers to the network) makes the load available for curtailment during an under-frequency event uncertain, and therefore increases the risk in managing the under-frequency event by UFLS action. The reduction in curtailable load is already becoming an issue, requiring AEMO to adopt alternative measures for managing under-frequency events in South Australia, as discussed in Section 8.

Operation of protection schemes

Due to a large uptake of renewable generation in areas of limited transmission capacity, the number of special protection schemes (SPSs) employed to increase the transmission capacity, as well as to connect generators in weakly meshed areas of the grid, is increasing – and so is the reliance on these schemes for managing system security.

Due to the advent of new renewable generation connections, several new protection schemes are in operation which may lead to inter-trips or ramping the generation levels of the concerned generating plants during system incidents. Operation of such schemes can have direct bearing on system frequency. The co-ordination of the operation of these schemes with other protection devices, and managing the robustness of operation, are expected to become more challenging in future. Identification of the protection trip element and cause of the contingency following a system event will become more difficult and could make the restoration process more complicated.

Consultation with TNSPs has highlighted the need for employing SPSs to release transmission capacity for renewable generation connection, and, more importantly, the need for any interactions of different SPSs to be carefully considered before their implementation. Reviews of recent power system incidents have also highlighted the potential for maloperation or unintended operation of such protection schemes to have an adverse impact on frequency stability.

Further, the operating conditions considered in designing and testing of some existing EFCSs have changed over the last 5-10 years. Some frequency events during 2018-20 highlighted the need to further review the design and operation of EFCSs and SPSs which may impact on AEMO's ability to manage frequency risks.

3.7 Managing frequency in 2020-25

AEMO is very closely monitoring the changes taking place in the industry[16], and in consultation with stakeholders will continue to plan and implement actions required for mitigating potential risks. Actions already implemented to manage emerging risks associated with managing system frequency include those described below.

Enhancing the frequency response contribution available from generators

Since the implementation of market-based FCAS procurement in the NEM, the PFR previously provided by generation has been gradually reduced. This has reduced the power system's resilience to events at a time when events are becoming more complex and less predictable. It has also resulted in a lack of effective control of frequency in the NEM under normal operating conditions. Lack of consistency and certainty of PFR delivery has also impacted AEMO's ability to effectively model and plan the system, understand the cause of power system incidents, and design EFCSs.

AEMO proposed a mandatory PFR rule change[17], which was made by the AEMC with effect from 4 June 2020[18] and is expected to be progressively implemented for capable generating systems from spring 2020.

Declaration of system strength shortfalls

AEMO has identified system strength shortfalls in South Australia, Tasmania, Victoria, and Queensland, and has requested the relevant TNSPs to implement system strength remediation solutions[19]. This will help mitigate further reductions in system strength which could lead to higher magnitude voltage step changes, instability of inverter-based plant, or maloperation of power system protection devices.

Review of the frequency control risks and associated processes

Through the PSFRR, AEMO is undertaking an overall review of the emerging frequency risks and its ability to monitor and assess the risks (including review of adequacy of models for assessment), and revision to its frequency management processes including EFCSs and protected events.

AEMO is also working closely with and supporting efforts by the Energy Security Board (ESB) and AEMC to address and set up the required frameworks for managing power system security risks, through a number of work streams including the AEMC's investigation of NEM system strength frameworks[20].

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[16] See https://aemo.com.au/energy-systems/major-publications/renewable-integration-study-ris.

[17] See https://www.aemc.gov.au/sites/default/files/2019-08/Rule%20Change%20Proposal%20-%20Mandatory%20Frequency%20Response.pdf.

[18] See https://www.aemc.gov.au/rule-changes/mandatory-primary-frequency-response.

[19] All system strength shortfall declarations are at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/system-operations/system-security-market-frameworks-review.

[20] See https://www.aemc.gov.au/market-reviews-advice/investigation-system-strength-frameworks-nem.

AEMO is closely monitoring the role of DER and their ability to provide frequency control following system disturbances. AEMO also supports the development and delivery of virtual power plants (VPPs) – collections of distributed battery storage, which can be controlled for providing FCAS support – and already has plans in place for effectively using electric vehicle (EV) battery charging systems for the same purpose.

Through its work on the Renewable Integration Study (RIS), AEMO is also anticipating requirements to effectively manage the security of the power system, including frequency control aspects, in the longer term. AEMO intends to publish a detailed frequency control workplan in 2020[21] covering:

- Revising ancillary service arrangements to meet the requirements of expected future operating conditions.
- Investigating the introduction of a system inertia safety net for the mainland NEM.
- Defining system RoCoF limits.
- Continued investigation into DPV penetration in UFLS load blocks.
- Applying appropriate limits to the total proportion of switched FCAS.
- Investigating appropriate regional contingency FCAS requirements.
- Improving AEMO's existing system frequency model.

[21] For more information, see AEMO, RIS Stage 1 report – Appendix B, at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-b.pdf?la=en.

4. Queensland

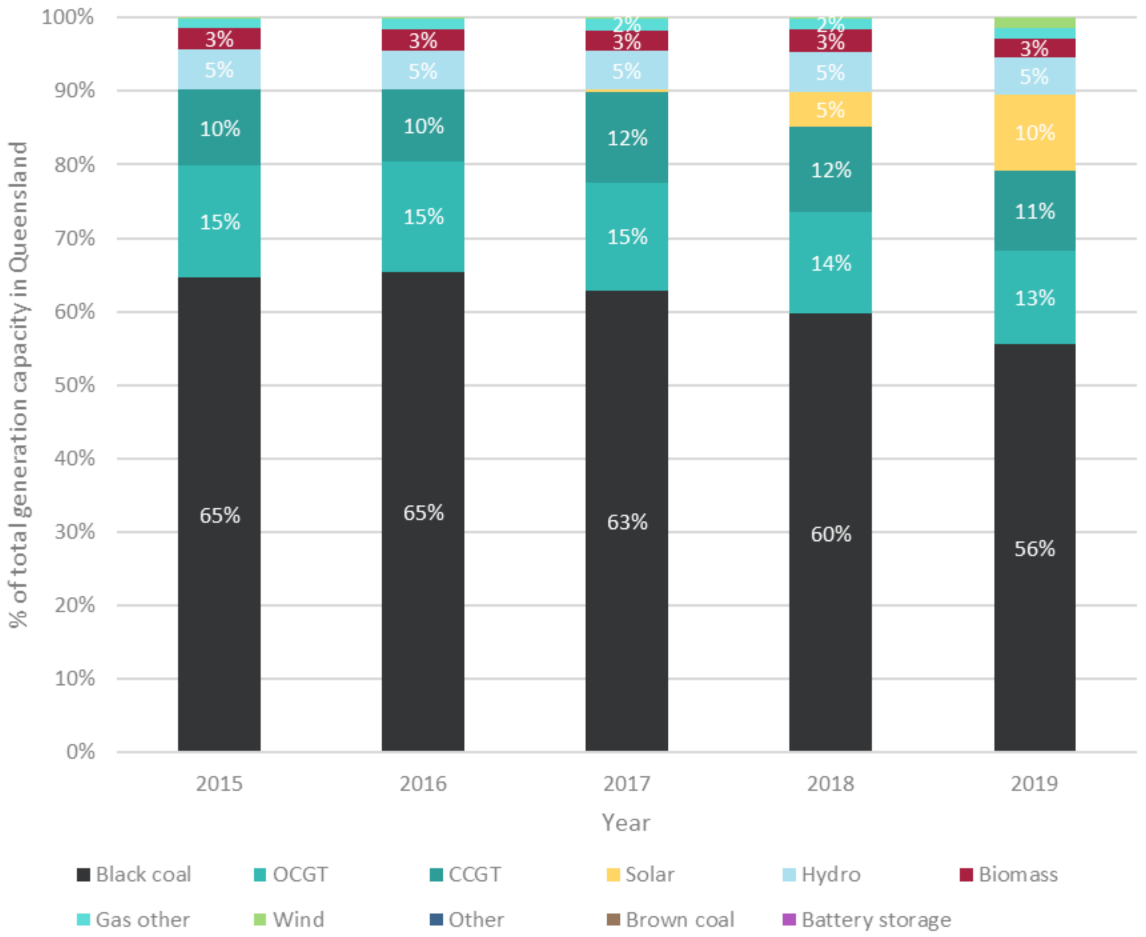
4.1 Introduction

4.1.1 Generation in Queensland

Queensland's scheduled generation is predominantly a combination of coal-fired, gas turbine, and hydro electric generators.

Figure 5 shows the Queensland generation mix over the past five years, based on data obtained from AEMO's Generation Information page[22].

Figure 5 Queensland generation mix changes, 2015-19



Note: the contributions of some generation sources are not large enough to be visible on this chart.

Since 2018, Powerlink has commissioned 11 large scale solar and wind farm projects adding 1,423 MW of generation capacity. In addition, 40 connection applications, totalling about 8,000 MW of new generation capacity, have been received by Powerlink and are in various stages of connection and construction phases[23].

[22] AEMO, Generation Information, at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information. Data used in this chart has been taken from the final update each year.

[23] Powerlink, 2019 Transmission Annual Planning Report, Executive Summary, Renewable Energy and Generation Capacity, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

Further, Ergon Energy is currently managing more than 110 connection enquiries totalling more than 3,000 MW of renewable connection to its distribution network[24].

4.1.2 Electricity demand in Queensland

At 18:00 hrs on 13 February 2019, Queensland recorded a maximum demand of 8,969 MW[25]. Queensland maximum demand is typically occurring between 18:00 hrs and 20:00 hrs, consistent with DPV generation in Queensland pushing maximum demand later into the day[26].

The maximum winter demand was 7,383 MW in 2018. Winter demand normally peaks after sunset and DPV has no impact on winter maximum demand[27].

4.1.3 Transmission system in Queensland

Existing transmission network

Powerlink owns, operates, and maintains the electricity transmission network in Queensland.

The existing 1,700 km long transmission network in Queensland is predominately radial and extends from Port Douglas in Far North Queensland to the New South Wales border. The network comprises[28]:

- A 275 kilovolt (kV) transmission network that connects Cairns in the North to Mudgeeraba in the South.
- A 110 kV and 132 kV transmission system in local zones and providing support to the 275 kV network.
- A 330 kV network that connects the New South Wales transmission network to Powerlink's 275 kV network at Braemar and Middle Ridge substations.

Interconnection with New South Wales

The 330 kV double circuit transmission line from Bulli Creek to Dumaresq, known as the QNI, is the alternating current (AC) interconnector connecting Queensland and New South Wales. QNI has a nominal flow capacity of 300-600 MW from New South Wales to Queensland, while the nominal flow capacity is 1,078 MW from Queensland to New South Wales[29].

The Terranora interconnector is defined as the flow across the two AC circuits from Mudgeeraba in Queensland to Terranora in New South Wales, which in turn connects to a direct current (DC) link to Mullumbimby. The nominal capacity of the DC link from New South Wales to Queensland is 107 MW, while the capacity is 210 MW from Queensland to New South Wales[30]. The capacity of the DC link is small and unlikely to have any material impact on the frequency, so the DC link flow patterns are not considered in detail in this review.

The capability and power flow of the interconnectors significantly depends on the dispatch of the generation plants, network conditions, weather, and load levels in both Queensland and New South Wales.

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[24] Ergon, Distribution Annual Planning Report 2019-20 to 2023-24, section 12.5, at https://www.ergon.com.au/__data/assets/pdf_file/0010/796744/Ergon-DAPR-2019.pdf.

[25] Powerlink, 2019 Transmission Annual Planning Report, Executive Summary, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[26] AEMO, 2019 Electricity Statement of Opportunities (ESOO), August 2019, Section A1.2, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2019/2019-Electricity-Statement-of-Opportunities.pdf.

[27] Powerlink, 2019 Transmission Annual Planning Report, Section 2.3.5, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

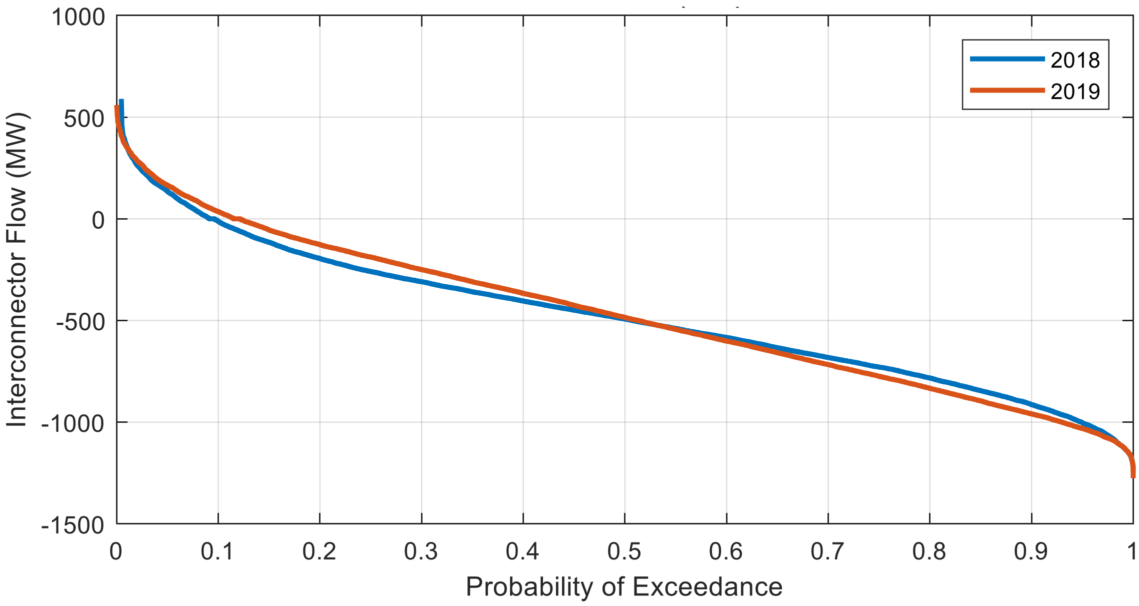
[28] Powerlink, 2019 Transmission Annual Planning Report, Section 9.1, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[29] AEMO, Interconnector capabilities, November 2017, Table 2, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2017/Interconnector-Capabilities.pdf.

[30] AEMO, Interconnector capabilities, November 2017, Table 1, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2017/Interconnector-Capabilities.pdf.

Figure 6 shows the QNI flow patterns in 2018 and 2019 via flow duration curves, illustrating that QNI was exporting to New South Wales approximately 90% of the time in 2018 and 2019.

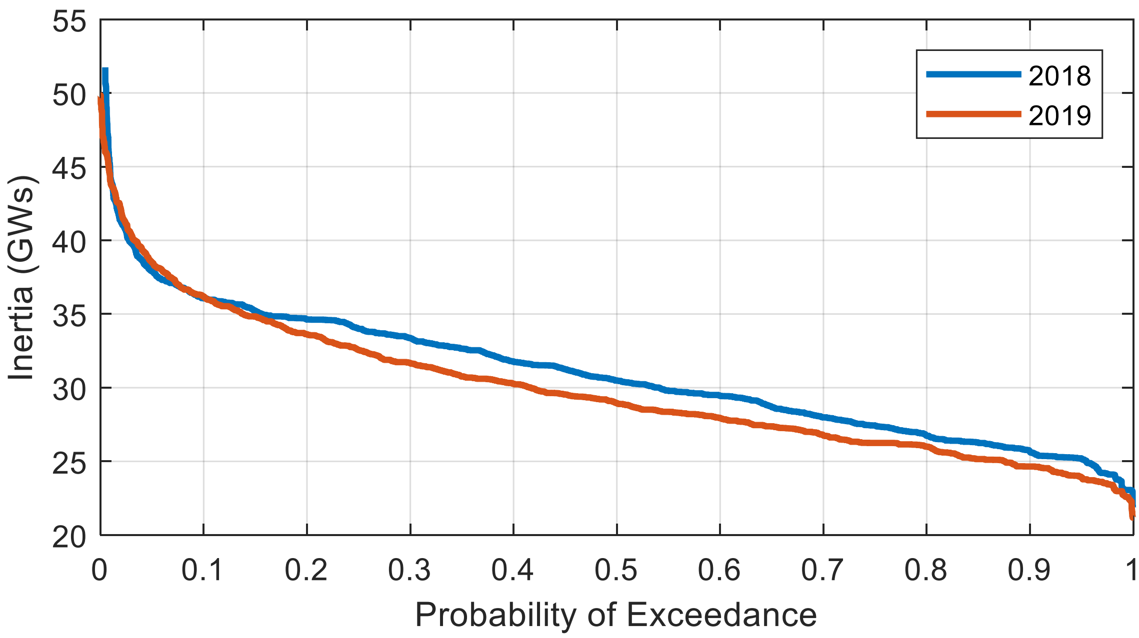
Figure 6 QNI flow duration curves, 2018 and 2019



Note: positive interconnector flow indicates flow direction from New South Wales to Queensland.

Figure 7 shows the inertia duration curves for Queensland in 2018 and 2019.

Figure 7 Inertia duration curve for Queensland, 2018 and 2019

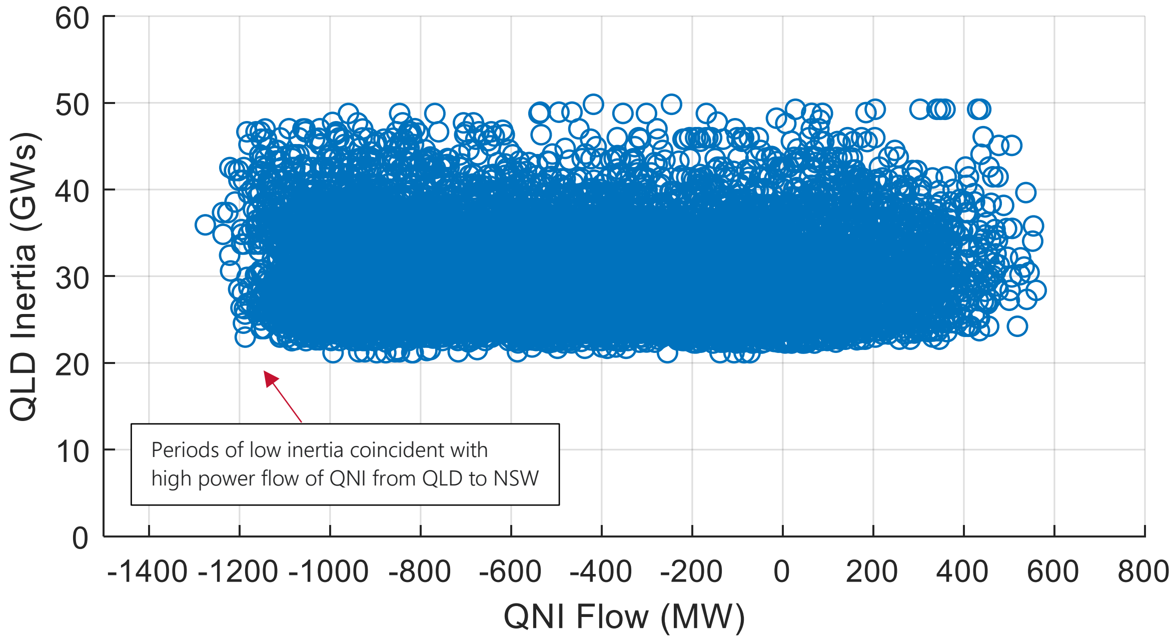


There is a decrease in the inertia levels in Queensland in 2019 compared to 2018 for 90% of the time, which could be due to the addition of 1,423 MW of large scale wind and solar farms projects during 2018-19[31].

[31] Powerlink, Annual Planning Report 2019, Section 6.2, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

Figure 8 presents the QNI flow and corresponding inertia levels in Queensland for 2019. The inertia level of Queensland remained above 20 gigawatt seconds (GWs) but below 50 GWs through the year. While more synchronous plants were dispatched when power export from Queensland to New South Wales was high, resulting in a higher level of system inertia in Queensland, there were also a significant number of dispatch intervals with high power export and lower levels of inertia. These dispatch periods with lower levels of inertia are likely to have resulted from generation from synchronous gas-fired and hydro power stations being displaced by generation from inverter-based wind and solar resources.

Figure 8 QNI flow and corresponding inertia levels



Note: positive interconnector flow indicates flow direction from New South Wales to Queensland.

Planned major network upgrades

Powerlink's future network development focus is on optimising the network topology based on forecast demand, new customer access requirements, potential power system developments, existing network configuration, and safety, condition, and compliance-based risk associated with existing assets[32].

Apart from expanding New South Wales – Queensland transfer capacity as identified in the 2018 ISP, based on the information available from Powerlink, all other upgrades are outside the scope of the PSFRR[33].

In the draft 2020 ISP, three upgrades were recommended to increase the transmission network capacity between New South Wales and Queensland. The project has progressed through regulatory approvals, and while it is subject to Australian Energy Regulator (AER) approval of contingent project applications from ElectraNet and TransGrid, the first upgrade is expected to be completed in 2021-22.[34].

The first upgrade in 2021-22 is named as Group 1 – Minor New South Wales to Queensland upgrade. This is aimed to reduce the requirement for new gas-fired generation in New South Wales once Liddell retires, as well as more efficient generation sharing between New South Wales and Queensland by increasing the

[32] Powerlink, 2019 Transmission Annual Planning Report, Section 5.3, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[33] Powerlink, 2019 Transmission Annual Planning Report, Section 5.7, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[34] AEMO, Draft 2020 ISP, December 2019, Section D in Executive Summary, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2019/Draft-2020-Integrated-System-Plan.pdf.

northward transfer capacity by 460 MW and southward transfer capacity by 190 MW[35]. Associated with the QNI upgrade, there are a few transmission line upgrades in New South Wales, indicated in Section 5.1.3.

4.1.4 Climate of Queensland

The climate in Queensland is tropical and sub-tropical, making it prone to extreme weather events.

The majority of the Queensland transmission network extends along the eastern coast and is exposed to tropical cyclones damaging the tower lines across the state. For example, in 2017, severe Tropical Cyclone Debbie and subsequent flooding damaged 19 towers on one of the parallel 275 kV single circuit lines between Broadsound and Nebo[36].

4.1.5 Overview of the 2018 PSFRR for Queensland

AEMO's investigation on the Queensland power system as part of the 2018 PSFRR highlighted the following:

- Queensland will be at risk of over-frequency leading to cascading outages following the non-credible trip of QNI during high export to New South Wales. AEMO anticipated that an OFGS scheme would be a preferable option to manage the risk.
  - At present there is no OFGS in Queensland.
  - As recommended in the 2018 PSFRR final report, AEMO and Powerlink have completed a joint study which considered the major supply disruptions which could lead to an over-frequency event. The study concluded that the recommended measures in AEMO's final report for the 25 August 2018 event will mitigate the risk of over-frequency[37].
  - The study recommended[38] improving frequency control through the NER rule changes on PFR which were made effective from 4 June 2020. This will require all capable scheduled and semi-scheduled generators dispatched to generate greater than 0 MW to operate their plant in accordance with the performance parameters set out in AEMO's PFRR[39].
- A requirement to modify the existing CQ–SQ SPS, to improve its effectiveness for anticipated increases in southerly flows associated with renewable generation connections in North Queensland. As a result of this finding, Powerlink initiated a project to implement a new wide area monitoring protection and control (WAMPAC) architecture into the CQ–SQ SPS by mid-2021. As per the plan, it is intended to include approximately 600 MW of renewable generators to the existing SPS along with the existing CQ–SQ SPS which will continue to trip the Callide units.

4.2 Emergency frequency control schemes and declared protected events in Queensland

4.2.1 Emergency frequency control schemes

Queensland has three existing EFCSs:

- Queensland UFLS scheme.

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[35] AEMO, 2018 ISP, July 2018 , Section 6.3.1, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf.

[36] Powerlink, Transmission Annual Report 2017, Executive summary, at https://www.powerlink.com.au/sites/default/files/2018-03/Transmission%20Annual%20Planning%20Full%20Report%202017_0.pdf.

[37] Powerlink, Annual Planning Report 2019, Section 6.3, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[38] AEMO, Final report – Queensland and South Australia system separation on 25 August 2018, 10 January 2019, Table 17, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[39] AEMO, Interim Primary Frequency Response Requirements, 4 June 2020, at https://aemo.com.au/en/initiatives/major-programs/primary-frequency-response.

- CQ–SQ SPS.
- Stanwell–Broadsound SIPS.

Queensland under-frequency load shedding scheme

The Queensland UFLS scheme is configured to disconnect load as a consequence of non-credible events during normal conditions. Presently, Queensland has a unified UFLS scheme configured to disconnect the loads as given in Table 3[40]. The Inhibit scheme makes an adjustment to the UFLS load blocks and tripping frequency level when there are moderate to high transfers from Queensland to New South Wales and minimises the risk of QNI separation[41].

The 2018 PSFRR assessment indicated that the existing Queensland UFLS scheme is adequate. The emerging DPV – which is forecast to increase from 2,400 MW[42] in 2018-19 to 4,000 MW in 2025-26[43] – will impact the existing UFLS scheme, and the adequacy of the settings need to be verified[44].

Table 3 Queensland existing UFLS

Scheme	Purpose
North Goonyella UFLS	Raise system frequency
Boyne Island UFLS relay	Raise system frequency
Queensland UFLS Inhibit scheme	Minimise risk of QNI separation for an UFLS event for moderate to high southern transfers on QNI compared to Queensland demand
Tarong UFLS relay	Raise system frequency
Middle Ridge UFLS relays	Raise system frequency

Central Queensland to Southern Queensland Special Protection Scheme

The CQ–SQ SPS is a generation shedding scheme designed to minimise the risk of a complete separation between Central and Southern Queensland, for a non-credible double circuit trip of the Calvale – Halys No. 8810 and No. 8811 275 kV lines. The existing scheme was commissioned in 2012 and is armed automatically by Powerlink's Energy Management System (EMS). The existing scheme is limited to transfers lower than 1,700MW and relies on the ability to disconnect high output generating units[45].

According to Powerlink's 2019 Annual Planning Report (APR), the historical transfer duration curves for CQ–SQ show a continued increase in power transfer since 2015 with further increase over time expected. In 2018, the CQ-SQ transfer was greater than 1,700 MW (the level above which CQ–SQ SPS is not effective) for approximately 5% of the time. This reveals that the existing CQ–SQ SPS is not effective for the full range of power transfers that are possible between CQ and SQ.

AEMO recommended in the 2018 PSFRR that the scheme be expanded to include other generating units in addition to the existing Callide generators.

[40] Powerlink, Annual Planning Report 2019, Table 6.3, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[41] AEMO, Power system frequency risk review report, June 2018, Section 4.2.1, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/psfrr/2018_power_system_frequency_risk_review-final_report.pdf?la=en&hash=1684259023A1FA274D7F3B8CE855D0BA.

[42] Powerlink, Annual Planning Report 2019, Section 8.1, at https://www.powerlink.com.au/sites/default/files/2019-06/Transmission%20Annual%20Planning%20Report%202019%20-%20Full%20report.pdf.

[43] AEMO, 2019 Annual Market Performance Review, 12 March 2020, Figure 2.16, at https://www.aemc.gov.au/sites/default/files/2020-04/2019%20AMPR%20final%20report%20-%20republished%20with%20minor%20amendments%20in%20April%202020.PDF.

[44] AEMO, Annual Market Performance Review 2018, 4 April 2019, Table 5.3, at https://www.aemc.gov.au/sites/default/files/2019-04/2018%20Annual%20Market%20Performance%20Review%20-%20final%20report%20%281%29.pdf.

[45] AEMO, Automated control scheme functionality, 21 August 2018, Section 6.18.

Currently Powerlink has initiated a project to implement a new wide area monitoring protection and control (WAMPAC) architecture into CQ–SQ SPS by mid-2021. As per the plan, it is intended to include approximately 600 MW of renewable generators in SPS along with the existing CQ–SQ SPS which will continue to trip the Callide units.

AEMO will continue to work with Powerlink and review the timing of these changes and the emerging risks to determine whether a protected event should be declared to allow AEMO to manage the risk through operational measures ahead of changes to the SPS. Subject to the outcome of Stage 2 2020 PSFRR studies and cost-benefit assessment, AEMO may make a submission to the Reliability Panel recommending a protected event be declared.

Stanwell–Broadsound System Integrity Protection scheme[46]

During a planned outage of one of the 275 kV lines between Stanwell and Broadsound (No. 856 or 8831 line), the loss of the remaining parallel line might result in severe overloads which could lead to system instability. This SIPS is designed to detect the severe overloads and act to avoid consequent overloads, while maintaining supply to North Queensland that can be supported by the remaining networks. After commissioning, it was armed for the first time in September 2017.

As the system conditions were not changed after commissioning, in the 2018 PSFRR AEMO did not identify any requirement to modify the Stanwell–Broadsound SIPS.

4.2.2 Protected events

There are no protected events in Queensland.

4.3 Review of incidents

Table 4 summarises relevant non-credible contingency events which occurred in Queensland since the last PSFRR. The non-credible contingency events are categorised in terms of the frequency excursion with respect to the FOS for the Mainland NEM and the state of operation of the power system, as outlined in Section 2.3.

The RoCoF values indicated in Table 4 for each incident are approximated based on available high speed monitoring data.

[46] AEMO – Automated control scheme functionality document

Table 4 Summary of relevant non-credible contingency events in Queensland

Date / time	Description of event	Primary cause	Load / generation Involved (MW)	Frequency response	RoCoF (Hz/s)	QNI flow prior to contingency	Inertia in Queensland (megawatt seconds [MWs])	Reference
Major event								
25 Aug 2018 **1311 hrs**	Series of events, separating Queensland, New South Wales and Victoria and South Australia into three islands	Environmental	No load or generation disconnected in Queensland[47]	Frequency reached 50.9 Hz Recovered to 49.5 – 50.5 Hz in 10 minutes and 8 seconds.	+0.4	870 MW from Queensland to New South Wales[48]	25,900 (The secure operating level of inertia for Queensland is 16,000 MWs[49])	AEMO Incident report[50]
Moderate event								
	No events occurred in Queensland under the moderate category.							
Minor event								
14 June 2018 0806 hrs	Trip of Wurdong No.1 275 kV Busbar	Busbar trip	No load or generation disconnected	No discernible impact	No discernible impact	375 MW from Queensland to New South Wales	29,400	AEMO Incident Report[51]
31 July 2018 1337 hrs	Trip of Nebo – Strathmore 878 and 8845 275 kV transmission lines	Operator error	No load or generation disconnected	No discernible impact	No discernible impact	661 MW from Queensland to New South Wales	29,363	AEMO Incident Report[52]

[47] AEMO, Final report- Queensland and South Australia system separation on 25 August 2018, January 2019, Executive summary, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[48] AEMO, Final report- Queensland and South Australia system separation on 25 August 2018, January 2019, Table 16, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[49] AEMO, Inertia requirements methodology, Inertia requirements and shortfalls, July 2018, Table 2, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.

[50] AEMO, Final report- Queensland and South Australia system separation on 25 August 2018, January 2019, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[51] AEMO, Trip of Wurdong 275 kV No. 1 Busbar on 14 June 2018, November 2018, https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/trip-of-wurdong-275kv-no1-busbar-on-14-june-2018.pdf?la=en&hash=7619CDAD796D6B98EDFE1A44BC6579F6.

[52] AEMO, Trip of Nebo – Strathmore 878 and 8845 275kV transmission lines on 31 July 2018, November 2018, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/trip-of-two-275-kv-transmission-lines-in-north-queensland-on-31-july-2018.pdf?la=en&hash=1CA858BAF52158AF117585744C770744

Date / time	Description of event	Primary cause	Load / generation Involved (MW)	Frequency response	RoCoF (Hz/s)	QNI flow prior to contingency	Inertia in Queensland (megawatt seconds [MWs])	Reference
23 Sep 2018 1618 hrs	Trip of Nebo No. 1 275 busbar	Human error	No load or generation disconnected	No discernible impact	No discernible impact	563 MW from Queensland to New South Wales	26,417	AEMO Incident Report[53]
9 Jan 2019 2133 hrs	Trip of Collinsville North Clare South and Strathmore Clare South 110 kV lines and Strathmore Static Var Compensator	Control system failure	No load or generation disconnected	No discernible impact	No discernible impact	85.87 MW from New South Wales to Queensland	34,665	AEMO Incident Report[54]
16 June 2019 0555 hrs	Power system in Queensland not in a secure operating state after the trip of the Calvale to Wurdong transmission line	Unplanned outage	No load or generation disconnected	No discernible impact	No discernible impact	297 MW from Queensland to New South Wales	24,432	AEMO Incident Report[55]
25 Aug 2019 1409 hrs	Trip of Nebo No. 2 275 kV busbar	Human error	No load or generation disconnected	No discernible impact	No discernible impact	910 MW from Queensland to New South Wales	24,491	AEMO Incident Report[56]
24 Sep 2019 1450 hrs	Trip of the No. 2 275 kV busbar at Calvale	Human error	No load or generation disconnected	No discernible impact	No discernible impact	908 MW from Queensland to New South Wales	26,449	AEMO Incident Report[57]

[53] AEMO, Trip of Nebo No1 275kV busbar on 23 September 2018, February 2018, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/nebo-bus-outage-23-sept-2018.pdf?la=en&hash=1C0726E388AE89100C7DFE841045CEF8.

[54] AEMO, Trip of Collinsville North – Clare South and Strathmore – Clare South 110 kV lines, and Strathmore Static Var Compensator, on 9 January 2019, November 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/7128-and-7208-lines-and-strathmore-svc-9-jan-2019.pdf?la=en&hash=DCE155196C208D1442BF7AE7CAC63721.

[55] AEMO, Power system in Queensland not in a secure operating state after the trip of the Calvale to Wurdong transmission line on 16 June 2019, December 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/qld-not-secure-16-june-2019.pdf?la=en&hash=69ABC01E77FD7399BD73E007AD0C3929.

[56] AEMO, Trip of the Nebo No. 2 275 kV busbar on 25 August 2019, November 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/report-nebo-busbar-outage.pdf?la=en&hash=EA250BE473C25FFDED1875121CF948B6.

[57] AEMO, Trip of the No. 2 275 kV busbar at Calvale on 24 September 2019, December 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/trip-of-calvale-no2-busbar.pdf?la=en&hash=E985F2684676C291A55BD414191E11CB.

25 August 2018 – Queensland and New South Wales system separation[58]

This event was triggered by a lightning strike on a transmission tower structure supporting the 330 kV QNI lines, and tripping off the double circuit transmission line between Dumaresq – Bulli Creek. This resulted in Queensland being islanded from the rest of the NEM. At the time of separation, 870 MW of power was flowing from Queensland to New South Wales. With the disconnection, Queensland experienced an immediate supply surplus, resulting in a rise in frequency to 50.9 Hz. The remainder of the NEM experienced a supply deficit, resulting in a reduction in frequency.

Following Queensland separation, the Heywood interconnector experienced rapid changes in power system conditions that triggered the Emergency Alcoa Portland Tripping (EAPT) scheme resulting in a separation of South Australia at Heywood.

Prior to the event, no credible risks of regional separation were identified. Generation at the time was predominantly from synchronous units, with only 4% of the total NEM contributed from wind and large-scale solar. Only 49% of the total installed capacity of DPV across the NEM was generating at the time of the event.

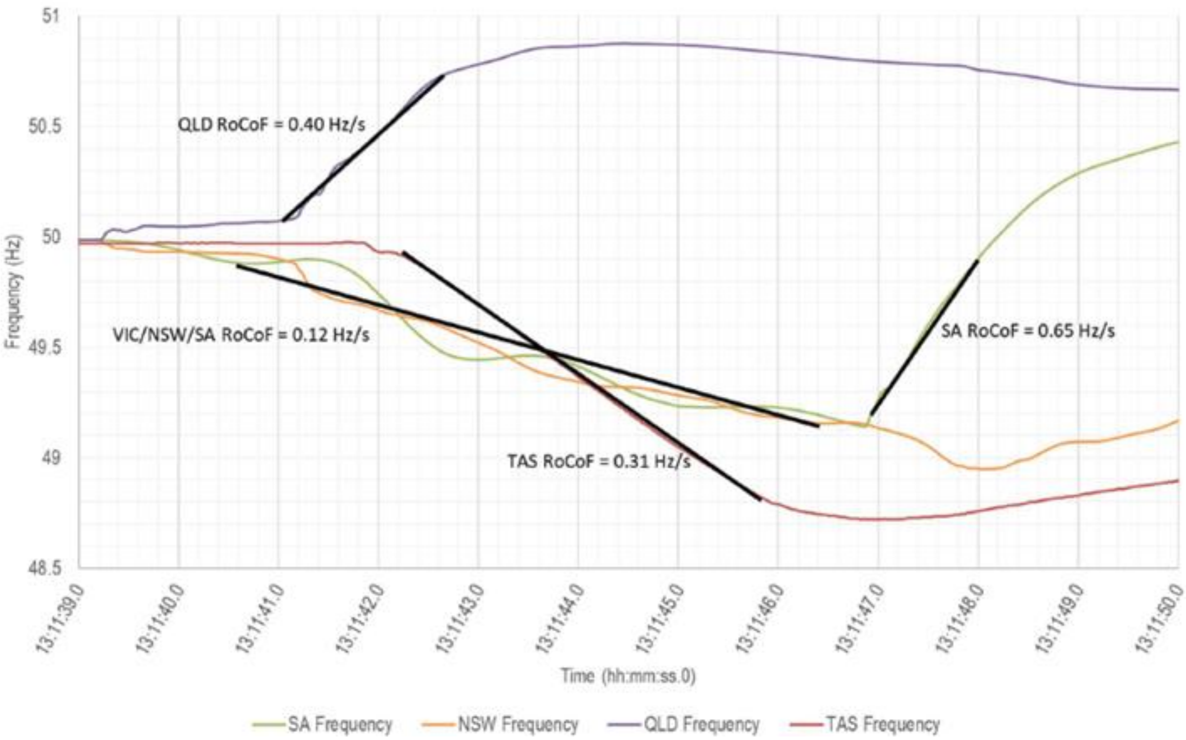
Due to this incident, the power system separated into three island regions:

- The Queensland region.
- The interconnected Victoria, New South Wales, and Tasmania regions.
- The South Australia region.

Consequently, RoCoF in Queensland reached 0.4 Hz/s, RoCoF in New South Wales, Victoria, and South Australia reached 0.12 Hz/s, and Tasmania RoCoF reached 0.31 Hz/s.

The regional frequencies and RoCoF during the event are shown in Figure 9[59].

Figure 9 Regional frequencies and RoCoF during separation event, 25 August 2018



[58] AEMO, Incident Report, January 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[59] AEMO, Final Report – Queensland and South Australia system separation on 25 August 2018, 10 January 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

To achieve the most economical and feasible outcome, in normal operating conditions, FCAS reserve is acquired from anywhere within a set of interconnected regions. At the time of this event, 50% of the enabled contingency raise FCAS sources were in South Australia and Queensland, but the raise services were ultimately required in the New South Wales and Victoria island. Due to the lack of coordinated frequency control available, there was a delay in synchronising the Queensland and New South Wales networks, and the power system in Queensland was not in a secure operating state 68 minutes. The Terranora DC link remained in service during the event, as it does not provide any MW response to frequency changes at either end of the link and hence was not impacted by the event.

AEMO identified the following key factors for the incident[60]:

- Limited or no primary frequency control response from many generators (this will be addressed for an initial period up to June 2023 by the mandatory PFR rule and PFRR described in Section 4.1.5).
- The geographic distribution of FCAS reserves across the NEM at the time of the event, which were unable to immediately respond to the needs of the power system after separating into islands.

In addition to the requirement of primary frequency control and better dispersion of FCAS reserves, AEMO identified the following improvements to strengthen NEM resilience:

- High frequency experienced in Queensland following the QNI separation, highlights a need for co-ordinating the over-frequency protection settings, particularly for new plants, to minimise the risk of multiple generator tripping simultaneously.
- The initial frequency response from some generators was delayed, highlighting a need to improve the speed of frequency control response where possible.

14 June 2018 – trip of Wurdong 275 kV No. 1 busbar

The trip of the No. 1 busbar occurred due to insufficient isolation of protection systems during planned secondary systems upgrade work. All protection systems operated as designed. There was no loss of generation or customer load, and the power system remained in a secure operating state. The cause of this incident was identified and AEMO was satisfied that a reoccurrence of this incident was unlikely, therefore the incident was not reclassified as a credible contingency.

31 July 2018 – trip of Nebo – Strathmore 878 and 8845 275 kV transmission lines

The incident involved the near simultaneous trip of the 878 Nebo – Strathmore 275 kV transmission line (878 line) and the 8845 Nebo – Strathmore 275 kV transmission line (8845 line). This occurred during a planned maintenance on the 7125 Collinsville North – Proserpine 132 kV transmission line (7125 line). Powerlink has reviewed the relevant procedures and made changes where considered necessary.

There was no loss of generation or customer load, and the power system remained in a secure operating state. AEMO determined that reclassification of the simultaneous loss of both the 878 and 8845 lines as a credible contingency was not required.

23 September 2018 – trip of Nebo No. 1 275 kV busbar

The trip of the No. 1 busbar was due to insufficient isolation of protection systems on the 8846 Broadsound – Nebo 275 kV transmission line during planned secondary systems work. There was no loss of generation or customer load, and the power system remained in a secure operating state. AEMO determined that reclassification of the No. 1 busbar as a credible contingency event was not required.

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[60] AEMO, Final Report – Queensland and South Australia system separation on 25 August 2018, 10 January2019 https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C

9 January 2019 – trip of Collinsville North – Clare South and Strathmore – Clare South 110 kV lines, and Strathmore Static Var Compensator

The incident involved the trip of the 7128 Collinsville North – Clare South and 7208 Strathmore – Clare South 132 kV transmission lines (7128 and 7208 lines) and the Strathmore No. 1 Static Var Compensator (1 SVC). There was no loss of generation or customer load, and the power system remained in a secure operating state. AEMO was not required to reclassify the loss of both lines as a credible contingency, because, in accordance with the Power System Security Guidelines, the lines were not considered vulnerable to lightning. However, after the incident, these lines were added to the vulnerable line list to enable to AEMO reclassify loss of both circuits as a credible contingency event.

16 June 2019 – power system in Queensland not in a secure operating state after the trip of the Calvale – Wurdong transmission line

The incident involved the power system in the Queensland region being operated in a non-secure operating state for 91 minutes after the unplanned outage of the Calvale – Wurdong 871 275 kV transmission line (871 line). There was no loss of generation or customer load as a result of this incident.

25 August 2019 – trip of the Nebo No. 2 275 kV busbar

The incident involved the trip of the Nebo No. 2 275 kV busbar (No. 2 busbar) due to a human error during a planned secondary systems maintenance work on the No. 1 Transformer 'X' protection system. The outage of the No. 2 busbar also resulted in the offloading of the Nebo – Strathmore 822 275 kV transmission line (822 line), due to the existing outage of the 834 line. There was no loss of generation or customer load. The power system was not in a secure operating state for 26 minutes. AEMO determined that reclassification of the loss of the No. 2 busbar and the 822 line as a credible contingency was not required.

24 September 2019 – trip of the No. 2 275 kV busbar at Calvale

The incident involved the trip of the Calvale No. 2 275 kV busbar (No. 2 busbar) due to insufficient isolation of secondary systems during planned work. The insufficient isolation was the result of human error. There was no loss of generation or customer load, and the power system remained in a secure operating state. AEMO determined the incident was unlikely to reoccur and therefore, that reclassification as a credible contingency event was not required.

Other notable incidents

One non-credible contingency event occurred in Queensland in early 2020 – trip of Calvale – Stanwell 8873 and 8874 lines, 26 February 2020 – however, the incident was still subject to review at the time of preparation of this report.

Further analysis will be undertaken in Stage 2, if required.

4.4 Operational experience and impact

4.4.1 Weather-related operational experience

Powerlink has a defined process for assessing operating risks and setting up mitigation plans to ensure system security during extreme weather events.

Initial investigations for the 25 August 2018 incident (simultaneous tripping of both QNI lines) were unable to identify a likely lightning strike near the QNI. Before the event, severe weather warnings were issued in southern Queensland and northern New South Wales. However, the QNI fault location is well outside the weather districts where warnings were issued.

To identify the reason for tripping, AEMO separately worked with two lightning detection system providers and both confirmed a cloud to ground lightning strike within 300 metres of the transmission tower where Powerlink discovered flash marks in a visual inspection[61].

After detailed independent analysis provided by lightning detection providers, AEMO concluded that the cause of the fault which resulted in the trip of QNI was a lightning strike.

The probability of lightning resulting in loss of both QNI lines is considered to be low, hence simultaneous tripping of both lines is classified as a non-credible event.

4.5 Frequency risk management 2020-25

Synchronous generators are sources of inertia in the power system. They inherently resist changes in frequency, consequently reducing the RoCoF and allowing time for FCAS to bring frequency to the stabilisation range. During high Northern Queensland (NQ) to CQ transfer, the disconnection of any additional large synchronous generators in addition to the Callide generators will be an issue for system inertia. To minimise the additional synchronous generator shedding, Powerlink is investigating the possibilities of shedding renewable generators or adding load blocks to the network.

Apart from the double-circuit QNI trip and contingencies on Halys – Calvale 275 kV circuits, there were no identified priority contingencies in discussions with Powerlink. This will be further reviewed in the PSFRR Stage 2 report.

4.6 Summary

4.6.1 Changes to primary frequency control and emergency frequency control schemes

Based on the 2018 PSFRR recommendations and investigation of subsequent system events, the following initiatives were undertaken:

- Submission of a rule change proposal to address the impacts of significantly reduced PFR observed during the 25 August 2018 separation incident, with the AEMC making a final rule effective from 4 June 2020.
- Initiation of planned modification of the existing CQ–SQ SPS by adding more generating units to the trip schedule. Powerlink's WAMPAC project is expected to operate approximately 610 MW of renewable generators by mid-2021, in parallel with the existing CQ–SQ SPS which will continue to trip the Callide units.

In the past, Queensland had experienced islanding events associated with under-frequency. With the expected emerging DPV, the adequacy of existing UFLS settings require review[62].

4.6.2 Adequacy of CQ–SQ SPS

There are increasing risks associated with the existing CQ–SQ SPS. Modifications to the existing SPS are required for the scheme to be effective during period of higher southerly flows, which are becoming increasingly frequent as new generation projects come online in north Queensland. AEMO will continue to work with Powerlink and review the timing of these changes and the emerging risks to determine whether a protected event should be recommended to allow AEMO to manage the risk through operational measures ahead of changes to the SPS currently expected by mid-2021.

[61] AEMO, Final report: Queensland and South Australia system separation on 25 August 2018, 10 January 2019, Section 2.3.3, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[62] AEMC, Final report, Annual Market Performance Review 2018, 04 April 2019, Table 5.3, at https://www.aemc.gov.au/sites/default/files/2019-04/2018%20Annual%20Market%20Performance%20Review%20-%20final%20report%20%281%29.pdf.

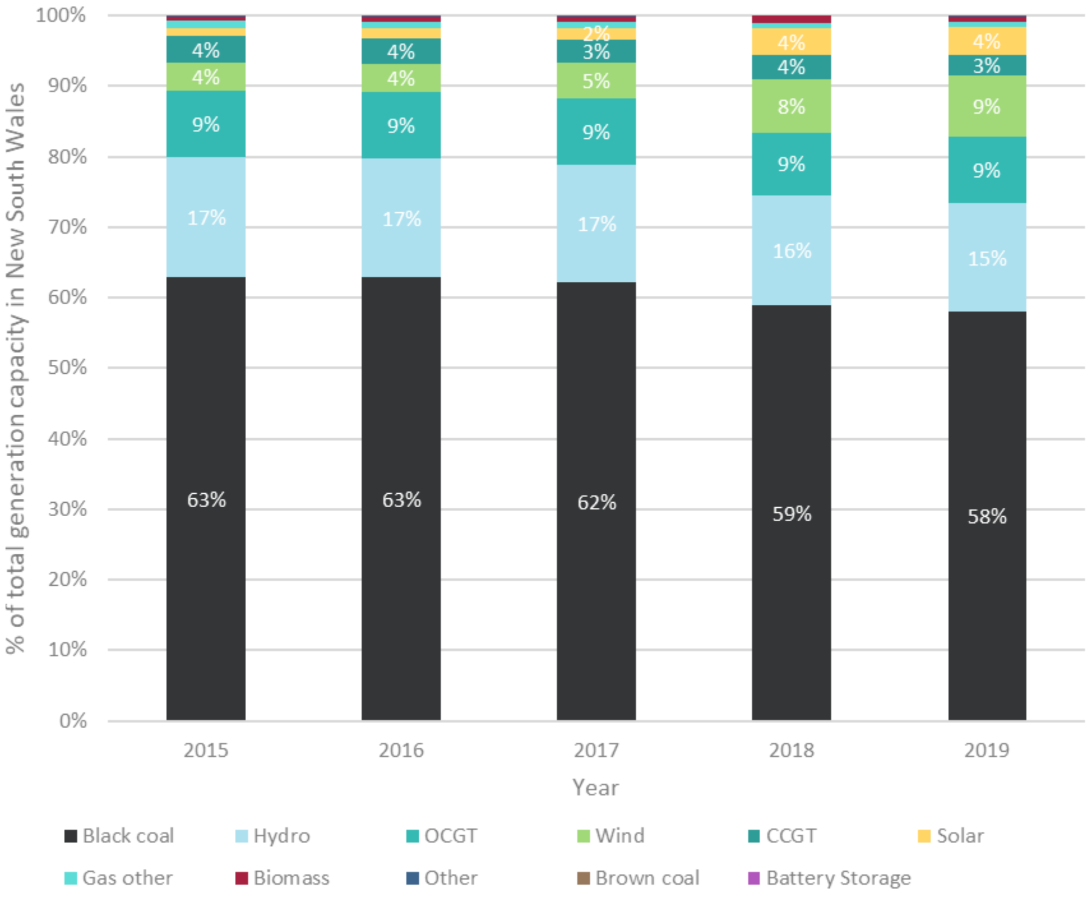
5. New South Wales

5.1 Introduction

5.1.1 Generation in New South Wales

The New South Wales region features the largest operational demand in the NEM, with summer maximum demand of around 14,000 MW[63,64]. The power system in New South Wales is undergoing rapid transformation as ageing synchronous generators like Liddell and Vales Point approach retirement[65] and the number of new inverter-based generation connections increases. This region already has around 1,504 MW of wind farms and 1,043 MW of solar farms[66]. 0 shows the New South Wales generation mix over the past five years, based on data obtained from AEMO's Generation Information page[67].

Figure 10 New South Wales generation mix changes, 2015-19



Note: the contributions of some generation sources are not large enough to be visible on this chart.

63 AEMO, 2019 ESOO, August 2019 at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2019/2019-electricity-statement-of-opportunities.pdf?la=en.

64 TransGrid, 2019 Annual Planning Report, at https://www.transgrid.com.au/what-we-do/Business-Planning/transmission-annual-planning/Documents/2019%20Transmission%20Annual%20Planning%20Report.pdf.

65 AEMO, 2018 ISP, at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2018-integrated-system-plan-isp.

66 AEMO, NEM registration and exemption list, at https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/information-for-current-participants/participants-registered-for-the-nem.

67 AEMO Generation Information, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/generation_information/nem-generation-information-april-2020.xlsx?la=en. Data used in this chart has been taken from the final update each year.

The contribution of renewable generation has increased over the years, and the trend is set to continue in the future with high generator connection interest shown in large wind and solar sectors. The contribution from coal-fired generation has decreased over the last five years, and is forecast to continue declining.

With synchronous generators retiring or being displaced in the generating mix, the system inertia of the New South Wales region is set to decrease. This will reduce the inertia margin available in the region to deal with loss of generator contingencies and planned or unplanned generator outages.

Renewable inverter-based generation has limited capability to respond to under-frequency events unless output is pre-curtailed. As the amount of online synchronous generation reduced, more FCAS raise services will be needed and the potential benefits of fast frequency response will increase.

5.1.2 Electricity demand in New South Wales

Normal grid demand in New South Wales is between 12,000 MW and 14,000 MW throughout the year; however, the demand can exceed 15,000 MW on summer peak days. During summer periods, the peak demand occurs towards late afternoon and during winter it occurs in the evening.

5.1.3 Transmission system in New South Wales

TransGrid owns, operates, and maintains the electricity transmission network in New South Wales. Ausgrid, Endeavour Energy and Essential Energy own, operate, and maintain the electricity distribution network in New South Wales, while Evoenergy is the main electricity distributor in the Australian Capital Territory.

The transmission network in this region is relatively meshed compared with other regions and features 500 kV, 330 kV, 220 kV, and 132 kV networks. Major transmission lines are located towards the east coast of the region. Regional loads are served by radial transmission and sub-transmission lines routed west.

Interconnection with Queensland and New South Wales

The New South Wales region is interconnected with the Queensland region via 330 kV AC interconnector (QNI) which includes two transmission lines between Dumaresq in New South Wales and Bulli Creek in Queensland. The present nominal capacity of QNI is 300-600 MW from New South Wales to Queensland and 1,078 MW from Queensland to New South Wales.

There is also a DC link at 110 kV, between Terranora and Mullumbimby in New South Wales. Terranora is connected to Queensland through double-circuit AC lines. The nominal capacity of the Terranora interconnector is 107 MW from New South Wales to Queensland and 210 MW from Queensland to New South Wales. Due to its low power rating, loss of the Terranora interconnector is not likely to cause frequency risks in New South Wales or Queensland.

QNI flow patterns in 2018 and 2019 are illustrated by flow duration curves, shown in Figure 6 (in Section 4.1.3), which show that New South Wales typically imports power from Queensland (around 90% of the time).

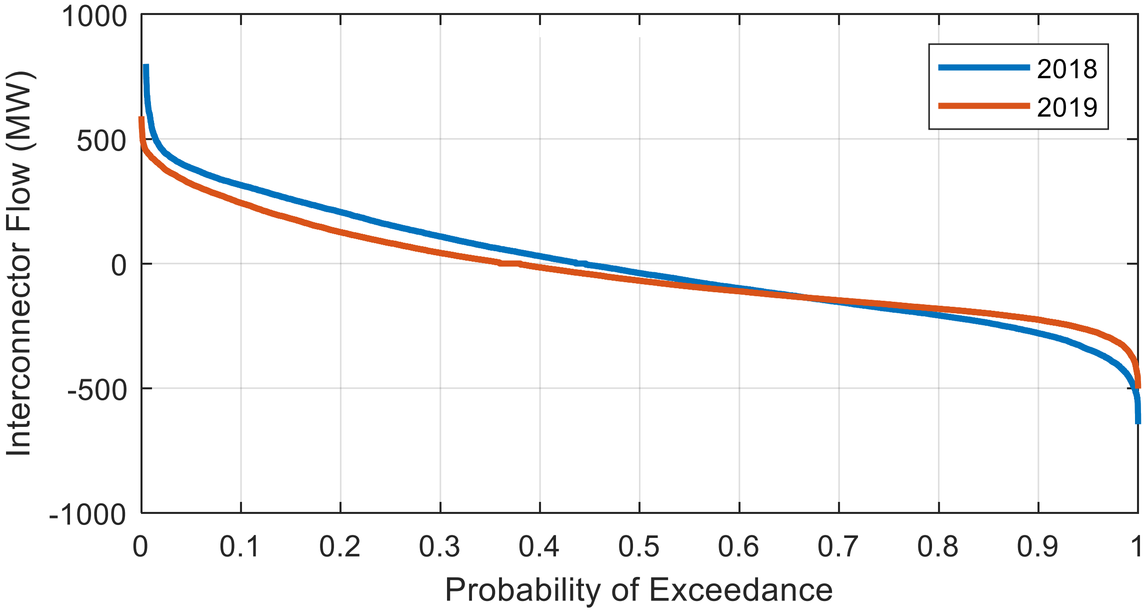
Interconnection with New South Wales NSW and Victoria

New South Wales is interconnected with Victoria via three 330 kV AC transmission lines (termed VIC1-NSW1) routed between Murray – Upper Tumut, Murray – Lower Tumut, and Jindera – Wodonga substations, and another 220 kV AC transmission line between Buronga and Red Cliffs. The nominal capacity of the New South Wales – Victoria interconnector is 400-1,350 MW from New South Wales to Victoria and 700-1,600 MW from Victoria to New South Wales.

The VIC1-NSW1 flow patterns in 2018 and 2019 are illustrated via flow duration curves, shown in Figure 11 (Murray – Upper Tumut), Figure 12 (Murray – Lower Tumut), and Figure 13 (Jindera – Wodonga). The following conclusions can be drawn:

- Flow direction on the Jindera – Wodonga circuit was from Wodonga (Victoria) to Jindera (New South Wales) approximately 80% of the time in both 2018 and 2019.
- New South Wales imported power from Victoria more of the time in 2018 than in 2019.

Figure 11 Murray – Upper Tumut interconnector flow duration curves in 2018 and 2019



Note: Positive interconnector flow indicates flow direction from Murray to Upper Tumut

Figure 12 Murray – Lower Tumut interconnector flow duration curves in 2018 and 2019

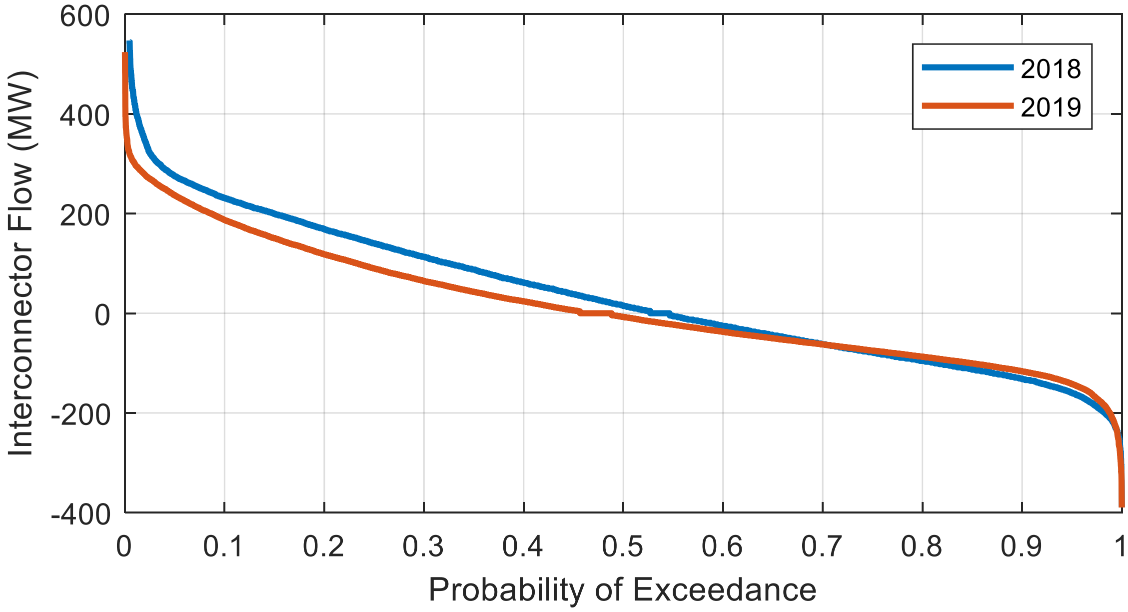
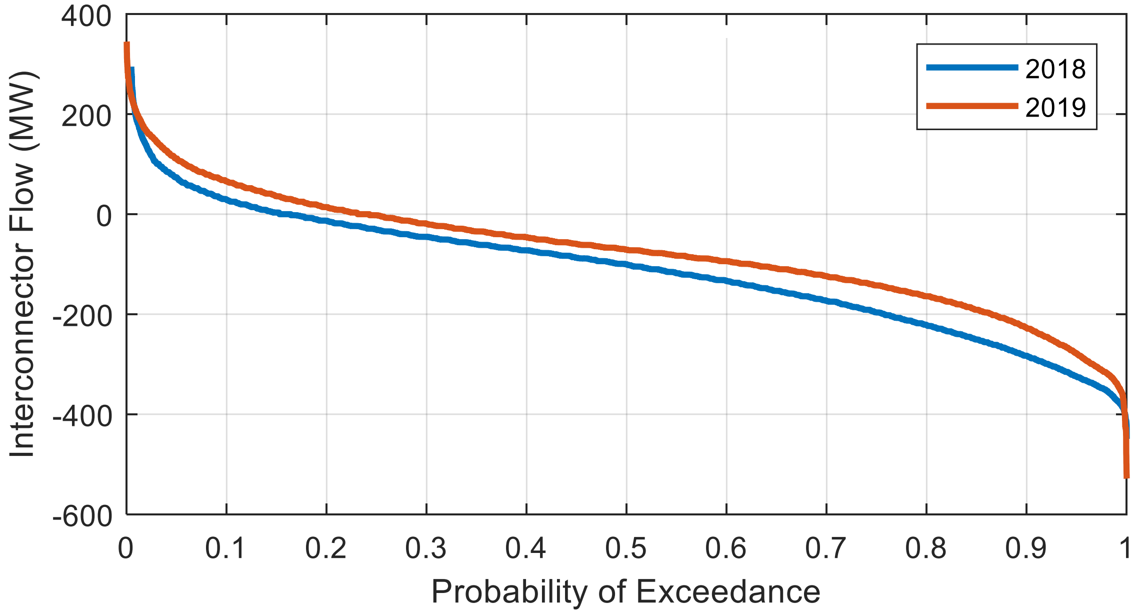


Figure 13 Jindera – Wodonga interconnector flow duration curves, 2018 and 2019



Note: Positive interconnector flow indicates flow direction from Jindera to Wodonga

Figure 14 shows the inertia duration curve for New South Wales in 2018 and 2019. There is an increase in the inertia levels in New South Wales in 2019 compared to 2018 (from 0% to 90% of the time). This could be correlated with the high import to New South Wales from Victoria in 2018 resulting in a lower number of synchronous machines online in New South Wales.

Figure 14 Inertia duration curve for New South Wales, 2018 and 2019

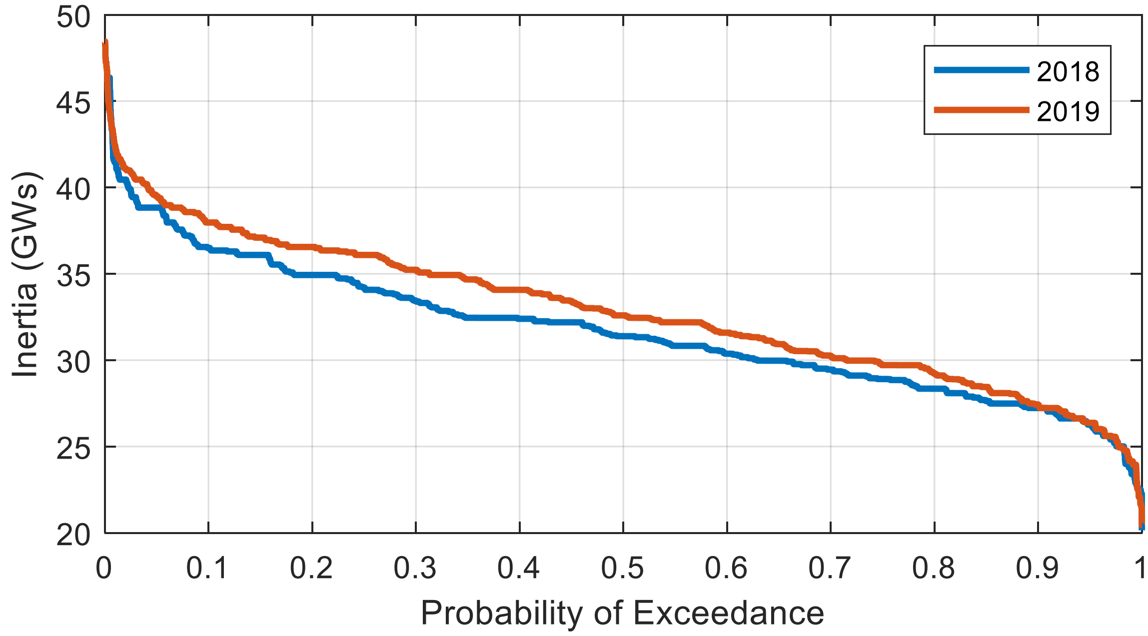
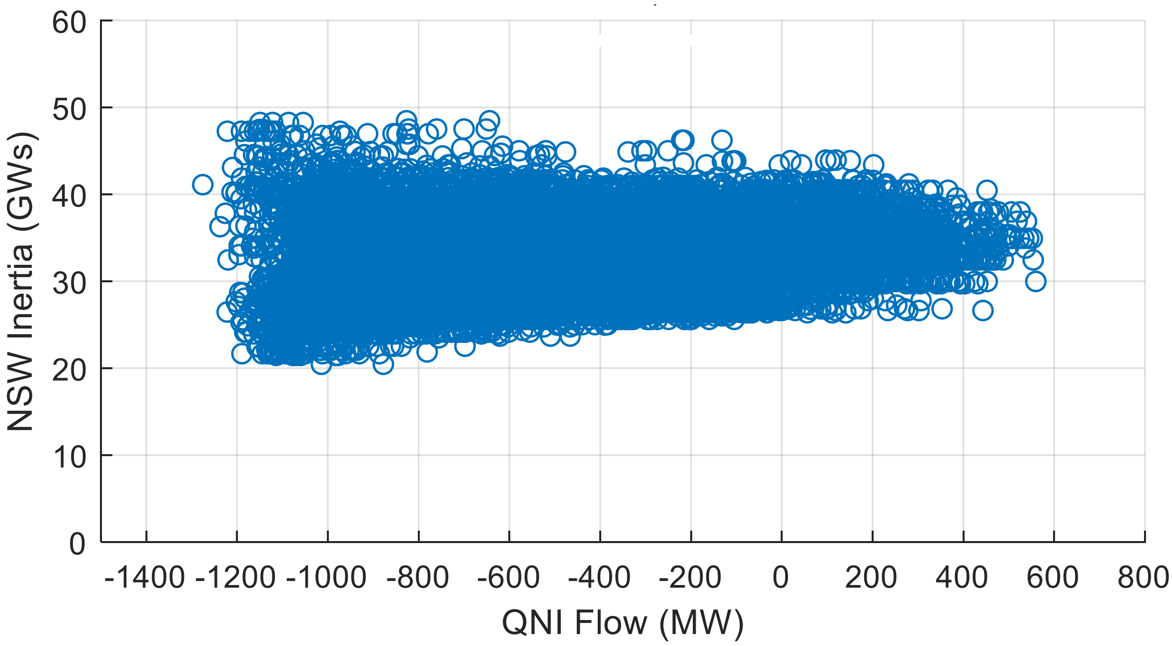


Figure 15 shows the QNI interconnector flow and corresponding inertia levels in New South Wales for 2019. A cluster of low inertia levels can be observed when New South Wales was importing power from Queensland. There is also a trend of decreasing inertia level in New South Wales as power import from Queensland increases. This could be due to a lower number of synchronous machines online in New South Wales during such times.

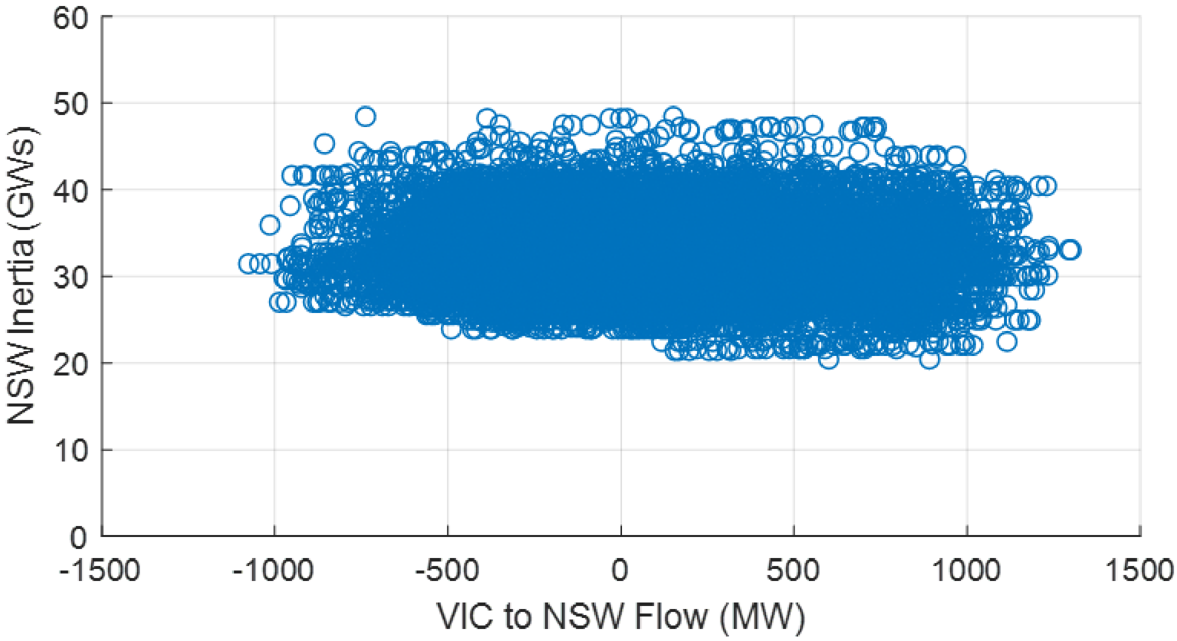
Figure 15 QNI interconnector flow and corresponding inertia levels in New South Wales for 2019



Note: Positive interconnector flow indicates flow direction from New South Wales to Queensland

Figure 16 shows the Victoria to New South Wales flow and corresponding inertia levels in New South Wales for 2019. A cluster of low inertia levels can be observed when New South Wales was importing power from Victoria. There is also a trend of decreasing inertia level in New South Wales as power import from Victoria increases. This could be due to a lower number of synchronous machines online in New South Wales during such times. There were also some instances where inertia in New South Wales was high even though there was high import from Victoria. This can be correlated with situations of high output from renewable generation in Victoria.

Figure 16 Victoria to New South Wales flow and corresponding inertia levels in New South Wales for 2019



Note: Positive interconnector flow indicates flow direction from Victoria to New South Wales

Planned major network upgrades in 2020-25

Major network developments are proposed in the New South Wales region to address transmission constraints and support the connection of new renewable generation. These include:

- Project EnergyConnect:
  - A new 330 kV interconnector is proposed between Wagga Wagga in New South Wales and Robertstown in South Australia.
- QNI interconnector upgrade:
  - QNI upgrade involves upgrade of 330 kV transmission lines between Liddell Power Station and Muswellbrook and Tamworth substations in New South Wales. The QNI upgrade will allow transfer of a further 460 MW of power from New South Wales to Queensland and 190 MW from Queensland to New South Wales. As part of the QNI upgrade, TransGrid will also upgrade substations at Tamworth, Dumaresq, Armidale, and Muswellbrook. The AER approved the Regulatory Investment Test – Transmission (RIT-T) for the project in March 2020.
- Victoria to New South Wales (VNI) interconnector upgrade:
  - VNI upgrade involves installing modular power flow controllers on both 330 kV Upper Tumut – Canberra and 330 kV Upper Tumut – Yass lines and potential upgrade of 330 kV transmission lines between Upper Tumut and Canberra in New South Wales. The upgrade will allow transfer of a further 170 MW of power from Victoria to New South Wales. See Section 6.1.2 for more details.
- HumeLink – reinforcement of the Southern New South Wales network:
  - HumeLink involves reinforcing the transmission network in Southern New South Wales with new 500 kV transmission lines between substations at Wagga Wagga, Bannaby, and Maragle. The project is proposed to provide additional transfer capacity between Snowy Mountains and the major load centres of Sydney, Newcastle, and Wollongong.
- Transmission reinforcements to support Central Western New South Wales network for renewables:
  - Central Western New South Wales is identified as a high potential large-scale renewable energy zone (REZ). There is substantial generator connection interest in this area, and the existing transmission system is inadequate to support this huge energy potential. TransGrid has identified a range of network options to address this. The options include a new Beryl 330 kV substation or upgrades to 132 kV lines from Mount Piper or Wellington.
- Transmission reinforcements to support North Western New South Wales network for renewables:
  - North and North Western New South Wales regions are also identified as a high potential REZs. There is substantial generator connection interest in this area, and the existing transmission system needs to be upgraded to support this huge energy potential. TransGrid has identified a contingent project to support renewable energy projects in this area.

The power system risk profile will change as the network topology evolves, as new generation connections and dispatch patterns change. It is crucial that these risks are thoroughly considered and assessed, both as part of the design of new assets, and as part of routine planning reviews including the PSFRR.

5.1.4 Climate of New South Wales

The east coast of New South Wales region is generally a temperate zone, ranging from warm temperate to cool temperate as it traverses from east to west. There are some alpine areas towards the south of the region. Inland west and north areas are characterised by hot dry summers and cool winters[68].

[68] Australian Government, Australian climate zones, https://www.yourhome.gov.au/introduction/australian-climate-zones.

New South Wales experiences a range of extreme weather conditions like bushfires, high temperatures and high-wind storms depending on the time of year and location. Consequently, the transmission network in this region is prone to these extreme weather events which could impact large areas of the region.

Weather extremes in the region have been on the rise during recent years. The summer months of December and January were unusually warm in 2018 and 2019, and hot and dry conditions contributed to significant bushfires in the region during these years.

5.1.5 Overview of the 2018 PSFRR of New South Wales

AEMO's assessment during the 2018 PSFRR did not identify the need to modify New South Wales EFCSs.

In the 2018 PSFRR, two historical switchyard current transformer (CT) failure incidents at Bayswater Power Station (on 13 August 2004 and 2 July 2009) were reviewed. TransGrid has since replaced CTs of the same batch and similar failure-prone CTs at other locations in the network. Therefore, the probability of a similar incident occurring is expected to be low. However, an unforeseen equipment failure at a high voltage switchyard leading to disconnection of large generators or loads from the system carries the risk of a major frequency event similar to these historical incidents.

AEMO, in consultation with TransGrid, identified the following three priority non-credible contingency events. There were no recommendations from AEMO on the management of frequency risks relating to these events, however AEMO supported TransGrid exploring options to manage the risks of transient instability during these events. Based on the TransGrid 2019 APR, AEMO notes the following plans by TransGrid:

- New South Wales power system separation at Yass.
  - Implementation of a SPS 'Yass area 330 kV smart grid controls' by 2025 to run back generation and load in the event of trip of two or more 330 kV lines in Yass area. The 330 kV lines considered for this scheme are Yass to Gullen Range (3J), Yass to Marulan (4, 5), Bannaby to Gullen Range (61).
- New South Wales separation from Queensland.
  - Implementation of a SPS 'North-west New South Wales 330 kV smart grid controls' by 2025 to run back generation and load in the event of trip of two or more 330 kV lines between Armidale and Liddell.
- New South Wales separation from Victoria.
  - Implementation of a SPS 'Snowy area 330 kV smart grid controls' by 2025 to run back generation and load in the event of simultaneous trip of Murray to Lower Tumut (66) and Murray to Upper Tumut (65) 330 kV lines.

5.2 Emergency frequency control schemes and declared protected events in New South Wales

5.2.1 Emergency frequency control schemes

The New South Wales region currently has only one EFCS, the New South Wales UFLS scheme. The scheme starts to operate from a frequency of 49 Hz shedding loads to 47 Hz where approximately 67% of New South Wales loads are shed. The load shedding occurs across transmission and distribution system connected loads.

There are no OFGS schemes in the region at present.

5.2.2 Protected events

There are no protected events declared for New South Wales region.

5.3 Review of incidents

Table 5 summarises the relevant non-credible contingency events which occurred in New South Wales since the last PSFRR in June 2018. The non-credible contingency events are categorised in terms of the frequency excursion with respect to the FOS for mainland and the state of operation of the power system, as stated in Section 2.3.

The RoCoF values indicated in the table for each incident are approximated, based on available high speed monitoring data.

Table 5 Summary of relevant non-credible contingency events in New South Wales

Date / time	Description of event	Primary cause	Load / generation involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow prior to contingency	Inertia in New South Wales (MWs)	Reference
Major event								
25 Aug 2018 13:11:39 hrs	Queensland and South Australia system separation	Lightning	622 MW of industrial load and 93.3 MW of non-industrial load were lost. There were no generator trips in New South Wales region.	Reached a nadir of 48.95 Hz from 50 Hz immediately prior to QNI trip.	-0.12	870 MW (Queensland to New South Wales)	28,350	AEMO Incident Report[69]
4 Jan 2020 15:10 hrs	Victoria - New South Wales Separation	Bushfire	43 MW of customer load and 34 MW of generation disconnected in New South Wales region.	Reached a nadir of 49.5 Hz from 50 Hz immediately prior to the event.	+0.11	618 MW (Victoria to New South Wales) 790 MW (Queensland to New South Wales)	41,591	AEMO Preliminary Incident Report[70]
Moderate event								
31 Jan 2020 13:24 hrs	Victoria - South Australia system separation	Thunderstorms resulting in collapse of transmission towers	No load or generation disconnected in New South Wales region.	Reached a nadir of 49.65 Hz from 50.1 Hz immediately prior to the event.	-0.08	575 MW (Victoria to New South Wales) 1,119 MW (Queensland to New South Wales)	42,647	AEMO Preliminary Incident Report[71]
Minor event								
				No events occurred in New South Wales under the Minor category				

[69] AEMO Incident Report, January 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[70] AEMO, Incident Report, March 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/preliminary-report-nsw-and-victoria-separation-event-4-jan-2020.pdf?la=en.

[71] AEMO, Incident Report, January 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/preliminary-report-31-jan-2020.pdf?la=en.

25 August 2018 – Queensland and South Australia system separation

On 25 August 2018, at 13:11:39, both lines on the QNI tripped due to lightning strike, resulting in the separation of Queensland region from the rest of the NEM. At 13:11:41 hrs, Tamworth – Armidale 330 kV line 86 tripped at Armidale end. This was followed by AC separation of the South Australia region from the rest of the NEM due to a trip of Heywood interconnector at 13:11:46 hrs.

New South Wales region remained synchronously connected to Victoria throughout this event. Due to loss of infeed from Queensland and South Australia, the frequency of the New South Wales and Victoria regions declined at a rate of -0.12 Hz/s. Automatic UFLS in New South Wales, Victoria, and Tasmania operated during this event. See Sections 4.3 and 7.3.1 for more details.

4 January 2020 – Victoria and New South Wales separation

A major bushfire event in the Snowy Mountains area resulted in the separation of Victoria and New South Wales. Prior to the event, there were 28 unplanned outages of 330 kV transmission lines in the Southern New South Wales region due to bushfires. The event resulted in a loss of 34 MW generation and 43 MW load, and a 2,267 MW reduction of generation availability in New South Wales. In anticipation of separation, AEMO managed the power flows in the VNI lines prior to separation, limiting the power system security risks.

31 January 2020 – Victoria and South Australia separation

At approximately 1324 hrs on 31 January 2020, the collapse of a number of steel transmission towers on the Moorabool – Mortlake and Moorabool – Haunted Gully 500 kV lines resulted in these lines tripping, which caused separation of the South Australia region from Victoria.

High flows were also recorded from Queensland to New South Wales on the QNI as a result of the loss of transfer from South Australia into Victoria. The frequency reached a nadir of 49.65 Hz from 50.1 Hz immediately prior to the event. No load or generation disconnected in New South Wales.

5.4 Operational experience and impact

5.4.1 Weather-related operational experience

New South Wales has experienced several weather extremes during 2018-20, with 2019 the warmest year on record for New South Wales and 2018 the second-warmest. The summer months of December and January have been particularly warm in recent years. Hot and dry conditions contributed to significant bushfires in 2018, 2019, and 2020, with 2019 bushfires being particularly destructive (more than 3.6 million hectares were burnt in New South Wales region from July to December 2019). South-eastern New South Wales was the most affected region during the 2019 bushfires.

Significant thunderstorms were recorded in November and December 2018 in New South Wales, with damaging winds, hailstorms, and intense bursts of rain. A strong cold front brought about damaging winds, storms and showers during August 2018. This cold outbreak resulted in heavy snow in many elevated areas of New South Wales.

The power system risks for these extreme weather events were managed by appropriate generation dispatch to control the line flows in the impacted lines and through reclassification of events.

5.5 Frequency risk management 2020-25

As indicated in Section 5.1.5, TransGrid has planned for implementation of special protection schemes to address the three priority non-credible contingency events identified in 2018 PSFRR. In consultation with TransGrid, the following contingencies and operational scenarios were identified as requiring further review in Stage 2 of 2020 PSFRR.

Loss of QNI link for both New South Wales exporting and importing cases

Non-credible contingency of QNI double-circuit trip during both export and import limit cases are planned to be reviewed in the Stage 2 report. QNI double-circuit trip during high import from Queensland to New South Wales could result in frequency impacts in New South Wales.

Voltage instability in the grid due to UFLS action

When significant load (around 60%) is lost in New South Wales due to UFLS action, voltage instability has been observed. This is due to slow response of reactive power control equipment. Voltage instability could cause generators to disconnect, resulting in a subsequent frequency event. This will be subject to review as part of development of the Stage 2 report.

Future non-credible contingencies after ISP projects

The following future non-credible contingencies could also have frequency stability implications:

- Trip of two units of Snowy Hydro 2.0 (300 MW each).
- Trip of both HumeLink circuits (with Snowy Hydro 2.0).

5.6 Summary

5.6.1 Adequacy of EFCS

TransGrid is presently auditing the UFLS relays with respect to their operating times to ensure they conform to FOS requirements. Low voltage blocking schemes of the relays are also being investigated. The rapid and higher penetration of DER in the distribution system has increased the risk of mal-operation and reduced the effectiveness of UFLS relay operations at the distribution levels.

These challenges include the appropriate settings for the following relay blocking functionalities:

- Voltage blocking capability and their settings – many of the high voltage (HV) UFLS relays make use of this feature, however the setting is quite important for the proper working of the relay; too low may result in the relay not operating when required, and too high may result in the relay operating spuriously.
- dV/dt loss of VT reference blocking, whereby UFLS action is blocked for rapid loss of VT reference magnitude.
- RoCoF UFLS action blocking, where subsystem islanding discrimination can be an issue.
- Reverse power flow blocking on UFLS to avoid load shedding net generation feeders.
- Application of smart meters for remote operation of the switches and reclosers from the system control centre for enhanced load/generation shedding and restoration.
- Coordination of low voltage (LV) capacitor switching to avoid excessive overvoltage during a frequency event.

Detailed information on the functionality of UFLS relays at distribution level is required to properly coordinate system-wide settings to mitigate the risk of cascading tripping and improve robustness of the current system.

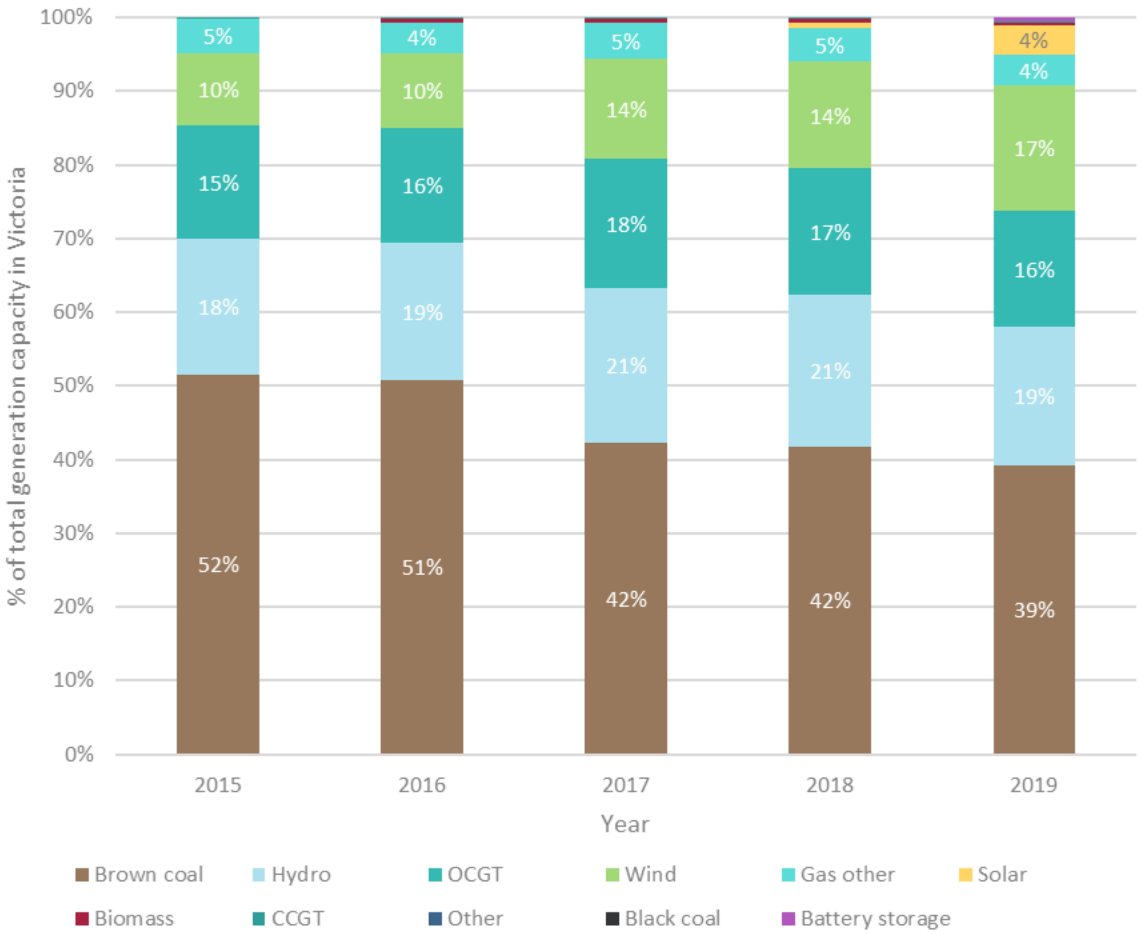
6. Victoria

6.1 Introduction

6.1.1 Generation in Victoria

Electricity generation in Victoria is predominantly a combination of coal-fired and gas turbine generators. The registered generation capacity in Victoria is shown in Figure 17[72]. The state's installed capacity at 2019 comprises 39% brown coal, 20% gas, 19% hydro, 17% wind, and 4% solar.

Figure 17 Victoria generation mix changes, 2015-19



Note: the contributions of some generation sources are not large enough to be visible on this chart.

Figure 17 shows that the total generation from synchronous sources has reduced since 2016, and the trend will continue as the state transitions to a higher level of renewable generation. At present, there is approximately 2.4 GW of committed renewable generation capacity, and an additional 8 GW of renewable generation is proposed to connect[73].

[72] AEMO Generation Information, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/generation_information/nem-generation-information-april-2020.xlsx?la=en. Data used in this chart has been taken from the final update each year.

[73] AEMO, Victorian Annual Planning Report, June 2020, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/vapr/2019/victorian-annual-planning-report-2019.pdf?la=en&hash=0AF8BABAA9315FB0A2D9B82E42D37C0C.

Victoria also has two utility-scale battery storage facilities (30 MW/30 MWh in Ballarat and 25 MW/50 MWh in Gannawarra solar farm).

The Victorian Government is aiming to achieve 40% generation from renewable sources by 2025 and 50% by 2030[74].

6.1.2 Electricity demand in Victoria

Victoria reached 9,667 MW of maximum demand in summer 2019-20 at 17:00 hrs on 31 January 2020. The minimum operational demand of 3,300 MW occurred at 12:30 hrs on 1 January 2020. Increased DPV has resulted in the transition of minimum demand occurrence from overnight to afternoon.

6.1.3 Transmission system in Victoria

Existing transmission network

The transmission network in Victoria comprises:

- A 500 kV transmission corridor that connects the Latrobe Valley power stations (south-east side of the state) to the Melbourne main load centre. The 500 kV network also connects to the Alcoa Portland (APD) aluminium smelter in the state's South-West (and to South Australia via the Heywood interconnector).
- 220 kV and 330 kV transmission lines connecting Melbourne to the North-East side of the state.

Interconnection with New South Wales, South Australia, and Tasmania

Victoria is strongly connected to the rest of NEM by four interconnectors:

- Victoria to New South Wales (VNI). New South Wales is interconnected with Victoria via three 330 kV AC transmission lines (termed VIC1-NSW1) routed between Murray – Upper Tumut, Murray – Lower Tumut, and Jindera – Wodonga substations, and another 220 kV AC transmission line between Buronga and Red Cliffs. The nominal capacity of the New South Wales – Victoria interconnector is 400-1,350 MW from New South Wales to Victoria and 700-1,600 MW from Victoria to New South Wales.
- The Heywood interconnector (HIC) – a 275 kV double-circuit transmission line from Heywood in Victoria to the South East substation in South Australia.
- Two DC links, Murraylink and Basslink, connecting Victoria to South Australia and Tasmania respectively.

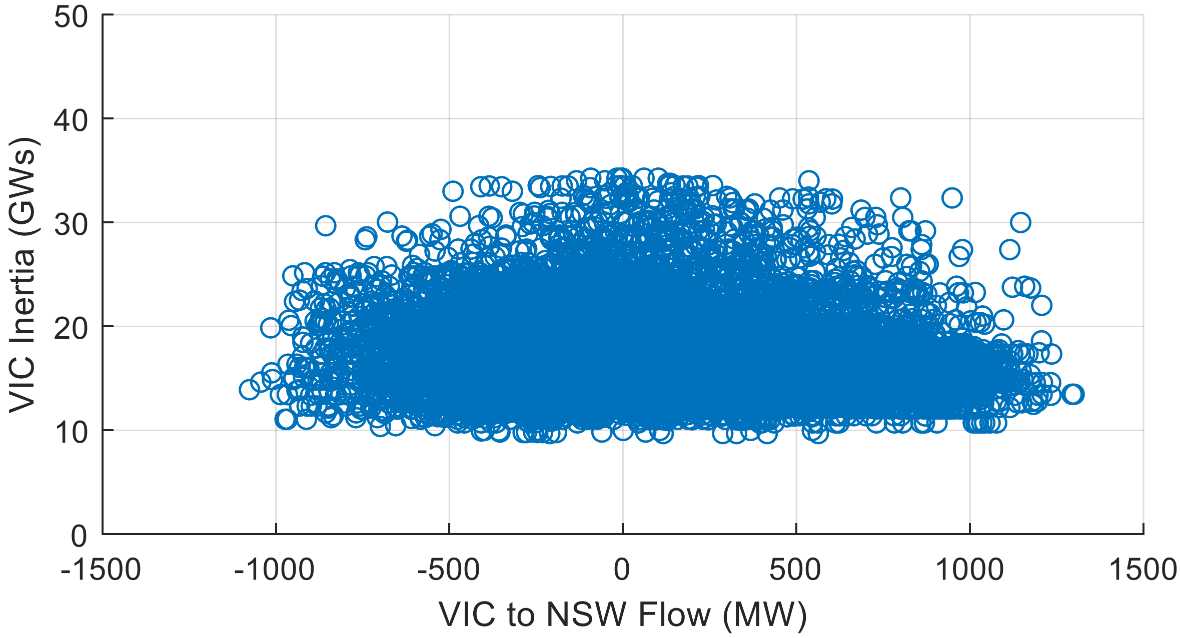
Victoria to New South Wales interconnector (VNI)

Figure 18 shows the VNI flow and corresponding inertia levels in Victoria for 2019.

High inertia levels, up to about 35 GWs, can be observed when Victoria was both importing and exporting in 2019, but generally with a low interconnector flow. At high interconnector flow, the inertia levels were typically 10-25 GWs for both importing and exporting. The flow patterns of VNI are provided in Section 5.1.3.

[74] Victoria State Government, Victoria's Renewable Energy Targets, April 2020, at https://www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-targets.

Figure 18 VNI flow and corresponding inertia levels in Victoria in 2019

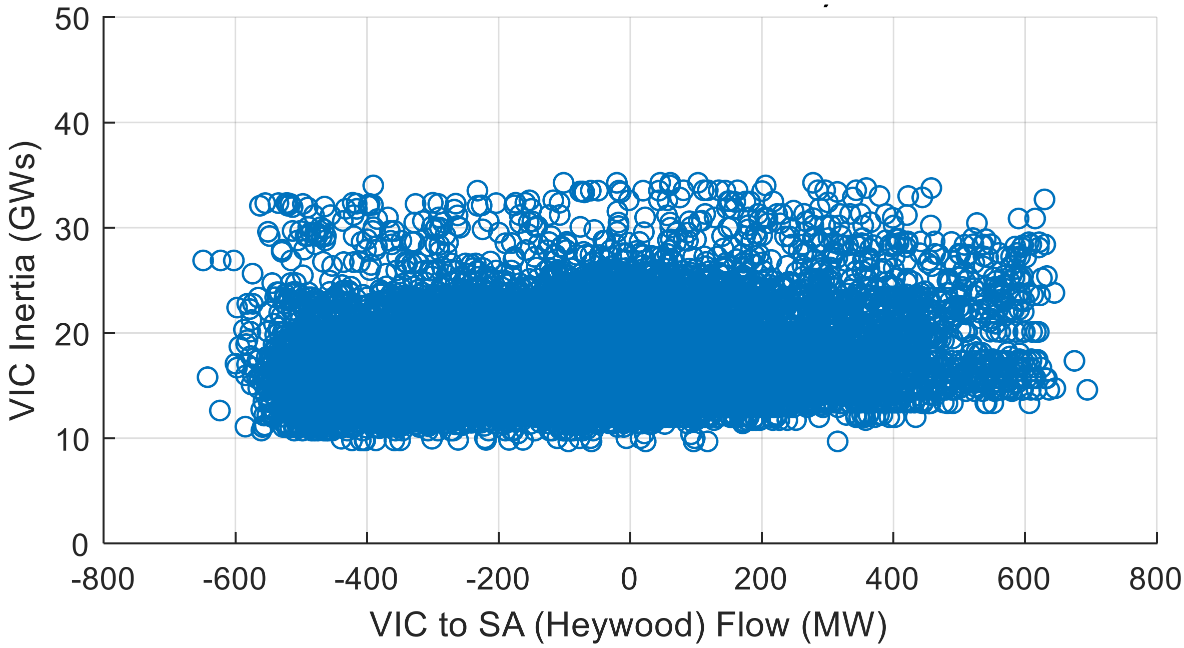


Note: Positive interconnector flow indicates flow direction from Victoria to New South Wales

Victoria to South Australia (Heywood interconnector)

Figure 19 shows the Heywood interconnector flow and corresponding inertia levels in Victoria for 2019. A cluster of low inertia levels can be observed when Victoria was importing in 2019. Compared to the importing scenarios, higher inertia levels can be observed during export to South Australia, which could be due to a larger number of synchronous machines available online. The flow pattern of the Heywood interconnector is provided in Section 7.1.3.

Figure 19 Heywood interconnector flow and corresponding inertia levels in Victoria in 2019



Note: Positive interconnector flow indicates flow direction from Victoria to South Australia

Planned major network upgrades

AEMO has identified the following planned major works up to 2025[75]:

- Western Victoria Renewable Integration – AEMO intends to expand transmission network capacity in Western Victoria as more renewable generation is expected to be built in this region. For this purpose, the following augmentations will be implemented by 2021-25:
  - Two new terminal stations, one at North Ballarat and one at North Sydenham.
  - A new 500 kV double circuit line between North Sydenham and North Ballarat.
  - A new 220 kV double circuit line between North Ballarat and Bulgana.
  - A new wind monitoring and upgraded terminal station equipment that currently limits the thermal rating of 220 kV transmission lines at Red Cliffs–Wemen–Kerang, Bendigo–Kerang, Moorabool–Terang, and Ballarat–Terang.
- Victorian Reactive Power Support – high voltages can arise on the transmission network under minimum demand condition due to line charging. Hence, to maintain the voltage within operational limits, the following reactive power support will be implemented by 2021-25:
  - Installation of two 100 megavolt amperes reactive (MVAr) 220 kV reactors at Keilor terminal station.
  - Installation of two 100 MVAr 220 kV reactors at Moorabool terminal station.
- VNI – AEMO and TransGrid jointly initiated a RIT-T to expand the transfer capability from Victoria to New South Wales[76]. Under this plan, the following augmentations will be implemented in Victoria by 2022-23:
  - Installation of a second 500/330 kV transformer in parallel with the existing South Morang F2 transformer at South Morang station.
  - Re-tension of the 330 kV South Morang – Dederang transmission lines, as well as associated works (including uprating of series capacitors), to allow operation at thermal rating.
- Project EnergyConnect – according to the South Australian Energy Transformation RIT-T conclusions report published in February 2019[77], a new 330 kV interconnector between South Australia and New South Wales with a transfer capability of 800 MW will be built.
  - The interconnector will be between Robertstown in South Australia and Wagga Wagga in New South Wales. This project also includes an augmentation between Buronga in New South Wales and Red Cliffs in Victoria.
- Marinus Link – TasNetworks and the Australian Renewable Energy Agency (ARENA) are currently accessing options for a second interconnector[78] between Victoria and Tasmania.
- Victoria SIPS – this scheme is proposed to enable additional import of electricity over VNI of up to 250 MW at peak times[79].

6.1.4 Climate of Victoria

The south-eastern coast of Victoria is generally cold, and hinterland Victoria (encompassing Ballarat and Melbourne) is mild in temperature[80]. During the summer, Victoria experiences a wide range of extreme weather conditions, such as high temperatures, bushfires, and heatwaves.

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75 75AEMO, Victorian Annual Planning Report, June 2019, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/vapr/2019/victorian-annual-planning-report-2019.pdf?la=en&hash=0AF8BABAA9315FB0A2D9B82E42D37C0C.

76 AEMO, Victoria to New South Wales interconnector upgrade, at https://www.aemo.com.au/initiatives/major-programs/victoria-to-new-south-wales-interconnector-upgrade-regulatory-investment-test-for-transmission.

77 ElectraNet ,South Australia Energy Transformation RIT_- PACR, February 2019, at https://www.electranet.com.au/wp-content/uploads/projects/2016/11/SA-Energy-Transformation-PACR.pdf.

78 TasNetworks, Marinus Link, at https://projectmarinus.tasnetworks.com.au/

79 AEMO, SIPS 2020 Update, at https://aemo.com.au/en/initiatives/major-programs/victorian-government-sips-2020.

80 Australian Government, Australian Climate Zones, at https://www.yourhome.gov.au/introduction/australian-climate-zones.

6.1.5 Overview of the 2018 PSFRR of Victoria

AEMO's investigation on the Victorian power system as part of the 2018 PSFRR has highlighted the following:

- The current mechanisms to protect against frequency risks are appropriate.
- AEMO's review of existing Victorian EFCSs did not identify any immediate need to modify UFLS and EAPT schemes.

6.2 Emergency frequency control schemes and declared protected events in Victoria

6.2.1 Emergency frequency control schemes

The following three EFCSs exists in Victoria:

- Victoria UFLS scheme.
- Emergency Alcoa-Portland Potline Tripping Scheme (EAPTS).
- Interconnector Emergency Control Scheme (IECS).

Additionally, the Victorian generators that are connected between Moorabool and Heywood terminal stations participate in the South Australian OFGS scheme (see Section 7.2.1).

Victoria under-frequency load shedding scheme

UFLS aims to protect the frequency collapse during contingencies involving multiple generation units. In response to a non-credible contingency event, the automatic UFLS scheme is activated from 49 Hz down to 47.5 Hz to maintain the NEM frequency in the range between 47 Hz and 52 Hz.

Emergency Alcoa Portland (APD) Potline Tripping Scheme

This scheme detects the loss of 500 kV connection between Heywood and Moorabool, leaving South Australia and any Victorian generation between Moorabool and Heywood supplying the APD load. This scheme trips the Heywood to Moorabool/APD lines at Heywood if necessary to prevent frequency or voltage collapse in South Australia.

The time delay and drop out time settings on the EAPTS have recently been updated to avoid recurrence of the 25 August 2018 event due to protection mal-operation. These setting changes are expected to reduce the risk of mal-operation of the EAPTS.

Interconnector Emergency Control Scheme

IECS has been developed to minimise the supply interruption in Victoria for the trip of multiple 330 kV and 220 kV transmission lines between Murray Switching Station and Thomastown terminal station. Currently the IECS is designed to shed up to 1,200 MW load in Victoria region if the below contingencies occur:

- – South Morang 330 kV lines, together with Eildon – Mt Beauty Dederang – Murray 330 kV line outages.
- Dederang – South Morang 330 kV line outages.
- Outage of Dederang – South Morang 330 kV lines, together with Eildon – Thomastown 220 kV lines.
- Outage of Dederang 220 kV lines.

As the Jurisdictional Planning Body (JPB) of Victoria, AEMO plans to implement a second stage of the IECS to also trip pre-selected generation following the above contingencies to arrest over-frequency events. The scheme has been commissioned and is expected to be enabled in the near term.

6.2.2 Protected events

There are currently no protected events declared in Victoria.

Based on AEMO's preliminary studies, it was identified that during certain levels of Heywood interconnector import into South Australia and high DPV generation in South Australia there will be insufficient UFLS load to cover the non-credible separation from Victoria. To mitigate this non-credible risk, this PSFRR report recommends a protected event to be declared. Further details in regard to the protected event declaration could be found in Section 7.5 and in Appendix A1. As separation of South Australia at Heywood can result from the loss of 500 kV sections from Moorabool to Heywood, including due to operation of the EAPT scheme, the proposed protected event will also consider these non-credible contingencies.

6.3 Review of incidents

Table 6 summarises the relevant non-credible contingency events which occurred in Victoria since the last PSFRR. Some events may have been reclassified as credible prior to the outage thereby reducing their impact on the network. The non-credible contingency events are categorised in terms of the frequency excursion with respect to the FOS for Mainland and the state of operation of the power system, as stated in Section 2.3.

The RoCoF values indicated in the table for each incident have been approximated, based on available high speed monitoring data.

Table 6 Summary of relevant non-credible contingency events in Victoria

Date / time	Description of event	Primary cause	Load / generation involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow prior to contingency	Inertia in Victoria (MWs)	Reference
Major event								
16 Nov 2019 18:06:47 hrs	Separation of Victoria and South Australia	Equipment failure / Protection mal-operation	No load or generation disconnected in Victoria	Peaked around 50.15 Hz in Victoria	No discernible impact in Victoria	438 MW (South Australia to Victoria)	15,305	AEMO Incident Report[81]
4 Jan 2020 15:10 hrs	New South Wales and Victoria separation	Bushfires	No load or generation disconnected in Victoria	Peaked around 50.45 Hz in Victoria	+0.11	981 MW (Victoria to New South Wales) 615 MW (Queensland to New South Wales)	19,455	AEMO Incident Report[82]
31 Jan 2020 13:24 hrs	Separation of Victoria and South Australia	Thunderstorms resulting in collapse of transmission towers	APD load tripped resulting in a loss of around 450 MW of load	Peaked around 49.65 Hz in Victoria	-0.08	Step change of approximately 1,000 MW due to change in flow direction (Victoria to South Australia)	29,352	AEMO Incident Report[83]
Moderate event								
9 Oct 2019 06:34 hrs	The 220/33 kV W1 and W5 transformers at APD tripped	Secondary systems mal-operation	APD tripped resulting in a loss of around 468 MW of load	In Victoria, peaked around 50.22 Hz	+0.06	510 MW (South Australia to Victoria)	15,269	AEMO Incident Report[84]

[81] AEMO, Preliminary Report – Non-Credible Separation Event South Australia – Victoria, December 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/preliminary-incident-report---16-november-2019---sa---vic-separation.pdf?la=en&hash=F26C20C49BD51164AE700A30F696A511.

[82] AEMO, Preliminary Report – New South Wales and Victoria Separation Event, March 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/preliminary-report-nsw-and-victoria-separation-event-4-jan-2020.pdf?la=en.

[83] AEMO, Preliminary Report – Victoria and South Australia Separation Event, January 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/preliminary-report-31-jan-2020.pdf?la=en.

[84] AEMO, Simultaneous Trip of Both Potlines at the Alcoa Portland Aluminium Smelter, February 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/trip-of-both-potlines-at-apd.pdf?la=en&hash=BED8CB5E7BFAD82D33E3EC5EAC2E270B.

Date / time	Description of event	Primary cause	Load / generation involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow prior to contingency	Inertia in Victoria (MWs)	Reference
11 Apr 2020 13:26 hrs	Loss of multiple Yallourn units	Trip of multiple generating units and disconnection of wind farm collector group	1076 MW of generation was lost in Victoria	Decreased around 49.65 Hz	-0.07	943 MW (Victoria to New South Wales) 382 MW (South Australia to Victoria)	18,132	-
Minor event								
9 Dec 2018 02:07 hrs	Trip of the Hazelwood Power Station to Rowville Terminal Station No. 1 and No. 2 220 kV transmission lines	Lightning	No load or generation disconnected in Victoria	The power system remained in a secure operating state throughout this incident.	High speed monitoring data not available	92 MW (Victoria to South Australia) 203 MW (Tasmania to Victoria)	12,602	AEMO Incident Report[85]
18 Feb 2019 19:56 hrs	Trip of the Sydenham - Moorabool No. 2 500 kV line and the Sydenham Keilor 500 kV line	Transmission line fault and protection mal-operation	No load or generation disconnected in Victoria	The power system remained in a secure operating state throughout this incident.	High speed monitoring data not available	256 MW (South Australia to Victoria) 377 MW (Victoria to Tasmania)	19,795	AEMO Incident Report[86]
1 Oct 2019 12:34 hrs	Trip of the No. 2 330 kV busbar at Wodonga Terminal Station	Unexpected protection operation	No load or generation disconnected in Victoria	The power system remained in a secure operating state throughout this incident.	High speed monitoring data not available.	217 MW (New South Wales to Victoria)	15,174	AEMO Incident Report[87]

[85] AEMO, Trip of the Hazelwood Power Station to Rowville Terminal Station No. 1 and No. 2 220 kV Transmission Lines, April 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/hwps-rots-1-and-2-lines-on-9-december.pdf?la=en&hash=CE1CCBB0B66301150C94EC73BD50C3F9 .

[86] AEMO, Trip of the Sydenham–Moorabool No. 2 500 kV line and the Sydenham–Keilor 500 kV Line, October 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/mlts-syts-syts-kts-lines-18-feb.pdf?la=en&hash=D6F8378372E53C31F3A42F91B780F358.

[87] AEMO, Trip of the No. 2 330 kV Busbar at Wodonga Terminal Station, February 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/trip-of-the-no-2-330-kv-busbar-at-wodonga-terminal-station.pdf?la=en&hash=592E5825881C7204260334D04F8A7E58

9 October 2019 – simultaneous trip of both potlines at the Alcoa Portland aluminium smelter

Two transformers at the APD aluminium smelter (220/33 kV W1 and 220/33 kV W5) were disconnected simultaneously. AEMO identified this incident happened due to secondary system mal-operation of UFLS at APD. This incident resulted in the disconnection of 468 MW of industrial customer load at APD.

As a result of the loss of APD load, the mainland frequency peaked at approximately 50.85 Hz, and settled below 50.15 Hz in three minutes. The FOS in the mainland was met for this incident.

The power system was in a secure operating state prior to this incident and remained in a secure operating state for the duration of the incident.

16 November 2019 – non-credible separation of South Australia – Victoria

Two simultaneous contingencies occurred on both 500 kV transmission lines Heywood – APD – Mortlake and Heywood – APD – Tarrone (HYTS–APD–MOPS and HYTS–APD–TRTS lines) in Victoria due to mal-operation of a communication multiplexer of both lines. This resulted in South Australia being islanded from the rest of NEM at Heywood for nearly five hours, and disconnection of electrical supply to APD in Victoria for nearly three hours. Approximately 300 MW of import was lost from South Australia immediately after the separation.

As a result of this incident, the impact on Victorian frequency was negligible (peaked to 50.15 Hz, followed by settling around 50.1 Hz), as the loss of infeed from South Australia was mostly compensated by the loss of load at APD. Further details of frequency impact in South Australia are provided in Section 7.3.17.3.

4 January 2020 – Victoria – New South Wales separation

A major bushfire event in the Snowy Mountains area resulted in the separation of the Victorian and New South Wales regions. During this incident, a significant increase in power flows occurred on the330 kV Wodonga – Jindera, Jindera – Wagga lines, and the 132 kV subsystem operating in parallel between 330 kV Wagga and 330 kV Yass substations.

As a result, the NEM was split into two regions:

- The Victorian, South Australian, and Tasmanian regions and South-West New South Wales.
- Queensland and the main portion of the New South Wales region.

This incident resulted in the loss of 34 MW of generation and 43 MW of customer load, and approximately 2,267 MW reduction of generation availability in New South Wales. The separation resulted in an increase in the QNI flow from Queensland to the New South Wales due to loss of supply from Victoria. However, there was no generation or load loss in Queensland.

As a result of the incident, the frequency in Victoria and South Australia peaked at approximately 50.45 Hz, while in Queensland and New South Wales it fell to 49.5 Hz.

31 January 2020 – Victoria and South Australia separation

Due to severe storm activity, numerous steel transmission towers collapsed on the Moorabool – Mortlake and Moorabool – Haunted Gully 500 kV lines (MLTS–MOPS and MLTS–HGTS lines), removing both lines from service. This caused South Australia to be separated from Victoria. In the meantime, the Haunted Gully – Tarrone 500 kV line (HGTS–TRTS line) also tripped, but the cause of this trip is unknown at this stage.

The Heywood interconnector was carrying 500 MW power from South Australia to Victoria just before this incident. The flow varied immediately after the incident by 1,000 MW. In response, both APD potlines tripped and 450 MW of load was disconnected. The separation resulted in an increase in the QNI flow from Queensland to the New South Wales due to loss of supply from South Australia into Victoria.

As a result of this separation, the frequency in Victoria is fell below 49.65 Hz.

Further details on the impact of this event in South Australia are in Section 7.3.1.

11 April 2020 – loss of multiple Yallourn units

During this event, three Yallourn generation units (W1, W3, W4) were tripped and some Macarthur wind farm collector groups were disconnected. The cause of W1, W3 and W4 trips is subject to ongoing review. This incident resulted in the disconnection of 1,076 MW of generation. It was identified that the Macarthur wind farm tripped due to possible malfunction of the plant's frequency protection relay.

As a result of the loss of multiple generation units, the mainland frequency fell to 49.65 Hz.

9 December 2018 – trip of the Hazelwood Power Station to Rowville Terminal Station No. 1 and No. 2 220 kV transmission lines

The incident involved the simultaneous trip of the Hazelwood Power Station to Rowville Terminal Station No. 1 and No. 2 220 kV transmission lines (HWPS–ROTS No. 1 line and HWPS–ROTS No. 2 line) due to lightning. No generation or customer load was lost as a result of this incident. The power system remained in a secure operating state throughout this incident.

18 February 2019 – trip of the Sydenham–Moorabool No. 2 500 kV line and the Sydenham–Keilor 500 kV line

The trip of the Sydenham – Moorabool No. 2 500 kV line was due to the protection equipment operation as a result of a high voltage fault on the line. The trip of the Sydenham – Keilor 500 kV line was due to the unexpected operation of a redundant element of the protection system. During this event, the power system remained in a secure operating state. No generation or customer load was disconnected as a result of this incident.

1 October 2019 – trip of the No. 2 330 kV busbar at Wodonga Terminal Station

The No. 2 busbar tripped due to the unexpected operation of protection system during planned work on the No. 2 330/66/22 kV transformer. The protection operation resulted from a fault on the 22 kV distribution system and insufficient isolation of secondary systems. During this event, the power system remained in a secure operating state. No generation or customer load was disconnected as a result of this incident.

6.4 Operational experience and impact

6.4.1 Weather-related operational experience

In recent years, Victoria has seen major weather-related events which have put the power system at risk. including the bushfires impacting VNI separation in January 2020, and thunderstorms resulting in collapse of several steel transmission towers in January 2020.

Hot conditions contributed to significant bushfires in recent summers, particularly during the 2019-20 season. On 4 January 2020, there was extreme fire weather forecast with 50 bushfires burning in Victoria and 137 in New South Wales[88], which resulted in separation of Victoria and New South Wales.

On 31 January 2020, a severe convective downburst during thunderstorm activity is understood to have caused the collapse of several steel transmission towers in south-western Victoria

The power system risks for these extreme weather events were managed by appropriate generation dispatch to control the line flows in the impacted lines and through reclassification of events.

6.5 Frequency risk management 2020-25

There were no identified priority contingencies, as discussed with AEMO as Victoria TNSP. This will be further reviewed in Stage 2 of the PSFRR.

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[88] The Guardian, at https://www.theguardian.com/australia-news/live/2020/jan/04/australia-nsw-fires-live-updates-victoria-bushfires-rfs-cfa-road-closures-near-sydney-melbourne-latest-news.

6.6 Summary

6.6.1 Adequacy of EFCS

Currently, Victoria has three EFCSs in operation. AEMO in its capacity as JPB is presently undertaking a review of the EAPT and IECS schemes to take into account recent changes to the power system and connected generation. The PSFRR stage 2 report will consider these changes, as well as longer-term EFCS requirements based on planned changes, such as new large-scale connections in south west Victoria.

6.6.2 Adequacy of protected events

Currently there is no protected event declared for Victoria.

As discussed elsewhere in this report, AEMO may propose a protected event to cover non-credible loss of 500 kV circuits between Heywood and Moorabool substations resulting in loss of the Heywood interconnection.

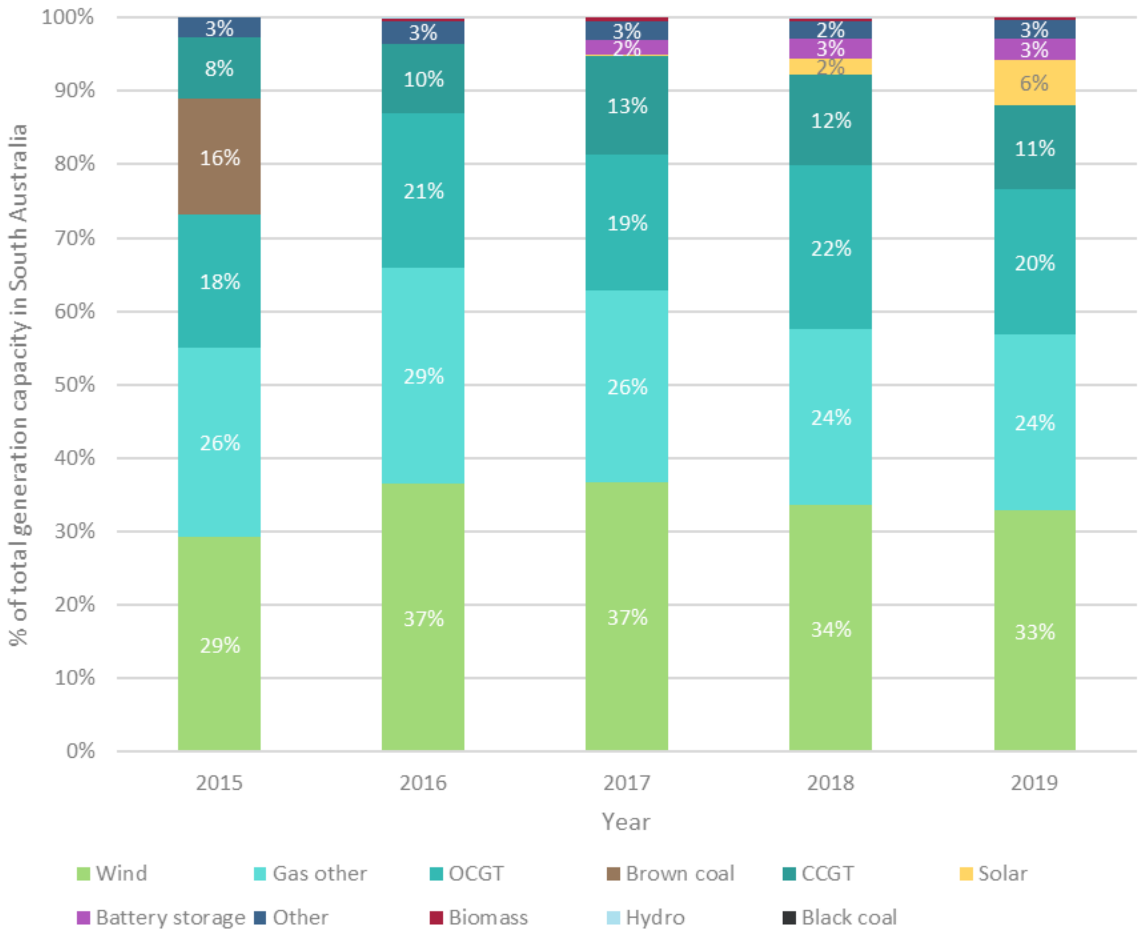
7. South Australia

7.1 Introduction

7.1.1 Generation in South Australia

Figure 20 shows the South Australian generation mix over the past five years, based on data from AEMO's Generation Information page[89].

Figure 20 South Australia generation mix changes, 2015-19



Note: the contributions of some generation sources are not large enough to be visible on this chart.

South Australia has seen an increase in renewable energy generation in 2019 compared to previous years. The first three large-scale solar plants in South Australia (Tailem Bend, Bungala One, and Bungala Two) commenced operation, with a total combined installed capacity of 378 MW. Barker Inlet, the first natural gas reciprocating engine power station in the region, commenced operation in November 2019[90].

[89] AEMO Generation Information, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/generation_information/nem-generation-information-april-2020.xlsx?la=en. Data used in this chart has been taken from the final update each year.

[90] AEMO, South Australian Electricity Report, November 2019, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2019/2019-South-Australian-Electricity-Report.pdf.

The overall increase of installed generation capacity in the 2018-19 financial year compared to the previous year was 12.2%, increasing the capacity to 7,066 MW, mainly due to increases in wind and large-scale solar generation.

7.1.2 Electricity demand in South Australia

Demand in South Australia is mostly between 1,000 MW and 2,000 MW throughout the year, however this can exceed 3,000 MW on hot summer days. State-wide demand reached a maximum of 3,264 MW on 24 January 2019 at 20:06 hrs, which recorded a maximum temperature of 46.6°C. This was despite a reduction in actual load relative to demand caused by an outage of a major zone substation transformer on the distribution network[91]. The increased level of DPV capacity in South Australia has resulted in the maximum operational demand shifting from the middle of the day to early evening, when DPV is at low output or not generating.

Operational minimum demand generally occurs during weekends or public holidays. Increases in DPV have resulted in a reduction in the minimum demand, which is now occurring during the middle of the day instead of overnight. In 2018, a record low minimum operational demand (sent-out[92]) for South Australia of 583 MW was observed on 21 October 2018. This record has since been broken on Sunday 10 November 2019, when a new record low minimum operational demand of 446 MW sent-out was set[93].

7.1.3 Transmission system in South Australia

Existing transmission network

ElectraNet owns, operates, and maintains the electricity transmission network in South Australia while SA Power Networks (SAPN) owns, operates and maintains the electricity distribution network.

The transmission network in South Australia operates at voltages of 275 kV, 132 kV, and 66 kV. The network includes 91 high voltage substations with approximately 5,600 circuit kilometres of transmission lines.

Interconnection with Victoria

South Australia is connected to the rest of the NEM via two interconnectors, Heywood and Murraylink:

- The Heywood interconnector (275 kV) is between Heywood substation in Victoria and South East substation in South Australia. This interconnector was upgraded in mid-2016 to a nominal design limit of up to 650 MW in both directions. However, the capability was limited until the OFGS scheme and the SIPS were commissioned in South Australia. Currently, due to uncontrolled interconnector flow drift, Heywood's nominal capacity has been limited to 600 MW from Victoria to South Australia, and 550 MW from South Australia to Victoria.
- Murraylink DC cable also connects between Red Cliffs in Victoria and Monash in South Australia. The DC underground cable was commissioned in 2002 with a nominal capacity of 220 MW from Victoria to South Australia, and 200 MW from South Australia to Victoria.

While imports to South Australia had been growing until the closure of Hazelwood Power Station in Victoria in 2017, the trend has since reversed, with South Australia now exporting in the majority of periods, driven by increases in wind and solar generation[94].

Figure 21 presents the Heywood flow pattern in 2018 and 2019 by flow duration curves. It shows that in 2019, Heywood was exporting to Victoria approximately 68% of the time, compared to 45% in 2018.

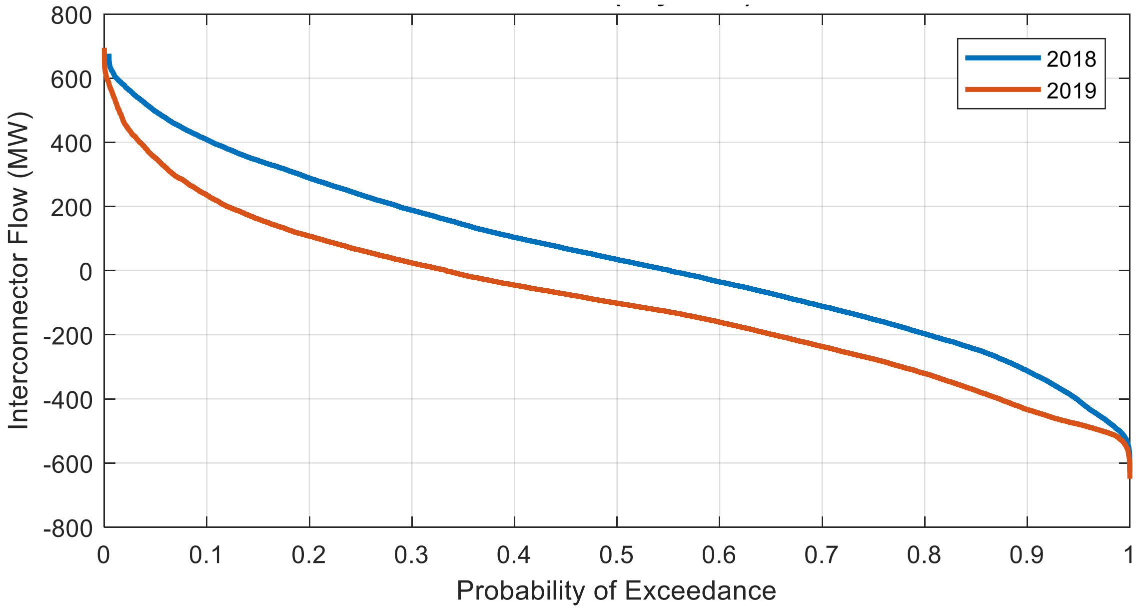
[91] ElectraNet, Transmission Annual Planning Report, June 2019, at https://www.electranet.com.au/2019-transmission-annual-planning-report-released/.

[92] Estimated value, based on actual operational demand as-generated, less estimated auxiliary loads.

[93] AEMO, South Australian Electricity Report, November 2019, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2019/2019-South-Australian-Electricity-Report.pdf.

[94] AEMO, South Australian Electricity Report, November 2019, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2019/2019-South-Australian-Electricity-Report.pdf.

Figure 21 Heywood interconnector flow duration curves, 2018 and 2019



Note: Positive interconnector flow indicates flow direction from Victoria to South Australia

Figure 22 shows the inertia duration curve for South Australia in 2018 and 2019. There is an increase in the inertia levels in South Australia in 2019 compared to 2018 (from 10% to 70% of the time). This could be due to more synchronous machines (gas-powered generation) coming online to provide sufficient inertia to South Australia in order to meet system security requirements[95].

Figure 22 Inertia duration curve for South Australia, 2018 and 2019

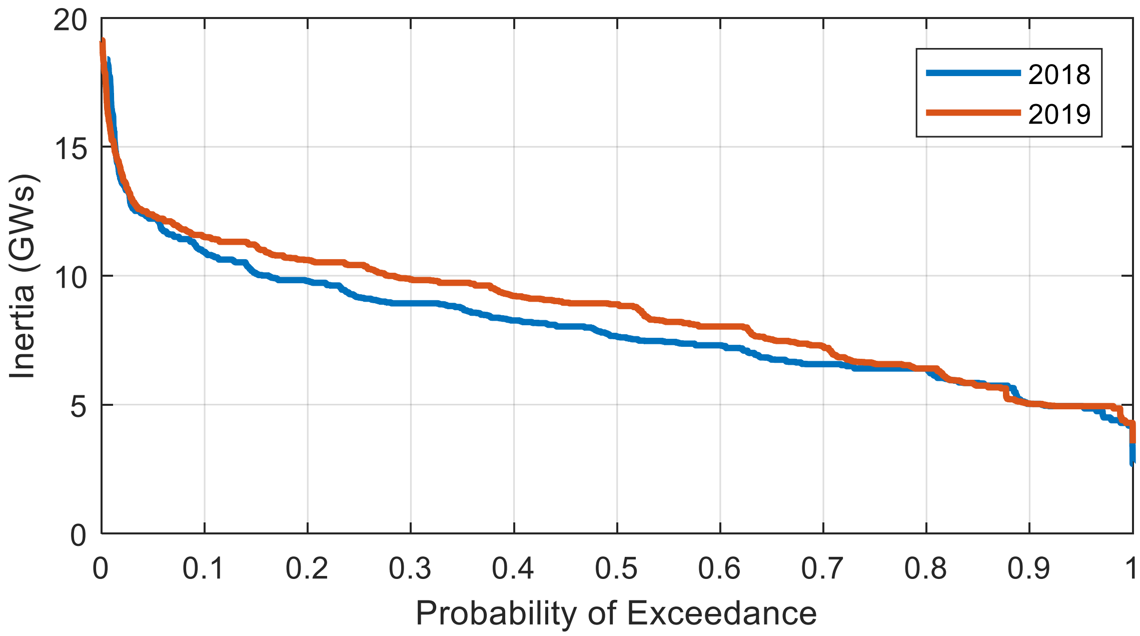
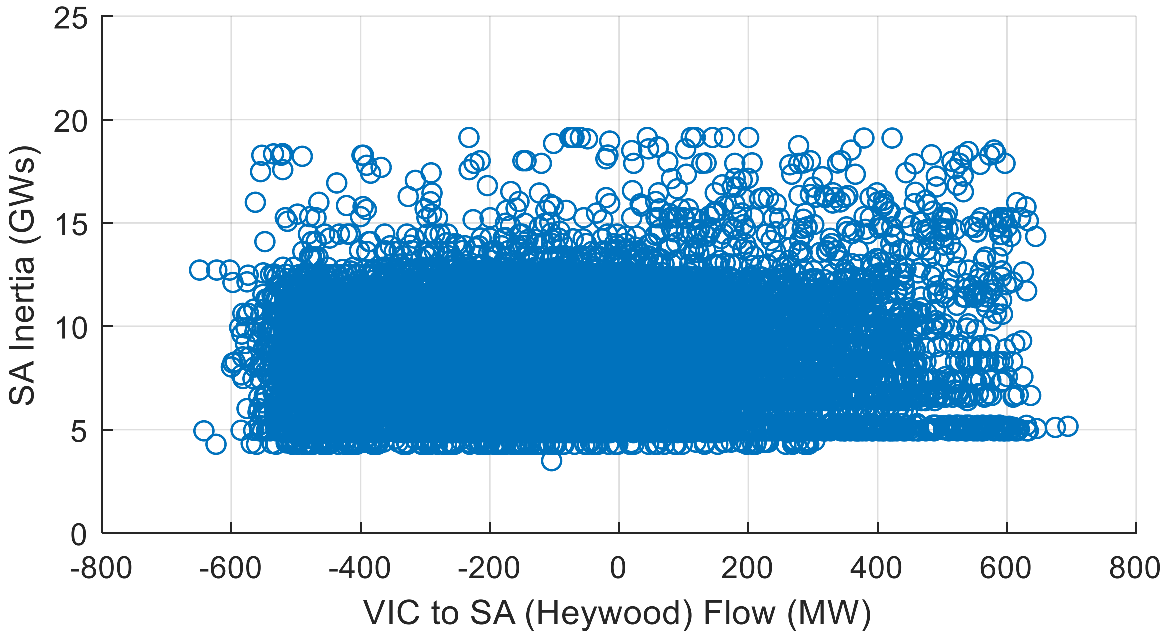


Figure 23 shows the Heywood interconnector flow and corresponding inertia levels in South Australia for 2019. High inertia levels can be observed when South Australia was importing in 2019. This could be due to more gas-powered generation coming online to support the state demand when both wind and solar

[95] AEMO, Transfer Limit Advice – System Strength, February 2020, at https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/transfer-limit-advice-system-strength.pdf?la=en

generation were low. Low inertia levels were also observed during high imports from Victoria, indicating that, under some operating conditions, South Australia demand was met with minimum synchronous generation, low wind and/or solar generation in South Australia. A cluster of low inertia levels can be observed when South Australia was exporting, which could be due to higher generation from wind and solar.

Figure 23 Heywood interconnector flow and corresponding inertia levels in South Australia for 2019



Note: Positive interconnector flow indicates flow direction from Victoria to South Australia

Planned major network upgrades

The status of series of transmission network upgrades and new projects planned in South Australia in 2020-25 is[96]:

- Heywood.
  - The increase in the transfer limit in the direction from Victoria to South Australia (from 600 MW to 650 MW) is currently under review as part of the ongoing commissioning of the previous upgrades. With this import limit increased up to the nominal design limit of 650 MW, the headroom currently available in the interconnector for voltage and transient stability limit for a contingency in South Australia will be reduced.
- Project EnergyConnect.
  - The South Australian Energy Transformation RIT-T conclusions report was published in February 2019[97], for a new 330 kV interconnector between South Australia and New South Wales with a transfer capability of 800 MW. The proposed interconnector route will be between Robertstown in South Australia, and Buronga and Wagga Wagga in New South Wales and also Buronga – Red Cliffs. This will reduce the risk of South Australia islanding from the NEM. Also, special protection schemes need to be designed and implemented to avoid cascade tripping from non-credible loss of either AC interconnector connected to South Australia.
- Eyre Peninsula Electricity Supply Options – to replace the existing 132 kV lines between Cultana and Port Lincoln.

[96] ElectraNet, Transmission Annual Planning Report, June 2019, at https://www.electranet.com.au/2019-transmission-annual-planning-report-released/.

[97] ElectraNet ,South Australia Energy Transformation RIT-T PACR, February 2019, at https://www.electranet.com.au/wp-content/uploads/projects/2016/11/SA-Energy-Transformation-PACR.pdf.

- Between Cultana and Yadnarie: a new double-circuit line that is initially energised at 132 kV, for a capacity of about 300 MW, with the option to be energised at 275 kV if required in the future, for a capacity of about 600 MW. This will increase reliability of electricity supply to homes and businesses on the Eyre Peninsula, reducing the frequency of outages.
  - Between Yadnarie and Port Lincoln: a new double-circuit 132 kV line with a capacity of about 240 MW. This will relieve constraints on existing wind farms on the Eyre Peninsula, but also provides opportunities for new renewable energy developments on the Eyre Peninsula.
- Extension of the 275 kV system from Davenport to develop a new 275 / 132 kV connection point at Mount Gunson South to service OZ Minerals' new and existing mines in the area.
  - The existing Oz Minerals load at Prominent Hill is currently connected through the Olympic Dam load from the Davenport to Olympic Dam West 275 kV line, accounting for the largest single load in South Australia. However, with this new extension, the existing Prominent Hill load will be disconnected from Olympic Dam load and connected to the ElectraNet network via a new connection point. This will reduce the size of the largest single load loss in South Australia.
- Installation of synchronous condensers to address system strength and synchronous inertia needs identified by AEMO, and to contribute to ongoing voltage control.
  - The first two of four planned synchronous condensers will be commissioned at the Davenport substation by end of 2020, and the second two will be commissioned at the Robertstown substation in mid-2021.

7.1.4 Climate of South Australia

South Australia's transmission backbone is prone to severe storms, destructive winds, and tornadoes on occasion. The 2018-19 financial year was drier than average over much of Australia. On 24 January 2019, a number of high temperature records were set across South Australia and operational demand reached 3,264 MW.

On 31 January 2020, Adelaide airport recorded its highest precipitable water value for January in at least 29 years – 66.6 mm. Widespread thunderstorm activity across South Australia and Victoria was observed ahead of a cold front. During one storm in south-west Victoria, a severe convective downburst is thought to have caused the collapse of six steel transmission towers leading to separation South Australia and part of the south-west Victorian network.

During the bushfire season, South Australia faces the risk of simultaneous trip of multiple transmission lines. To mitigate the bushfire risk, AEMO may reclassify certain non-credible contingency events as credible contingency events.

7.1.5 Overview of the 2018 PSFRR of South Australia

In the 2018 PSFRR, the following recommendations were made based on pre-2018 system events:

- An upgrade to the SIPS to further reduce the likelihood of a loss of multiple generators in South Australia leading to separation and a black system. This included looking into:
  - Alternative mechanisms to detect onset of loss of synchronism between South Australia and the rest of the NEM.
  - Dynamic arming of load blocks, batteries, and potentially the Murraylink interconnector, based on real-time measurement and pre-processing of information in real time for a number of different sizes of generation loss events ('Stage 2').
- Declaration of a new protected event to manage risks relating to the loss of multiple transmission elements causing generation disconnection in South Australia during periods where destructive wind conditions are forecast. Upgrade to the SIPS to be progressed as a protected event EFCS to assist in economically managing the risk in all periods.

On 19 June 2019, the Reliability Panel declared 'the loss of multiple transmission elements causing generation disconnection in the South Australia region during periods where destructive wind conditions are forecast by the Bureau of Meteorology' as a protected event[98].

7.2 Emergency frequency control schemes and declared protected events in South Australia

7.2.1 Emergency frequency control schemes

South Australia has the following three EFCSs currently in place:

- South Australia SIPS.
- South Australia UFLS scheme.
- South Australia OFGS scheme.

System Integrity Protection scheme

This is normally enabled and managed by ElectraNet. The SIPS is activated when power flow on the Heywood interconnector is from Victoria to South Australia.

The SIPS has three discrete progressive stages. Each stage has a different trigger and results in different outcomes. The three stages are:

- Stage 1 – a fast response trigger to inject energy from one or more BESS to reduce import from Victoria based on the interconnector flow and the rate of change of flow at South East.
- Stage 2 – if a protection is initiated by loss of synchronism measurement at Tailem Bend, or if the Heywood interconnector flow is too high, load will be shed at selected ElectraNet connection points to reduce flows from Victoria to South Australia.
- Stage 3 – the out-of-step trigger is initiated from an existing pair of distance protection relays located at South East substation. The out-of-step signal initiates tripping of the 275 kV circuit breakers at the South East substation to open the Heywood interconnector, islanding the South Australian power system.

Under-frequency load shedding scheme

Automatic UFLS scheme is activated from 49 Hz down to 47.5 Hz. In South Australia, in case of a frequency decrease, pre-defined loads in the ElectraNet network and SAPN are automatically disconnected through relays.

Over-frequency generator shedding scheme

The automatic OFGS scheme is installed on a number of generators in South Australia and south-western Victoria that are designed to trip when the system frequency exceeds 51 Hz. Generation to be tripped is split into eight blocks, each with around 150 MW of wind generation, set to trip between 51 Hz and 52 Hz in stages.

7.2.2 Protected events

In the 2018 PSFRR, it was identified that a number of scenarios could result in the loss of multiple generators in South Australia, which could lead to a sudden and rapid increase in the power imported over the Heywood interconnector, and that the existing SIPS may be unable to prevent a loss of the Heywood interconnector under all circumstances.

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[98] Reliability Panel AEMC, Final report AEMO request for protected event declaration, June 2019, at https://www.aemc.gov.au/sites/default/files/2019-06/Final%20determination%20-%20AEMO%20request%20for%20declaration%20of%20protected%20event.pdf.

South Australia currently has the following protected event which was declared after 2018 Power System Frequency Risk Review;

> *'The loss of multiple transmission elements causing generation disconnection in the South Australia region during periods where destructive wind conditions are forecast by the Bureau of Meteorology.'*

In addition to SIPS operation, AEMO is currently managing the risks associated with the protected event by limiting the maximum flow into South Australia on the Heywood interconnector to 250 MW during destructive wind conditions. AEMO considers a 250 MW import limit continues to be necessary, considering the limitations on the available load shedding and injection of energy from battery storage systems, as this allows maintains the system in a secure operating state.. AEMO considers that this amount of headroom accounts for the size of historic generation contingency events of between 450 MW and 520 MW, as well as potential increases in interconnector flow due to increased system losses and additional tripping of DPV[99].

7.3 Review of incidents

7.3.1 Review of frequency incidents 2018-20

Table 7 summarises the relevant non-credible contingency events which occurred in South Australia since the 2018 PSFRR. The non-credible contingency events are categorised in terms of the frequency excursion with respect to the FOS for Mainland and the state of operation of the power system, as stated in Section 2.3.

The RoCoF values indicated in Table 7 for each incident have been approximated, based on available high speed monitoring data.

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Table 7 Summary of relevant non-credible contingency events in South Australia

Date / Time	Description of event	Primary cause	Load/generation Involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow (Heywood) prior to contingency	Inertia in South Australia (MWs)	Reference
Major event								
25 Aug 2018 13:11:47 hrs	South Australia system separation	Lightning	No load or generation disconnected in South Australia	Reached an initial peak of 50.46 Hz, from around 49.14 Hz immediately prior to separation	+0.65	170 MW (South Australia to Victoria)	9,830	AEMO Incident Report[100]
16 Nov 2019 18:06:47 hrs	South Australia system separation	Equipment failure / Protection mal-operation	No load or generation disconnected in South Australia	Peaked around 50.85 Hz	+1.15	428 MW (South Australia to Victoria)	6,401	AEMO Incident Report[101]
31 Jan 2020 13:24 hrs	South Australia system separation	Thunderstorms resulting in collapse of transmission towers between Moorabool and Heywood	640 MW generation in South Australia was lost	Peaked around 51.11 Hz	+0.84	A step change of approximately 1,000 MW due to the change in flow direction	11,914	AEMO Incident Report[102]
2 Mar 2020 12:00 hrs	South Australia -Victoria system separation	Circuit breaker tripping at Heywood Terminal Station	No load or generation loss	Frequency deviations were minimal as the interconnector was lightly loaded at the time	+0.03	55 MW (South Australia to Victoria)	4,940	AEMO Market Notices[103]

[100] AEMO, Incident Report, January 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2018/qld---sa-separation-25-august-2018-incident-report.pdf?la=en&hash=49B5296CF683E6748DD8D05E012E901C.

[101] AEMO, Incident Report, December 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/preliminary-incident-report---16-november-2019---sa---vic-separation.pdf?la=en&hash=F26C20C49BD51164AE700A30F696A511.

[102] AEMO, Incident Report, January 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2020/preliminary-report-31-jan-2020.pdf?la=en.

[103] AEMO, Market Notice, March 2020, at https://aemo.com.au/market-notices?marketNoticeQuery=&marketNoticeFacets=GENERAL+NOTICE%2cPOWER+SYSTEM+EVENTS&MarketNoticeList=3.

Date / Time	Description of event	Primary cause	Load/generation Involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow (Heywood) prior to contingency	Inertia in South Australia (MWs)	Reference
5 May 2019 **10:30 hrs**	South Australia not secure due to post-contingent voltage levels at Blyth West and Willalo substations exceeding the satisfactory operating limits	Operational	No load or generation disconnected in South Australia	No frequency event occurred, however, power system was not in a secure operating state for more than 30 min	No frequency event occurred, however, power system was not in a secure operating state	169 MW (South Australia to Victoria)	24,217	AEMO Incident Report[104]
14 May 2019 **11:59 hrs**	South Australia not secure due to post-contingent voltages on the 132 kV network around the Tailem Bend and Keith substations were below the required limits	Operational	No load or generation disconnected in South Australia	No frequency event occurred, however, power system was not in a secure operating state for more than 30 min	No frequency event occurred, however, power system was not in a secure operating state	43 MW (Victoria to South Australia)	24,117	AEMO Incident Report[105]
Moderate event								
	No events occurred in South Australia under the moderate category.							
Minor event								
20 June 2019 **07:47 hrs**	Trip of the No. 1 Transformer and No. 2 Static Var Compensator at South East substation	Control system failure	No load or generation disconnected in South Australia	The power system was in a secure operating state prior to this incident and remained in a secure operating state for the duration of the incident.	No discernible impact.	11 MW (Victoria to South Australia)	31,687	AEMO Incident Report, November 2019[106]

[104] AEMO, Incident Report, January 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/sa-not-secure-5-may.pdf?la=en&hash=A9C69FDC29C73936AFF7764E4B30E634.

[105] AEMO, Incident Report, January 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/sa-not-secure-14-may.pdf?la=en&hash=C41F446CE259DC03884A1C46FC011294.

[106] AEMO, Incident Report, November 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/trip-of-1-transf-and-1-svc-at-sess.pdf?la=en&hash=D0D28511CA6801B7B2BBB65EECC183C5.

Date / Time	Description of event	Primary cause	Load/generation Involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow (Heywood) prior to contingency	Inertia in South Australia (MWs)	Reference
20 Jan 2020	Fault at Torrens Island 'A' 275 kV west bus	Data not available, will be analysed in Stage 2	Data not available, will be analysed in Stage 2	Data not available, will be analysed in Stage 2	No discernible impact.	Data not available, will be analysed in Stage 2	Data not available, will be analysed in Stage 2	Data not available, will be analysed in Stage 2

25 August 2018 – Queensland and South Australia system separation

This event was triggered by a lightning strike on a transmission tower structure supporting the 330 kV QNI lines, and tripping off of the double circuit transmission line between Dumaresq and Bulli Creek. This resulted in islanding Queensland from rest of the NEM. Power transfer on the Heywood interconnector immediately prior to the lightning strike on QNI was about 170 MW towards Victoria. With these changes, the South Australia – Victoria Heywood interconnector experienced rapid changes in power system conditions that triggered the EAPTS, resulting in a separation in South Australia at Heywood.

South Australia frequency fell to around 49.14 Hz at a rate of around 0.12 Hz/sec when Queensland separated. As South Australia was exporting towards Victoria at the time of the separation, frequency in South Australia immediately reversed its decay on disconnection from the 500 kV network in Victoria and began to increase. The frequency rose more rapidly to a maximum of around 50.46 Hz, at a peak rate of around 0.65 Hz/sec and then returned to within the range. However, frequency then increased again over a period of minutes, and reached just under 50.5 Hz, remaining there for almost three minutes. The frequency was contained between 47-52 Hz for the duration of the event in all regions.

Before a 0 MW target was established for the Heywood interconnector by AEMO control centre once South Australia was disconnected from Victoria, the interconnector was targeted for 164 MW export from South Australia to Victoria. This resulted in generation dispatch in South Australia exceeding the regional demand, further contributing to the high frequency condition. Once a separate Automatic Generation Control (AGC) control area had been established and 0 MW target was set on the open Heywood interconnector, frequency in South Australia was able to be controlled within the 'normal' frequency band.

Due to low wind speed conditions, total South Australia wind generation output was low at the time of the event, at around 7% of the 1,811 MW South Australia installed capacity. Four wind farms (with the same wind turbine model) in South Australia were observed to cease output during this event. AEMO has been advised that this was caused by incorrect turbine protection operation, in response to the rapid decline, then increase, in system frequency.

The 110 MW Bungala Solar Farm, which was the only transmission-connected PV generation in service in South Australia at the time of the event, did not provide any response to the initial under-frequency condition in South Australia as it was operating without headroom. There was a reduction in solar farm output in response to the high frequency condition following South Australia separation from Victoria, consistent with the plant's performance standards. However, as this response only commenced around 1 second after the frequency in South Australia had already peaked, it did not contribute to arresting the frequency rise in South Australia.

Hornsdale Power Reserve, which has a capacity of +100 MW/-80 MW, was in operation at the time of the event and charging at -38 MW immediately prior to the event. It contributed to both arresting the initial decline in system frequency, and then by rapidly changing output from generation back to load, to arrest the over-frequency condition in South Australia following separation from Victoria. The rapid active power response from the Hornsdale battery assisted with limiting the under- and over-frequency conditions.

16 November 2019 – South Australia – Victoria system separation

The Heywood – APD – Mortlake 500 kV line and Heywood – APD – Tarrone 500 kV lines in Victoria were disconnected simultaneously, due to false signals from telecommunications equipment that triggered the unexpected operation of protection equipment. This resulted in the islanding of South Australia from the rest of the NEM power system for nearly five hours, and disconnection of electrical supply to the APD aluminium smelter in Victoria for nearly three hours.

Immediately after the islanding, frequency in South Australia increased as a rate of 1.15 Hz/s and peaked at approximately 50.85 Hz, followed by settling at around 50.6 Hz approximately 2 seconds after the initial separation. During the event frequency remained below 51.0 Hz, at which protection schemes on some generation in South Australia begin to operate. The frequency outcome in South Australia met the frequency operating standards for an islanding event.

To arrest the rise in frequency due to a sudden loss in around 300 MW of export, generation in South Australia reduced by around 300 MW. Synchronous generation collectively reduced by around 140 MW.

Most wind farms in South Australia did not show any material change in output in response to the frequency change and remained close to their pre-disturbance outputs. Based on the data available to AEMO, Lincoln Gap and Willogoleche Wind Farms showed a relatively rapid and controlled reduction in output in response to the frequency increase, which in aggregate contributed to arresting the rise in frequency.

Due to the low irradiance levels, output of the Tailem Bend solar farm which is connected to the transmission network at the time of the event was around 20 MW. The solar farm reduced its output rapidly contributing to arresting the rise in system frequency.

Two grid-scale BESS, Hornsdale and Dalrymple, provided a rapid change in output in response to the frequency change, which assisted in arresting the frequency rise.

South Australia currently has a Virtual Power Plant (VPP) formed from the aggregation of approximately 650 units of 5 kilowatts (kW) PV and storage (3.25 MW). Even though the relative size of the VPP is small, it reduced the active power in response to South Australia frequency increase.

The largest load in South Australia is the Olympic Dam load (180 MW), and it can be disconnected due to a single credible transmission contingency at any time. When South Australia is islanded, a large volume of contingency lower FCAS is required to control the rise in frequency that would result from a subsequent credible trip of this load. To address this, AEMO directed ElectraNet to reduce load at Olympic Dam to 130 MW during this event.

Due to low system strength conditions in the islanded South Australia, and the relatively remote connection points of the generation, the Lake Bonney (Stage 1, 2, and 3) and Canunda Wind Farms were instructed to reduce the dispatch to zero during the islanded operating condition.

31 January 2020 – South Australia – Victoria system separation

Due to severe weather conditions, a number of steel transmission towers on the Moorabool – Mortlake and Moorabool – Haunted Gully 500 kV lines collapsed (MLTS–MOPS and MLTS–HGTS lines), resulting in these lines tripping and remaining unavailable for service. This caused South Australia to be separated from Victoria, but left Mortlake Power Station, Macarthur Wind Farm, and Portland Wind Farm connected to the South Australian network. It took 17 days to restore the lines to service on temporary towers, during which time South Australia was operated as an extended island. This was a unique event in terms of both configuration and duration.

Immediately following the separation, the flow on the Heywood interconnector changed from approximately 500 MW into Victoria to 500 MW into South Australia, a step change of approximately 1,000 MW. This was a result of the trip of both APD potlines and generation remaining online at Mortlake Power Station and the Macarthur and Portland wind farms.

Islanding of South Australia triggered the frequency in South Australia to rise to 51.11 Hz. The frequency in South Australia met the NEM frequency operating standard for a multiple contingency event in terms of the containment, recovery and stabilisation bands.

Scheduled generation in South Australia reduced by approximately 640 MW immediately following the separation event.

It was also found that immediately following the separation, the South Australia region scheduled demand increased. This was likely caused by the reduction in output from DPV generation and other non-scheduled generation in response to the high frequency in South Australia.

AEMO has released a preliminary report on the incident and is presently preparing a final report.

2 March 2020 – South Australia – Victoria system separation

Due to protection maloperation a circuit breaker at Heywood Terminal Station tripped, resulting in disconnection of the South Australian region and Mortlake Power Station from the rest of the NEM for approximately eight hours. However, there was a pre-existing unplanned outage of the Moorabool Terminal Station – Mortlake Power Station (MLTS–MOPS) 500 kV line, which meant that the event resulted in credible separation of South Australia. Due to this, the Heywood interconnector flow was around 50 MW prior to the event and hence caused only minimal impact. AEMO is currently investing the incident.

Following the separation event, the frequency deviations were minimal, as the interconnector was lightly loaded at the time. The frequency performance is being analysed as part of the power system investigation for this incident.

5 May 2019 – power system in South Australia not in a secure operating state

Wind generation in the Northern area of South Australia unexpectedly reduced to zero or near zero output, causing voltage levels in the area to rise. Between 1030 hrs and 1145 hrs, the power system was not in a secure operating state as AEMO's Contingency Analysis tools showed post-contingent voltage levels at Blyth West and Willalo substations would have exceeded the satisfactory operating limit. No load or generating unit were disconnected because of this incident.

14 May 2019 – power system in South Australia not in a secure operating state

The power system in South Australia was not in a secure operating state for 100 minutes due to post-contingent voltages on the 132 kV network around the Tailem Bend and Keith substations being below the required limits. No load or generation was disconnected because of this incident.

20 June 2019 – trip of the No. 1 transformer and No. 2 static var compensator at South East substation

This event occurred due to a control system failure. No load or generation was lost due to this incident. The power system remained in a secure operating state over the course of this incident. In response to this and similar recent incidents, ElectraNet has commenced a project to modify the 415 V supply to the SVCs to reduce the likelihood of future events.

7.4 Operational experience and impact

7.4.1 Weather-related operational experience

With the increasing penetration of wind generation in South Australia, there is an increased risk of generation contingency events associated with high speed wind cut-out. With more solar farm connections and increases in DPV, cloud cover is also becoming increasingly challenging to manage.

On 9 December 2019, from 10:00 hrs to 16:00 hrs, there was considerable cloud cover while sunny, which resulted in a significant movement of DPV. This resulted in a notable movement of the Heywood interconnector flow. As there is a significant density of DPV over a small footprint across the Adelaide metropolitan region, any clouds passing can result in a substantial change in generation (back and forth) which is difficult to predict and manage effectively.

The power system risks for these extreme weather events were managed by appropriate generation dispatch to control the line flows in the impacted lines and through reclassification of events.

7.5 Under-frequency load shedding in South Australia and new protected event

AEMO has conducted extensive preliminary studies into an emerging risk that the South Australian UFLS will not be capable of arresting a frequency decline and preventing cascading failure in the event of a separation from the rest of the NEM in a growing number of future periods.

This is related to a number of factors, including ongoing growth in DPV (which reduces the robustness of the UFLS by reducing the net load disconnected by under-frequency tripping), and the anticipated increase in imports into South Australia on the Heywood interconnector, associated with the commissioning of ElectraNet's synchronous condensers.

AEMO is presently working with ElectraNet to develop a power system constraint designed to limit imports on the Heywood interconnector to the level where there is confidence that cascading failure will be avoided if a separation event occurs. This will replace the existing constraint under regulation 88A of the *Electricity (General) Regulations 2012* (SA), in conjunction with limits advice from ElectraNet, to keep the rate of change of frequency (RoCoF) below 3 hertz per second (Hz/s) for the non-credible trip of both Heywood interconnector circuits. It should be noted that RoCoF would exceed 3 Hz/s once cascading failure starts to occur, so the constraint would be designed to avoid frequency falling to 47 Hz during periods when UFLS schemes are unlikely to be effective.

Although this provides a reasonable interim solution, AEMO considers it is preferable to manage the identified risks under the NER protected event framework. This will provide greater transparency, and allow more detailed consideration of all non-credible contingency events that result in separation of the South Australia region, and a wider range of options to mitigate this risk.

The PSFRR therefore recommends a protected event be declared to allow AEMO manage the risk of cascading failure and a black system in South Australia under the protected event framework. This would apply to South Australia separation from Victoria for a non-credible loss of the Heywood interconnector or any section of the double-circuit 500 kV network between Heywood and Moorabool terminal stations when South Australia is importing from Victoria.

A detailed explanation of the UFLS issues in South Australia and the recommended protected event are documented in the report at Appendix A1.

AEMO has also recommended a suite of complementary measures that will further support system security in periods with high levels of DPV generation, and will minimise the market impacts of managing the protected event. These include:

- Adding more load to the UFLS.
- Implementing 'dynamic arming' of UFLS relays (such that they arm/disarm in real time depending upon the direction of flows on the UFLS circuit).
- Assessing possible UFLS topology changes to disconnect load only (and not DPV).
- Exploring pathways to increase the availability of Fast Active Power Response (FAPR) in South Australia.

AEMO has shared its analysis, findings, options, and recommendations with the South Australian Government and NSPs, and provided in depth exploration in Appendix A1. Stage 2 of the PSFRR will include further investigation of the functionality of the EFCSs in South Australia under high DPV generation conditions.

AEMO intends to prepare a detailed submission to the Reliability Panel in relation to the proposed protected event by the end of 2020. Subject to the outcome of a cost-benefit analysis, AEMO may recommend a protected event for non-credible separation of the South Australia region during all periods (not only when the Heywood interconnector is importing into South Australia).

In addition to the EFCS and declared protective events in South Australia, operational measures such as minimum synchronous unit commitments in SA also help to control frequency during non-credible events by providing increased inertia and FCAS. These help to limit RoCoF and assist frequency recovery and stabilisation as required by the FOS.

Network investments currently being planned, committed, or implemented will, in different ways, change the need for operational constraints and additional services to manage the frequency risks following significant non-credible contingencies, notably:

- Installation of four, high inertia, synchronous condensers.
- New interconnector between South Australia and New South Wales – Project Energy Connect.
- Installation of large grid-connected battery energy storage.

Improved responsiveness from the renewable generation plants (for example, synthetic inertia) and distributed generation and controllable loads may also support the management of frequency risks. The continuing need of presently employed operational constraints for managing frequency risks after the completion of the above asset investments will be assessed and reported in stage 2 report.

7.6 Frequency risk management 2020-25

As discussed, at times of high DPV output, it has been identified that the effectiveness of UFLS protection scheme may be reduced or even exacerbate disturbances. ElectraNet and SAPN are collaborating to quantify the available UFLS using SCADA data. It is envisaged that this SCADA data will be used in the AEMO dispatch system to facilitate operational management of emerging risks. This enhancement is expected to be operational in Q4 2020. SAPN is also expanding the existing UFLS coverage to include eight additional substations, which will serve to increase the aggregate load available for UFLS. Further analysis on the impacts of DPV on the functionality of UFLS is included in the report at Appendix A1.

AEMO and ElectraNet have analysed the impact of a trip of a large generator on subsequent DPV disconnection. This analysis has indicated that an additional amount of generation may be lost as a result of subsequent UFLS operation (that is, the net result of loss of DPV together with load across South Australia) following a fault associated with the loss of the largest generator in the Adelaide metro area. As such, the contingency size in the constraint equations for Victoria to South Australia power flow will need to be increased by an additional amount, dependent on DPV output at the time (considering field measurements from South Australia solar plants), to model the possible DPV tripping during daylight hours[107]. AEMO and ElectraNet are continuing to review and refine these limits.

AEMO has also identified emerging system security risks including potential inability to maintain the FOS under some conditions in low load periods, associated with the behaviour of DPV. These findings are also presented in Appendix A1.

7.7 Summary

7.7.1 Adequacy of EFCS

Over-frequency generation shedding scheme

Only one relevant non-credible contingency event since the 2018 PSFRR triggered an EFCS in South Australia, associated with the separation on 31 January 2020.

The high frequency in South Australia immediately after separation triggered the OFGS to trip wind farms in OFGS group 1 and 2, the first time the OFGS has been required to operate. AEMO's final operating incident for this event will include a review of the operation of this scheme.

Under-frequency load shedding scheme

With the increased penetration of DPV in South Australia, there is a risk that UFLS will not be effective in arresting an under-frequency event. The under-frequency disconnection behaviour of DPV at frequencies below 49 Hz further reduces UFLS capabilities to arrest a severe frequency decline. Further analysis is provided in the report at Appendix A1.

Irrespective of the PSFRR process, network service providers have ongoing responsibilities, in consultation with AEMO, to ensure sufficient load included in UFLS schemes to minimise or reduce the risk of cascading failures in response to multiple contingency events. AEMO will continue to work with ElectraNet and SAPN to develop solutions to address issues with existing UFLS schemes.

[107] See South Australia system normal constraint update – Metro generation and PV contingency Market notice24042020, at https://aemo.com.au/market-notices?marketNoticeQuery=&marketNoticeFacets=GENERAL+NOTICE&MarketNoticeList=1.

System Integrity Protection Scheme

Currently, ElectraNet is upgrading the SIPS to a Wide Area Protection Scheme (WAPS). The adequacy of the WAPS scheme will need to be carefully reviewed when the proposed Project EnergyConnect is built. New special protection schemes need to be designed and implemented to avoid cascade tripping from the non-credible loss of either AC interconnector connected to South Australia.

7.7.2 Adequacy of protected events

As stated in Section 7.2.2, South Australia currently has one protected event declared, which is related to the loss of Heywood interconnector during import conditions under forecast destructive wind conditions. This will be further reviewed as part of the development of the Stage 2 report.

AEMO has identified the need for a new protected event to manage the non-credible separation of South Australia in periods where the UFLS is inadequate. AEMO intends to make a submission to the Reliability Panel by the end of 2020.

8. Tasmania

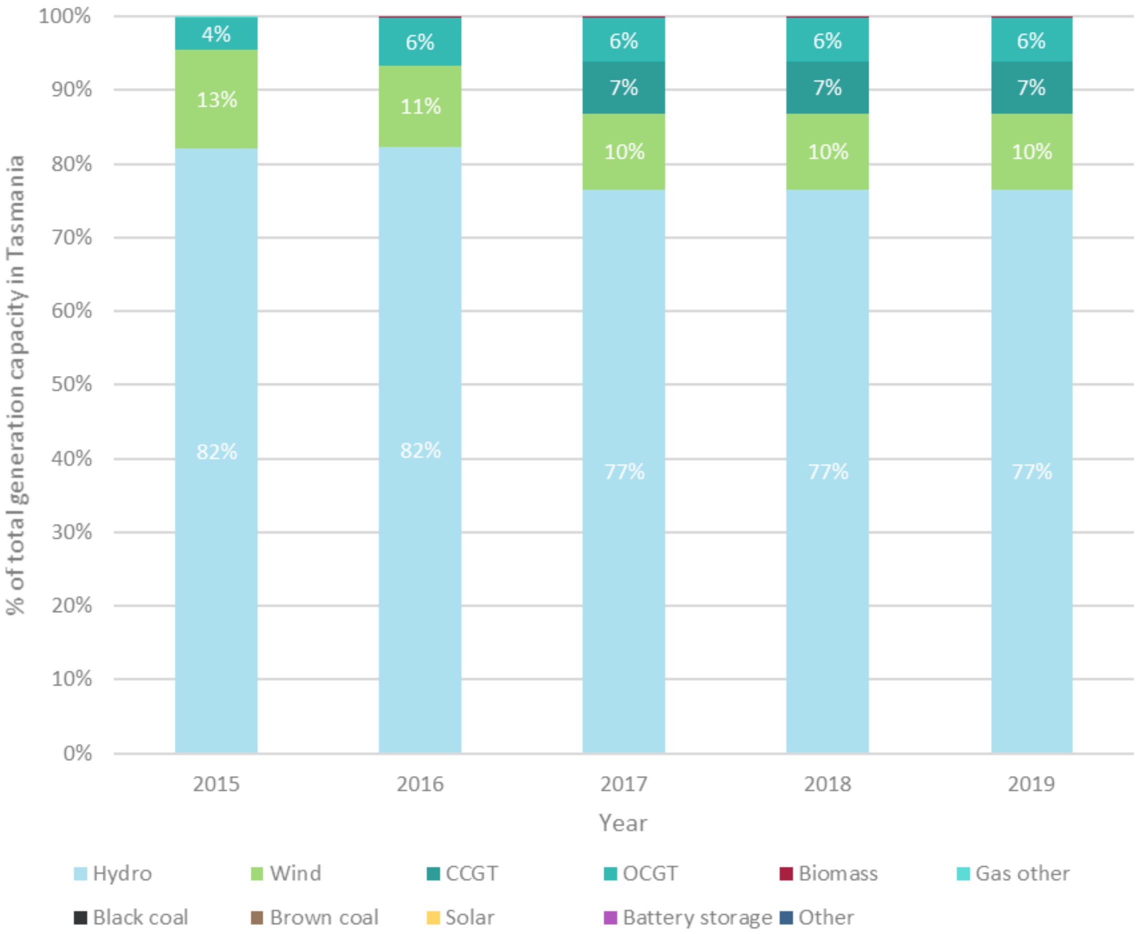
8.1 Introduction

8.1.1 Generation in Tasmania

Figure 24 shows the Tasmanian generation mix over the past five years, based on data obtained from AEMO's Generation Information page[108]. Electricity generation in Tasmania is dominated by hydro power, which supplies around 77% of the region's energy. The Tasmanian generation mix has largely remained the same over the past five years.

Hydro generating units are slower to respond to frequency deviations than steam generating units. As Tasmania has a high penetration level of hydro power and has larger generators relative to the size of the network, it is prone to large frequency deviations. Accordingly, Tasmania has a different FOS than the mainland, with wider frequency bands[109].

Figure 24 Tasmania generation mix changes, 2015-19



Note: the contributions of some generation sources are not large enough to be visible on this chart.

[108] AEMO, Generation Information, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/generation_information/nem-generation-information-april-2020.xlsx?la=en. Data used in this chart has been taken from the final update each year.

[109] AEMC, Frequency Operating Standard, Effective 1 January 2020, at https://www.aemc.gov.au/sites/default/files/2019-04/Frequency%20operating%20standard%20%E2%80%93%20effective%201%20January%202020.pdf.

8.1.2 Electricity demand in Tasmania

Tasmania has a small load compared to other NEM regions. The median demand during 2017 to 2018 was approximately 1,200 MW, and was between 1,100 MW and 1,300 MW for 54% of the time. The minimum demand occurs during the daytime in summer and was 879 MW in 2017 to 2018. The time at which the minimum demand occurs is changing from summer night to day, and is forecast to reduce over coming years as increasing DPV generation reduces the summer day demand on the network[110].

More than half of Tasmania's demand consists of large industrial loads connected to the transmission network, and their participation is crucial in the performance of EFCS.

8.1.3 Transmission system in Tasmania

Existing transmission network

TasNetworks owns, operates, and maintains the electricity transmission and distribution network in Tasmania. The transmission network in Tasmania comprises:

- A 220 kV, and some parallel 110 kV, bulk transmission network that provides corridors for transferring power from several major generation centres to major load centres and Basslink.
- A peripheral 110 kV transmission network that connects smaller load centres and generators to the bulk transmission network.
- Substations that form interconnections within the 110 kV and 220 kV transmission network and provide transmission connection points for the distribution network and large industrial loads.

Interconnection with Victoria

Tasmania's power system is connected to the mainland network via Basslink, a 500 MW privately owned undersea high voltage direct current (HVDC) cable. Basslink has the capability to provide bi-directional transfer of electricity, enabling Tasmanian generators to export to the mainland and also enabling import from the mainland to the Tasmanian network. Basslink has a frequency controller and can provide frequency control ancillary services between Victoria and Tasmania. As Basslink is a HVDC link, power system characteristics such as fault level and inertia, as well as power system performances following disturbances are decoupled between the mainland and Tasmanian power systems. However, when not operating at its limits, Basslink is capable of providing fast frequency response support for management of frequency during frequency disturbances.

Basslink has nominal rating of 500 MW and has bidirectional power transfer capability. Most of the limitations on Basslink transfers (in both directions of flow) are driven by the availability of FCAS for mainland and Tasmanian contingency events.

Furthermore, the Basslink transfers can be reduced when there is reduced load or generation available for tripping via the Frequency Control System Protection Scheme (FCSPS) in Tasmania[111].

The Basslink flow pattern in 2018 and 2019 is illustrated via flow duration curves in Figure 25, which shows:

- In 2019, Basslink was exporting to Victoria approximately 42% of the time, compared to 51% in 2018.
- In 2019, Basslink was importing from Victoria approximately 45% of the time, compared to 28% in 2018.
- In both 2018 and 2019, there were extended periods of zero transfer due to Basslink outages[112], with reduced periods of zero transfer observed in 2019 compared to 2018.

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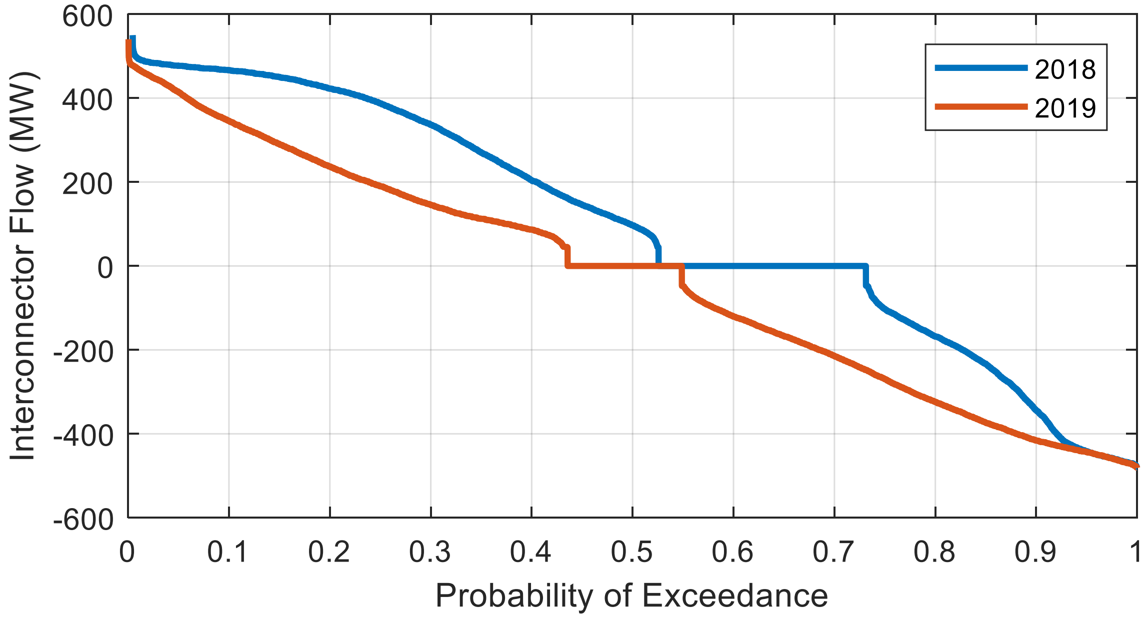
[110] TasNetworks, Transmission Annual Report 2019, at https://www.tasnetworks.com.au/config/getattachment/03c10b58-4a28-4fed-bc74-15a7e6aeffef/2019-annual-planning-report.pdf.

[111] AEMO, Interconnector Capabilities, November 2017, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2017/Interconnector-Capabilities.pdf.

[112] Hydro Tasmania, Media Releases, "Basslink Return to Service", June 2018, at https://www.hydro.com.au/news/media-releases/2018/06/05/basslink-return-to-service and "Basslink Return to Service Two Weeks Early", September 2019, at https://www.hydro.com.au/news/media-releases/2019/09/26/basslink-to-return-to-service-two-weeks-early.

In summary, Basslink was importing from Victoria more of the time in 2019, compared to 2018; however, the data is skewed due to extended outages in both 2018 and 2019.

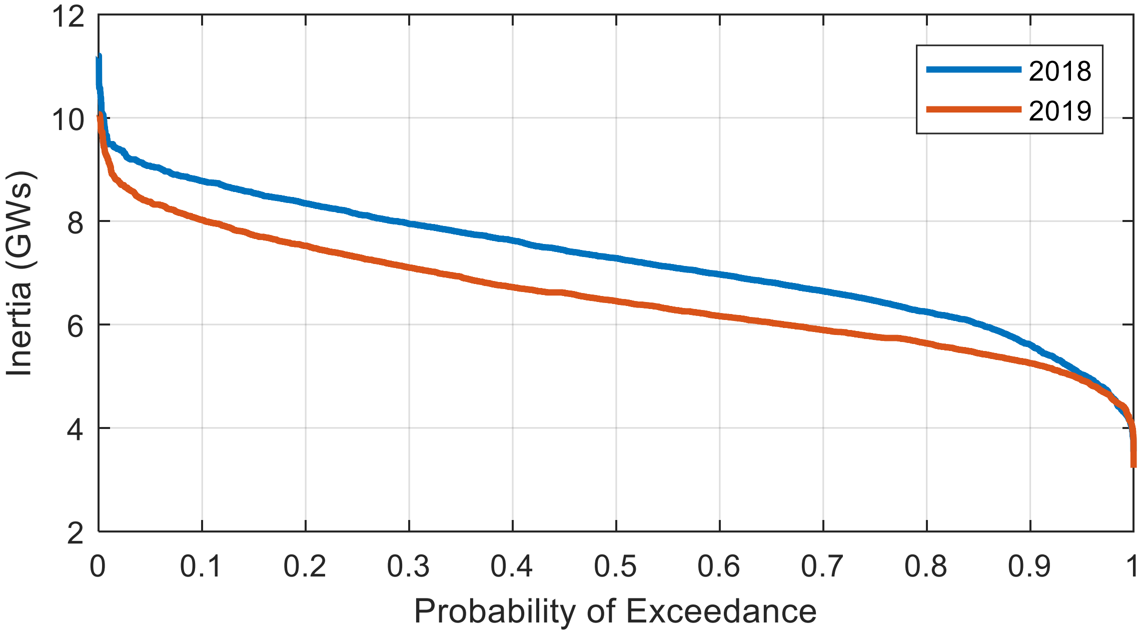
Figure 25 Basslink interconnector flow duration curves, 2018 and 2019



Note: Positive interconnector flow indicates flow direction from Tasmania to Victoria

Figure 26 shows the inertia duration curves in 2018 and 2019, indicating an overall reduction in inertia in 2019, compared to 2018. This could be attributed to longer periods of Basslink import from Victoria in 2019, consistent with Figure 25, and more wind generation displacing synchronous generation in 2019 than in 2018.

Figure 26 Inertia duration curve for Tasmania, 2018 and 2019



Summary of planned major network upgrades in 2020-25

TasNetworks has identified the following major works planned from 2020 to 2025[113]:

- Hydro Tasmania has identified opportunities to redevelop Tarraleah Power Station and other capacity increases from continuing refurbishment and upgrade works around the state.
- Wind power in Tasmania is increasing with Granville Harbour (112 MW) and Wild Cattle Hill (144 MW) wind farms under construction and being commissioned at present, and a number of proposed wind farm developments also being assessed.
- Small-scale generation, including DPV, continues to increase in Tasmania, with a number of proposed large-scale solar farm proposals also being assessed.
- Hydro Tasmania is continuing its studies into pumped hydro energy storage in Tasmania, referred to as 'Battery of the Nation", and is currently assessing the feasibility of priority sites.
- TasNetworks is also currently investigating the case for further interconnection to Victoria, known as Marinus Link, to operate in addition to Basslink, and working through the RIT-T process[114].
  - Detailed analysis by TasNetworks thus far indicates that the optimal capacity and timing for Marinus Link and supporting transmission under the RIT-T framework is:
    - Stage 1: an initial 750 MW HVDC link between Burnie in Tasmania and Hazelwood in Victoria with supporting network augmentations in Tasmania, to be commissioned in 2028.
    - Stage 2: the commissioning of a further 750 MW HVDC link in 2032.
  - It is noted that the timeline for Marinus link is outside the projection scope of this PSFRR and it is expected that future PSFRRs will capture the impact of this project on frequency.

8.1.4 Review of 2018 PSFRR for Tasmania

AEMO's investigation on the Tasmanian power system as part of the 2018 PSFRR highlighted the following:

- The current mechanisms to protect against frequency risks are appropriate.
- AEMO's review of existing Tasmanian EFCSs did not identify any immediate need to modify any scheme.
- AEMO has no recommendations regarding the management of non-credible contingencies in Tasmania.

8.2 Emergency frequency control schemes and declared protected events in Tasmania

The following EFCSs exist in Tasmania:

- Tasmanian UFLS scheme.
- Tasmanian OFGS scheme.

It is noted that in the 2018 PSFRR, the FCSPS associated with the Basslink HVDC interconnector and the Tamar Valley Generator Contingency Scheme (TVGCS) associated with the CCGT at George Town were also considered. However, these are not EFCSs as defined by the NER, because they are used to manage credible contingency events in conjunction with dispatched FCAS. According to TasNetworks, the FCSPS and TVGCS are utilised as part of normal power system operations and the UFLS and OFGS schemes act as backups should the FCSPS and TVGCS schemes partially or completely fail.

[113] TasNetworks, Transmission Annual Report 2019, at https://www.tasnetworks.com.au/config/getattachment/03c10b58-4a28-4fed-bc74-15a7e6aeffef/2019-annual-planning-report.pdf.

[114] TasNetworks, Marinus Link RIT-T Process, at https://www.marinuslink.com.au/rit-t-process/.

8.2.1 Tasmanian under-frequency load shedding scheme

There is an existing UFLS scheme in Tasmania. All Major Industrial (MI) customers and a significant portion of the distribution network participate in the UFLS in accordance with NER load shedding requirements.

8.2.2 Tasmanian over-frequency generator shedding scheme

The Tasmanian OFGS scheme is a non-distributed scheme involving the local tripping of generators by relays at Gordon and Farrell substations. The objective of the OFGS scheme is to contain a system frequency rise during an over-frequency event through the staggered tripping of OFGS scheme nominated generators, at different frequency thresholds.

TasNetworks also has an over-frequency coordination (OFC) scheme which provides increased coordination of OFGS scheme-nominated generators with those having agreed plant limitations.

8.2.3 Protected events

There are no protected events declared in Tasmania.

8.3 Review of incidents

Table 8 summarises the relevant non-credible contingency events which occurred in the Tasmanian region since the last PSFRR. None of these events resulted in operation of the UFLS or OFGS schemes. Some events may have been reclassified (as credible) prior to the outage thereby reducing their impact on the network.

The non-credible contingency events are categorised in terms of the frequency excursion with respect to the FOS for Tasmania and the state of operation of the power system, as stated in section 2.3.

The RoCoF values indicated in Table 8 for each incident have been approximated, based on available high speed monitoring data.

Table 8 Summary of relevant non-credible contingency events in Tasmania

Date / Time	Description of event	Primary cause	Load / generation involved (MW)	Frequency response	RoCoF (Hz/s)	Interconnector flow (Basslink) prior to contingency	Inertia in Tasmania (MWs)	Reference
Major event								
	No events occurred in Tasmania under the 'Major' category.							
Moderate event								
28 May 2019 2113 hrs	FA–JB and FA–RB–NT–QT trip	Lightning	Load: Newton and Queenstown Customer 12 MW Gen: John Butters Unit 135 MW	49.32 Hz (minimum) 49.85 Hz (recovery which occurred within 48 s and FOS was met)	-0.56	117 MW (Tasmania export to Victoria)	7,523	AEMO Incident Report[115]
13 Jul 2019 0539 hrs	BG–DB plus No. 1 & No. 2 Tx at TA trip	Equipment failure / protection mal-operation	Load: Customer 2 MW Gen: Butlers Gorge PS 9 MW, Tarraleah PS 83 MW	49.65 Hz (minimum) 49.85 (recovery which occurred within 3 s and FOS was met)	High speed monitoring data not available	443 MW (Tasmania export to Victoria)	6,622	AEMO Incident Report[116]
28 Feb 2018 1443 hrs	TU–MB–NN double circuit trip	Lightning	Load: Customer 3 MW Gen: Hydro Meadowbank 10 MW	49.69 Hz	High speed monitoring data not available	176 MW (Tasmania import from Victoria)	7,560	TasNetworks
Minor event								
21 Aug 2019 0400 hrs	FA-JB and FA-RB-NT-QT trip	Lightning	Load: Newton and Queenstown Customer 7 MW Gen: John Butters Unit 33 MW	No discernible impact on Frequency in Tasmania	No discernible impact on Frequency in Tasmania		5,569	AEMO Incident Report[129]

[115] AEMO, Trip of the Farrell – John Butters and Farrell – Roseberry – Newton – Queenstown lines, December 2019, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/report-trip-of-fa-jb-and-fa-rb-nt-qt-lines.pdf?la=en&hash=0E580D2504D16A29E5CBB711E7076074.

[116] AEMO, Simultaneous Trip of Tungatinah – Butlers Gorge – Derwent Bridge 110 kV Transmission Line and No. 1 and No. 2 Transformers at Tarraleah Power Station, January 2020, at https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/tu-bg-db-line-and-t1-and-t2-at-tarraleah.pdf?la=en&hash=5BF6F3FF184E19109CF07A9ED7F31297.

13 July 2019 – simultaneous trip of Tungatinah – Butlers Gorge – Derwent Bridge 110 kV transmission line and No. 1 and No. 2 Transformers at Tarraleah Power Station (BG-DB plus No. 1 and No. 2 Tx at TA)

This incident resulted in the disconnection of 92 MW of generation and 2 MW of customer load.

As a result of the loss of 92 MW of generation at the Tarraleah and Butlers Gorge Power Stations, the frequency in Tasmania fell to a minimum of 49.65 Hz and recovered to above 49.85 Hz within three seconds. The frequency standard in Tasmania was met for this incident.

The power system was in a secure operating state prior to this incident and remained in a secure operating state for the duration of the incident.

AEMO reclassified the simultaneous trip of the TU-BG-DB line and both the No. 1 and No. 2 Transformers at Tarraleah Power Station as a credible contingency, following this event.

28 May 2019 and 21 August 2019 – trip of the Farrell – John Butters and Farrell – Roseberry – Newton – Queenstown lines (FA–JB and FA–RB–NT–QT)

This incident resulted in the disconnection of 135 MW of generation and 12 MW of customer load on 28 May 2019, and 33 MW of generation and 7 MW of customer load on 21 August 2019.

As a result of the loss of generation at John Butters on 28 May 2019, the frequency in Tasmania fell to a minimum of 49.32 Hz and recovered to above 49.85 Hz within 48 seconds. The frequency standard in Tasmania was met for this incident.

The loss of generation at John Butters on 21 August 2019 had no discernible impact on the frequency in Tasmania.

The power system was in a secure operating state prior to these incidents and remained in a secure operating state for the duration of the incidents.

AEMO reclassified the simultaneous trip of the FA-JB and FA-RB-NT-QT lines as a credible contingency after both incidents.

Other notable incidents

The following non-credible contingency events resulting in frequency excursions are also noted to have occurred in Tasmania since the last PSFRR. According to TasNetworks, none of these incidents resulted in operation of EFCSs and TasNetworks did not develop a report, since the incidents did not have a significant power system impact.

- 18 January 2018 – New Norfolk distribution fault plus Boyer load trip.
- 27 January 2019 – Liapootah – Waddamana – Palmerston 1 and 2 double-circuit trip.
- 30 January 2019 – Waddamana – Lindisfarne trip plus loss of Nyrstar 70 MW.
- 18 February 2019 – Sheffield – Wesley Vale plus Sheffield – Davenport three phase fault.
- 6 July 2019 – Lindisfarne – Risdon plus Boyer load trip.
- 21 August 2019 – Farrell – Reece 1 and 2 trip.
- 6 October 2019 – Lindisfarne – Sorell and Lindisfarne – Sorell – Triabunna trip.
- 6 November 2019 – Farrell – Reece 1 and 2 trip.

Further analysis of these incidents will be undertaken in PSFRR Stage 2, if deemed necessary.

8.3.1 Low inertia dispatch in Tasmania

On 23 October 2019, the power system in Tasmania was not in a secure operating state for 37 minutes due to low inertia levels as result of a generating commitment variation modifying the available generation mix as part of normal operation. The inertia level in Tasmania was 3,725 megawatt seconds (MWs), which is below the 3,800 MWs required to maintain the power system in a secure operating state[117].

As a result of this event, AEMO updated its internal procedures dealing with managing inertia shortfalls. On 31 October 2019, AEMO implemented alarming on the inertia value for the Tasmanian region. Alarms are configured at 4,200 MW to provide time to respond before critical levels are reached.

In November 2019, AEMO published a Notice of inertia and fault level shortfalls in Tasmania[118]. In response to this Notice, TasNetworks and Hydro Tasmania successfully negotiated the provision of inertia and system strength in Tasmania, which has been made available from 1 April 2020. As a result, this incident should not recur; AEMO and TasNetworks will actively monitor inertia and AEMO will dispatch the inertia services contracted by TasNetworks to ensure the 3,800 MWs limit is maintained.

8.4 Operational experience and impact

8.4.1 Weather-related operational experience

In recent years, Tasmania has seen major-weather related events which have placed the power system at risk, including the bushfires south of Hobart in 2017 and bushfires in 2018. TasNetworks has discussed with AEMO that bushfires last year summer resulted in risk to major substations and the need to manage a potential Tasmanian north-south separation event.

At this stage, TasNetworks and AEMO agree that the reclassification process would be the way to manage such events. This has occurred already for some weather-related contingency events in Tasmania.

With the increasing penetration of wind farms in Tasmania, TasNetworks has also noted increasing risk of large-scale wind farms prone to high speed wind cut-out. With many wind farms in the same geo-location, there is a high risk of wind cut-out resulting in drastic changes in wind farm output.

The Gordon-Chapel St line is prone to ice-loading, however, according to TasNetworks, this is managed through operational procedures by running a minimum load to keep conductors warm.

8.5 Frequency risk management 2020-25

There were no identified priority contingencies.

8.6 Summary

8.6.1 Adequacy of EFCS

There were no non-credible contingencies in Tasmania which resulted in EFCS operation, therefore the adequacy of the schemes cannot be assessed based on historical events since the last PSFRR.

However, TasNetworks is currently undertaking its own design review of EFCSs, to take into account recent network changes:

- Modifications to the OFGS have been necessary to facilitate network connections for Cattle Hill (CHWF) and Granville Harbour (GHWF) wind farms. Both generating systems have negotiated access standards for NER S5.2.5.3 given their limited over-frequency withstand capability. Both wind farms have been added into the OFGS scheme in the 52.0-53.0 Hz range. The ongoing operation of two new wind farms, collectively rated at 256 MW, will also affect the typical system inertia profile in Tasmania, and the

[117] AEMO, Inertia Requirements Methodology - Inertia Requirements & Shortfalls, Version 1.0, June 2018, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.

[118] AEMO, Notice of Inertia and Fault Level Shortfalls in Tasmania, Version 1.0, November 2019, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2019/Notice-of-Inertia-Fault-Level-Shortfalls-Tasmania-Nov-2019.pdf.

corresponding impacts need to be considered with respect to the performance of Tasmanian EFCS schemes.

- Increase in maximum load demand at Bell Bay Aluminium (BBA) has marginally increased the total load that can be disconnected for a non-credible double-circuit 220 kV transmission line contingency event. The simultaneous loss of both circuits supplying the BBA site is an example of a non-credible contingency event which the OFGS scheme is designed to mitigate.
- DPV generation has now surpassed 144 MW, which is the maximum generation contingency size in Tasmania. TasNetworks believes there is a material risk that some portion of this embedded generation will trip as a result of a major network disturbance which significantly perturbs frequency and/or network voltages, and is investigating the potential impacts. Previous design reviews of the UFLS scheme have not considered the risk of generation loss from within the distribution network. The complicating factor is that UFLS performance may vary from day to night, even when the underlying load demand is comparable.
- TasNetworks continues to review what design alterations may be necessary to the UFLS scheme, should there be a major change in Tasmanian operational demand. As the contribution of direct connect industrial customers to the UFLS scheme is critical to the current design, any potential reduction in load shedding capability from this sector would have a material impact. While not necessary at the present time, TasNetworks believes it prudent to have mitigation plans in place to deal with a variety of future scenarios.
- The Adaptive UFLS (AUFLS) scheme has been introduced in Tasmania to provide a switched FCAS response to deliver additional fast raise capability. The potential failure of the AUFLS scheme following loss of the largest generating unit has been added as a new non-credible contingency for consideration as part of the UFLS design. It is important that a minor under-frequency event 'just below 48.0 Hz' can be adequately controlled without a disproportionate response from the UFLS scheme.

The Stage 2 PSFRR will include a detailed assessment of EFCS performance and adequacy, in consultation with TasNetworks.

9. Stage 2 report

9.1 Introduction

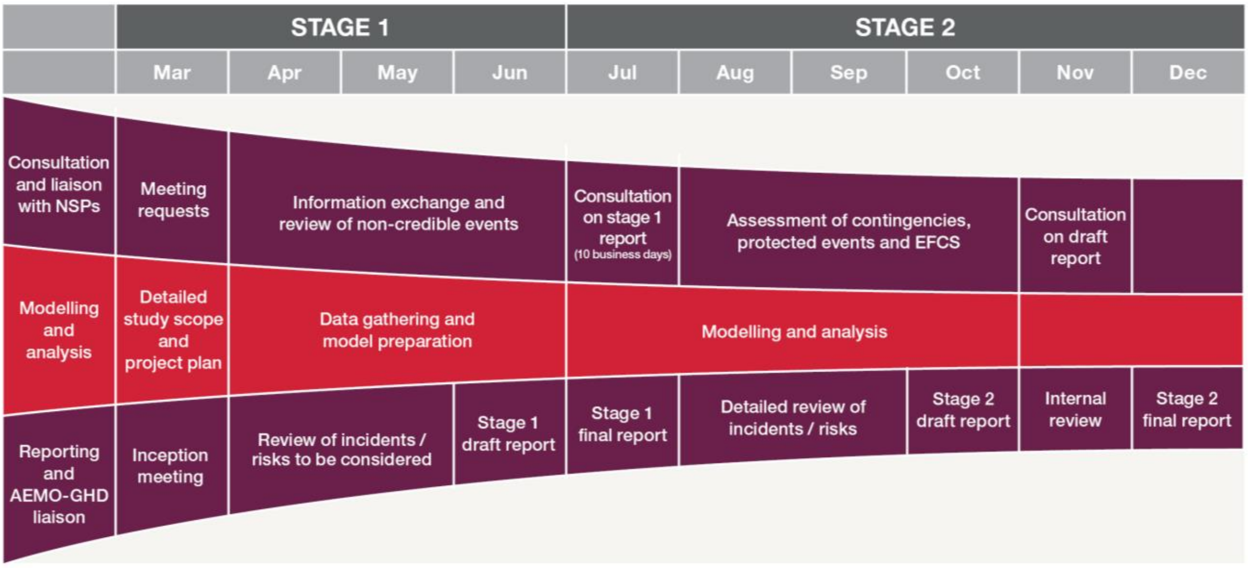
The planned work for Stage 2 assessment and reporting of PSFRR will be built on the reviews undertaken in Stage 1.

The work will involve:

- Updating AEMO's existing system frequency model to be able to predict post-contingent frequency outcomes, as recommended in AEMO's RIS Stage 1 report[119].
- Detailed analysis and simulation of priority non-credible contingency events which AEMO expects could likely involve uncontrolled frequency changes leading to cascading outages or major supply disruption.
- Assessing the performance and adequacy of existing EFCSs for management of potential frequency risks in the next two years (until the next PSFRR).
- Reviewing options for future management of such events, which may include new or modified EFCSs, declaration of a protected event, network augmentation, and non-network alternatives to augmentation.

The timeline for delivery of the Stage 2 of PSFRR and its interplay with Stage 1 assessment is illustrated in Figure 27. The final PSFRR Report, including the Stage 2 assessment, will be published by 31 December 2020.

Figure 27 Timeline for delivery of PSFRR – Stage 1 and Stage 2



9.2 Detailed simulation and analysis

Stage 2 will include detailed assessments of priority non-credible contingency events which AEMO expects could likely involve significant power system frequency impact, such as uncontrolled frequency changes leading to cascading outages or major supply disruption. The assessment will:

- Ascertain the performance of the power system, including that of generators, ancillary service providers, and EFCSs, and the adequacy of the available EFCSs for mitigating the impacts.

[119] AEMO, April 2020, at https://aemo.com.au/en/energy-systems/major-publications/renewable-integration-study-ris.

- Consider a number of scenarios where the power system may be stretched closer to its operating technical boundary prior to an incident taking place.
- Include detailed simulation of the dynamic performance of the power system. As a part of this assessment, the power system dynamic models available to AEMO, in particular for assessing the impact of power system incidents on frequency will be reviewed, including:
  – Governor models for synchronous generating units.
  – Models to simulate EFCSs.
  – Simulation models to capture DPV units.
  – Dynamic load models.

Stage 2 will also consider the impact of new transmission investments which are presently in implementation phase, being committed, or being planned, together with any resulting change in operational procedures, on the management of frequency risks following non-credible contingencies.

9.3 Priority non-credible contingency events

Non-credible contingencies are being identified for consideration in Stage 2 of the review. The list for priority review in Stage 2 will be based on those identified by TNSPs and agreed with AEMO.

The impacts of following scenarios will be considered, in the planning horizon of 2020-25:

- Committed and likely new generation and generation retirements.
- Committed and likely transmission augmentations.
- Impacts of disconnection of large load blocks as a result of UFLS action (for example, over-voltage and consequent generator trips).
- Impact of large uptake of DER including DPV.

9.4 Review of emergency frequency control systems

In the assessment of the considered non-credible contingencies, the adequacy of the following major EFCSs will be considered:

- UFLS.
- South Australian OFGS.
- Emergency APD Potline Tripping Scheme (EAPDTS).
- Heywood Interconnector SIPS.
- Interconnector protection schemes.

9.5 Protected events

The need for and adequacy of the existing protected event for adequately managing identified risks will be re-assessed in Stage 2 through detailed simulation studies, including assessment of changes that have occurred since the time of declaration (such as additional BESS in South Australia). In addition:

- The proposed protected event for managing the risks of ineffective UFLS in South Australia will be assessed in detail and a proposal submitted to the Reliability Panel.
- Based on the outcome of the non-credible contingencies considered for detailed review, recommendations for any new protected events will be made.

A1. Emerging issues with UFLS adequacy for Heywood interconnector contingency events

A1.1 Background

AEMO recently released a report exploring power system operation in low load periods in South Australia[120]. This report presented analysis on AEMO's ability to operate a secure system in South Australia in periods with low load and high generation from DPV, and focused on management of credible contingency events. This analysis identified emerging frequency risks, and is therefore summarised briefly in Section A1.3 for completeness.

The majority of this Appendix presents complementary analysis which explores non-credible contingency events in low load, high DPV periods. The focus is on the effectiveness of South Australia's EFCSs to arrest a frequency decline in the event of a non-credible separation.

A1.1.1 UFLS in South Australia

There is an existing UFLS scheme in South Australia (as in all NEM regions), designed to arrest the frequency decline following a severe under-frequency event, such as the separation of South Australia from the rest of the NEM while importing into South Australia, or other multiple contingency events. The UFLS scheme is intended to contain frequency fall by the controlled disconnection of load. It is one of South Australia's EFCSs, designed as a 'last line of defence' to manage multiple contingency events including separation events.

Challenges identified

AEMO has completed preliminary studies which show that DPV reduces the effectiveness of UFLS in South Australia to arrest severe under-frequency events in several ways:

- **Reducing net load** – increasing levels of generation from DPV reduces the 'net' load on UFLS load circuits. The total net load on all UFLS load circuits in South Australia reached as low as 100 MW in spring 2019. By spring 2020, total net load on all UFLS stages is anticipated to reach close to 0 MW, and may become negative (due to reverse flows) at times of highest PV output. If a severe under-frequency event occurred during a high PV period, even if all customers in the UFLS circuits were disconnected, the scheme would have little or no impact on frequency.
- **Reverse flows** – by spring 2020, with continuing growth of DPV, it is anticipated that more than half of the UFLS load blocks in South Australia could be in reverse flows at certain times. This means the action of UFLS relays to trip load circuits will exacerbate an under-frequency event, rather than helping to correct

[120] AEMO, Minimum operational demand thresholds in South Australia – Technical Report, May 2020, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2020/Minimum-Operational-Demand-Thresholds-in-South-Australia-Review.

the disturbance. SAPN advises that the majority of the UFLS relays in its network cannot be configured to arm/disarm based on active power flow direction without replacing UFLS relays. This has been approved as part of a contingent project in SAPN's final regulatory determination[121].

- **DPV disconnection** – DPV demonstrates under-frequency disconnection behaviour when frequency falls below 49 Hz[122]. This means a severe under-frequency event can be exacerbated by the disconnection of DPV that trips earlier than UFLS stages, including tripping of DPV that is not on UFLS circuits. This exacerbates the size of the contingency event, further increasing the probability that the UFLS will be inadequate to arrest a severe under-frequency event.

South Australia relies on UFLS to arrest a frequency decline caused by a significant non-credible event, like the simultaneous trip of multiple generating units, or both Heywood interconnector circuits when it is importing into South Australia. As daytime UFLS load declines with the continued growth in DPV generation, UFLS will be unable to effectively contain a fall in frequency from a large non-credible event that occurs during a high PV period. Without an effective means of arresting frequency decline, generation and other power system equipment will disconnect or shut down, causing major supply disruption and potentially a region-wide black system.

AEMO's studies have identified a small number of historical periods where the South Australian UFLS scheme would have been unlikely to prevent cascading failure in the event of a double-circuit loss of the Heywood interconnector. The incidence of risk has been low to date because the Heywood interconnector rarely imports high amounts of energy from Victoria into South Australia during periods where South Australia has low load and significant DPV generation.

Projections for future years suggest the incidence of high risk periods could increase, due to:

- Increasing installation of DPV.
- An increasing incidence of imports on the Heywood interconnector, even when load in South Australia is low. This is because the commissioning of synchronous condensers in South Australia will reduce the minimum synchronous generation that must currently operate in South Australia for system security, and also due to forecasts of significant growth in low cost generation in Victoria.

In addition to the capability to mitigate the consequences of separation events, a functional South Australian UFLS scheme needs to be maintained on a continuous basis, irrespective of Heywood flows, to reduce the impact of other events and conditions. For example:

- South Australian UFLS is an important component of a NEM-wide UFLS scheme, protecting against multiple contingency events within or outside the region when the NEM is fully interconnected.
- UFLS can help to manage possible 'overshoot' of OFGS (where an excessive OFGS response may lead to a subsequent under-frequency occurrence) and help achieve a stable island if separation occurs when the Heywood interconnector is exporting from South Australia at high levels.
- If South Australia is operating as an island in high PV periods, a credible fault can cause the disconnection of sufficient DPV to cause frequency to fall below 49 Hz, meaning the UFLS scheme is now important for managing credible events under islanded conditions. AEMO has very limited operational tools to manage these circumstances. This is discussed further in Section A1.3..

As the South Australian power system increasingly operates in new and untested territory, the importance of effective EFCS as the last line of defence becomes increasingly critical. This means it is important to improve the capability of the UFLS scheme, even if a protected event is declared that allows AEMO to manage the security risks associated with non-credible separation events. These additional measures will also reduce the level of response required to manage a protected event, lessening its market impact.

[121] AER Final Decision, SA Power Networks Distribution Determination 2020 to 2025, June 2020, Attachment 5, Capital Expenditure, at https://www.aer.gov.au/system/files/Final%20decision%20-%20SA%20Power%20Networks%20distribution%20determination%202020-25%20-%20Attachment%205%20-%20Capital%20expenditure%20-%20June%202020.pdf.

[122] AEMO, Response of existing PV inverters to frequency disturbances, April 2016, at https://aemo.com.au/-/media/Files/PDF/Response-of-Existing-PV-Inverters-to-Frequency-Disturbances-V20.pdf.

Remedial actions

AEMO has identified a suite of actions that could be taken to address the identified risks. These actions are complementary, and recommended in combination:

- **Constrain Heywood imports** – a constraint on Heywood imports in periods where the UFLS is known to be inadequate will significantly reduce the risk that a separation event will lead to cascading failure and a black system. Since market start in 1998, South Australia has separated from the rest of the NEM 16 times, with six occurring in the past four years. Of these, three were 'clean' separation events (simultaneous loss of both Heywood – South East circuits or the circuits exiting the Heywood Terminal Station), and there was one further event involving a non-credible separation in the 500 kV network in Victoria. Prudent power system operation dictates that significant Heywood imports should not be allowed in periods where it is known that the mechanisms to prevent cascading failure are no longer functional. A constraint can be implemented rapidly, to mitigate risk in the interim, while other measures are progressed to better manage risk over the long term. Since this constraint relates to managing a non-credible event, AEMO proposes to recommend the non-credible islanding of South Australia be declared as a protected event. In the interim, and after discussion with the South Australian Government, AEMO intends to implement the constraint under the limits advice provided by ElectraNet as required by jurisdictional regulation[123]. A protected event declaration, if made by the Reliability Panel, would make AEMO's management more transparent within the NER framework, and allow the event to cover the full range of potential events causing islanding at Heywood. This is discussed further below.
- **Increase and optimise load in the UFLS** – AEMO has advised SAPN and ElectraNet that the net load interrupted by the South Australia UFLS scheme is no longer sufficient, and requested that this be increased as much as possible. SAPN and the South Australian Government have identified a further 100 MW of load which is now being added to the scheme. AEMO has analysis underway to re-optimise the South Australia UFLS scheme settings to improve effectiveness as much as possible with the existing technology, while carefully managing UFLS balance with other NEM regions, and respecting the relative sensitivity of various loads. SAPN and ElectraNet are exploring how much further opportunity there may be to add more loads beyond this amount, using conventional technologies; SAPN has advised that even if all additional distribution-connected load were added, in light load periods this would add only 20-30 MW to the UFLS. There may be options for inclusion of more commercial loads or large industrial customers, or to explore emerging technologies that allow more granular relays at individual customer sites that can separately trip load while DPV remains operating. It is anticipated that these may take some time to implement, and the quantity of load provided will not be sufficient in isolation. Additional intervention may also be required to manage distribution network voltages during this process. AEMO is collaborating with SAPN and ElectraNet on the development of these options.
- **Dynamic arming of UFLS relays** – dynamic arming allows UFLS relays to be armed/disarmed in real time, based on flows on each UFLS circuit. When circuits are in reverse flows, the UFLS relay can be disarmed, such that it will not actively exacerbate an under-frequency disturbance. AEMO's analysis suggests this considerably improves UFLS functionality and halts further decline, although it is not adequate in isolation to restore UFLS functionality to the levels required.
- **Enduring frameworks** – the regulatory frameworks in the NER never envisioned a power system supplied primarily by distributed generation at individual customer sites, and do not provide a clear or adequate basis for investment in the optimal solutions for the long term. Review is required. AEMO is preparing concepts for a possible rule change proposal.

A number of other work streams underway at present will also assist with mitigating the identified risks, including processes to improve compliance with DER standards, Project EnergyConnect, and pursuit of pathways for increased FAPR in South Australia.

[123] Regulation 88A of the Electricity (General) Regulations requires that Heywood flows are limited to the level that maintains RoCoF below 3 Hz/s. In the event of a cascading failure, when frequency falls below 47 Hz, RoCoF will exceed 3 Hz/s as the system collapses. This Regulation therefore requires that Heywood flows are maintained to the level where there is confidence that cascading failure will be avoided in the event of a non-credible coincident trip of both circuits of the Heywood interconnector. Refer to *South Australia Electricity (General) Regulations 2012* under the *Electricity Act 1996*.

Further options may be identified as this work progresses. AEMO is collaborating with SAPN and ElectraNet to explore the various ways in which their obligations to provide sufficient emergency frequency response can be met. Long-term replacement of the functionality of conventional UFLS with alternative options is highly novel, and at the forefront of power system development internationally.

Protected event

This would be an interim measure while longer-term solutions are implemented to restore the capability of the UFLS scheme and other EFCSs in South Australia to adequately perform the risk mitigation role envisaged by the NER for multiple contingencies. Limiting Heywood imports to the level where there is confidence that the UFLS scheme will be adequate would help prevent cascading failure in the event of a non-credible separation from the rest of the NEM. Since this relates to a non-credible contingency, AEMO will apply this initially to meet the limits advice provided under South Australian regulations, and then seek to formalise this under the NER frameworks via a protected event declaration.

The Heywood interconnector is currently constrained in certain periods as part of the approved actions to manage an existing protected event recommended by 2018 PSFRR, being the loss of multiple transmission elements causing generation disconnection in the South Australia region during forecast destructive wind conditions. The actions taken to manage this existing protected event will not address the identified risks in periods where UFLS is considered inadequate to prevent cascading failure due to high DPV generation. By spring 2020, net UFLS load in South Australia is projected to become zero or negative in some periods. The incidence of risk periods is projected to increase from 2021, when the ElectraNet synchronous condensers are installed and Heywood may be importing more often.

A suitable constraint can be implemented within several months. SAPN and ElectraNet are establishing a SCADA feed that will provide AEMO with real-time data on the total net UFLS load available. This can be used in combination with AEMO's real-time estimates of DPV generation, power system inertia, availability of FAPR, and other relevant parameters to inform a constraint that calculates suitable Heywood limits in real time. AEMO is in the process of designing this constraint based on extensive power system studies, seeking to maximise accuracy and minimise market impacts. The objective of the constraint will be to maintain confidence that frequency will remain above 47 Hz (and hence the RoCoF will not exceed 3 Hz per second) for a clean separation event, taking into account modelling uncertainties, and the escalating risks of unforeseen power system behaviour if frequency falls far outside of normal ranges.

As part of the process of developing the submission to the Reliability Panel on declaration of the protected event, AEMO will also consider whether additional measures may be required to meet the FOS for a protected event. This may involve the need for additional frequency services in South Australia to provide suitable restoration of frequency, following separation.

The incidence and extent of the constraint binding (and the associated market costs and impacts) would naturally grow over time in the absence of Project EnergyConnect, as DPV penetration increases and as the Heywood interconnector starts importing more often. However, AEMO anticipates that these impacts will be reduced with the progressive implementation of the recommended complementary actions, summarised above. As described, the formulation of the constraint will attempt to optimise the Heywood interconnector import capacity.

AEMO will prepare a submission to the Reliability Panel proposing that a protected event be declared, outlining options and a cost/benefit analysis. AEMO is currently liaising with the Reliability Panel on the intention of making a formal submission by the end of 2020.

Stage 2 of the 2020 PSFRR will consider South Australian separation events in further detail, and may provide further recommendations.

A1.1.2 Low load, high PV periods and South Australia islanded operation

AEMO's analysis has also identified a broader suite of emerging security challenges in low load, high DPV generation periods in South Australia, particularly when operating as an island.

AEMO's analysis shows that a large proportion of DPV can disconnect in response to voltage disturbances. This can lead to frequency risks, particularly under South Australia islanded conditions. To minimise the growth in these risks, AEMO has a program of work underway to improve DER performance standards, and improve processes for compliance with those standards.

Further, until Project EnergyConnect or other additional synchronous interconnection is available to reduce the probability of South Australia operating as an island, there is a need to maintain sufficient load to operate the minimum units required for frequency control, inertia, system strength, and voltage control for South Australia to operate as a secure island if necessary. This may no longer be possible in some periods with high levels of DPV generation, with studies suggesting frequency may fall below 49 Hz for credible faults during islanded operation, due to the disconnection of DPV. To facilitate secure islanded operation, AEMO has recommended that DPV generation manual shedding capabilities are introduced as soon as possible[124], and is working with stakeholders to implement these capabilities. It is anticipated that manual generation shedding capability will be utilised very rarely, and only under conditions of network outages or other unusual conditions (such as operation of South Australia as an island).

A1.2 Under-frequency load shedding

A1.2.1 Background

The NER recognise UFLS as a form of EFCS established to arrest frequency decline and minimise the risk of cascading failure following a severe, non-credible underfrequency event, such as the separation of South Australia from the rest of the NEM. The UFLS scheme is intended to limit frequency fall by the controlled disconnection of load, using frequency sensing relays located at various points in the distribution and transmission network.

AEMO has conducted a preliminary review of the design of the UFLS scheme for South Australia, focusing particularly on:

- The impacts of an increasing penetration of DPV.
- Potential increases in imports on the Heywood interconnector in low load periods, related to the commissioning of synchronous condensers in South Australia, and significant investment in new entrant generation in Victoria.

This Stage 1 report summarises relevant findings to date. Updates from AEMO's full review will be included in the PSFRR Stage 2 report, to be released in late 2020.

A1.2.2 Approach

AEMO assessed the performance of the UFLS in South Australia using a single mass model (SMM) representation of the South Australian network. The results and analysis presented below are based on the outcome of these studies. Further studies will be undertaken as part of the development of a detailed submission to the Reliability Panel, and development of the Stage 2 PSFRR report.

'Net UFLS load' is used to refer to the aggregate load as measured by the network on circuits included in the UFLS. This is equivalent to the underlying load (the total load consumed by customers on that circuit), net of the DPV operating on that circuit. If the generation from DPV exceeds the underlying load, the circuit will be in reverse flows.

Assumptions

The following assumptions were applied for SMM studies:

[124] AEMO, RIS Stage 1 Report – Appendix A, April 2020, at https://aemo.com.au/energy-systems/major-publications/renewable-integration-study-ris.

- The contingency event modelled in all cases was a double-circuit loss of the Heywood interconnector (a 'clean' separation event). Other multiple contingency events within South Australia could occur and may require UFLS response to prevent cascading failure. This has not been examined in these studies.
- The amount of aggregate load at each trip frequency (load block) was informed by detailed hourly load data at each trip frequency and each UFLS circuit provided by SAPN for calendar year 2018 and 2019[125].
- The quantity of DPV in each load block was explicitly modelled. DPV tripping in response to under-frequency was modelled as follows:
  - For DPV installed prior to October 2015 (under AS/NZS4777.3:2005), the under-frequency trip settings in AEMO's 2016 survey of manufacturer settings[126] were applied. This applies to approximately half of the DPV installed in South Australia as of December 2019.
  - For DPV installed after October 2015 (under AS/NZS4777.2:2015), the same under-frequency trip settings from the 2016 manufacturer survey were applied to half of the new installed capacity. This assumes improvement in frequency ride-through behaviour as per the new standard, but with low rates of compliance. Poor compliance as high as 50% of capacity installed under the 2015 standard has been demonstrated in AEMO's investigation of DPV behaviour in recent power system disturbances, including 25 August 2018[127], 16 November 2019, 26 November 2019, and 31 January 2020. AEMO is developing improved datasets to validate this assumption.
- The amount of DPV was increased by a range of increments in various scenarios from the 2020 ISP scenarios, as indicated throughout the report, to explore possible future impacts as DPV levels grow.
- Load relief of 0.5% was assumed, consistent with AEMO's current contingency FCAS procurement procedures[128].
- For base-case studies, the Hornsdale BESS was assumed to contribute 70 MW FAPR with 1.7% droop[129]. Other BESS (such as the 50 MW Hornsdale expansion) may contribute additional response, but it cannot be guaranteed that they will be at a suitable dispatch level or state of charge to contribute FAPR for a given power system disturbance. Sensitivity studies were also performed, exploring the impacts of increased FAPR on power system outcomes.

Scenarios

Outcomes for a range of dispatch scenarios were explored, including:

- Historical periods in calendar years 2018 and 2019.
- Future periods predicted by simulations for AEMO's planning studies in the draft ISP for 2020.
  - The 'High DER' scenario was examined, since DPV growth in this scenario aligns most closely with observed recent growth in South Australia.
  - Projections for distributed storage were adjusted to match the 'Central' scenario from the 2020 ISP, aligning with recent observations.
  - Dispatch scenarios were modelled based upon 'strategic bidding' approaches, since this is believed to provide the most realistic representation of future market outcomes.

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125 For projections in future years, the UFLS load at each frequency stage was scaled proportionally with forecast operational demand, with the underlying load patterns represented by the 2019 historical reference year.

126 AEMO, Response of existing PV inverters to frequency disturbances, April 2016, at https://aemo.com.au/-/media/Files/PDF/Response-of-Existing-PV-Inverters-to-Frequency-Disturbances-V20.pdf.

127 AEMO, Final Report – Queensland and South Australia system separation on 25 August 2018, published 10 January 2018, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2018/Qld---SA-Separation-25-August-2018-Incident-Report.pdf.

128 AEMO, Review of NEM load relief, November 2019, at https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/ancillary_services/2019/update-on-contingency-fcas-nov-2019.pdf.

129 AEMO, Battery Energy Storage System Requirements for Contingency FCAS Registration, January 2019, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Ancillary_Services/Battery-Energy-Storage-System-requirements-for-contingency-FCAS-registration.pdf.

  - The synchronous condensers were assumed to be commissioned in South Australia in April 2021.
  - Heywood imports up to a limit of 650 MW were assumed, anticipating a possible increase from the present nominal limit of 600 MW.
- Possible worst case future periods based upon potential Heywood interconnector imports that could occur in low load periods, taking into account anticipated operational practices. These were used to explore the potential operational zones where risks could arise.

These scenarios were used to explore the anticipated incidence of risk, and the full range of potential conditions where risks may arise.

Acceptance criteria

In this analysis, the UFLS scheme is identified to be inadequate to meet the FOS requirement of maintaining frequency above 47 Hz if:

- The RoCoF exceeds 3 Hz/s, or
- Minimum frequency is below 47.6 Hz (allowing a buffer of 0.6 Hz over the requirement in the FOS).

These are the criteria that have been applied in previous reporting on UFLS functionality, such as in the 2018 PSFRR. These criteria are applied in this study to identify a 'fail' scenario, where cascading failure to system black is very likely.

AEMO has also identified potential 'risk' periods, where:

- RoCoF exceeds 2 Hz/s, or
- Minimum frequency is below 48 Hz.

These risk criteria have been introduced in addition to the 'fail' criteria above to provide a representation of the escalating risk associated with progressively more severe events. If frequency falls below 48 Hz, there is an increasing risk of complications and adverse outcomes, with many power system elements operating far outside of their normal ranges.

AEMO conducted extensive analysis in 2017 exploring the RoCoF ride-through capabilities of synchronous units and other power system elements. Consultants were engaged to conduct detailed modelling of the behaviour of specific units in South Australia to understand risks of pole slipping (losing synchronism) under high RoCoF. GE was also engaged to provide a review of all power system elements in the South Australian grid, and identify any further potential areas of risk.

The modelling found that most inverter-connected units are capable of RoCoF ride-through, successfully remaining connected up to 4 Hz/s. However, some synchronous units in South Australia were identified that may trip for RoCoF exceeding 1 Hz/s or 2 Hz/s, with higher inertia units being more vulnerable. Risks are escalated if units are operating with a leading power factor, and operating at higher loading levels.

GE's analysis identified a range of further risks that may cause generator tripping at high RoCoF, including risks of gas-fired generation tripping due to lean blow out or compressor surge. The study also advised that all synchronous units may also have potential for misbehaviour of power system stabilizers, and high RoCoF may lead to mis-operation of protective schemes.

To complement this analysis, AEMO also engaged with EirGrid, the system operator in Ireland, which has been supervising an extensive testing regime for units in its grid to determine RoCoF ride-through capabilities. Preliminary findings echoed AEMO and GE's other analysis and supported these conclusions around identified RoCoF risks.

On the basis of these findings, AEMO's assessment is that risks are likely low at RoCoF levels up to 1 Hz/s, but escalate when RoCoF exceeds 2 Hz/s, and power system cascading failure is likely at RoCoF exceeding 3 Hz/s.

If synchronous generating units are likely to trip, this reduces the probability that UFLS action will be sufficient to prevent cascading failure. This is an important risk factor that AEMO has captured in these studies through the 'risk' category, highlighting power system scenarios where RoCoF exceeds 2 Hz/s.

PV growth scenarios

For the Draft 2020 ISP, AEMO engaged the CSIRO to develop projections of possible uptake of DER in each scenario[130]. The latest installation data for DPV, which includes the period up to and including January 2020 indicates that DPV is growing significantly faster than projected in the Central scenario and at a rate closer to that projected in the High DER scenario. As of January 2020, the quantity of DPV installed in South Australia already exceeds the amount of DPV projected in the Central scenario of the ISP in 2025-26. SAPN has also advised that DPV connection applications are roughly consistent with AEMO's High DER scenario. This suggests that PV installation rates are best projected based upon the High DER scenario at present. This has therefore been used as the main basis for the analysis in this report.

The COVID-19 pandemic may slow DPV installations in the first year of the projection. However, the pandemic may also result in lower underlying demand, which could offset a slowing in PV installations, and may exacerbate some of the security challenges outlined. These effects will be taken into account in AEMO's revised forecasts.

A1.2.3 Risks identified

Reduction in net UFLS load due to distributed PV

DPV offsets a significant amount of customer load in some periods, meaning the amount of net load[131] on UFLS feeders has reduced. Table 9 shows the minimum net load levels reached on the South Australian UFLS in each year. This analysis shows that total net UFLS load reached a minimum of 99 MW in late 2019. With DPV growth continuing as per AEMO's High DER scenario from the 2020 ISP, total UFLS net load could become negative by spring 2020, and reach as low as -150 MW by spring 2021.

Table 9 Minimum UFLS net load

	Date/time	SAPN UFLS net load – all stages (MW)*	ElectraNet UFLS net load – all stages (MW)	Total UFLS net load – all stages (MW)	UFLS net load at frequency stages >48Hz (MW)**
Historical	25/12/2017 13:30	273	38	311	198
	21/10/2018 13:30	239	61	300	187
	10/11/2019 13:30	76	23	99	49
Forecast (Based on 2020 ISP High DER scenario forecasts for DPV and underlying load)	Spring 2020	-64	20 to 60	-45 to -5	-95 to -55
	Spring 2021	-165		-145 to -105	-165 to -125
	Spring 2022	-222		-200 to -160	-205 to -165
	Spring 2023	-278		-260 to -220	-245 to -205
	Spring 2024	-329		-310 to -270	-280 to -240

* Forecast SAPN values include the addition of ~100 MW of new load to the UFLS 47.6 Hz and 47.5 Hz stages, due for completion in late July 2020.
** This does not take into account possible rebalancing of UFLS stages as part of AEMO's re-optimisation of the scheme.

[130] CSIRO, Projections for small scale embedded energy technologies, June 2019, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/2019-Projections-for-Small-Scale-Embedded-Technologies-Report-by-CSIRO.pdf.

[131] Throughout this document, "net UFLS load" refers to the aggregate load measured by the network on circuits included in the UFLS. This is equivalent to the underlying load (the total load consumed by customers on that circuit), net of the DPV operating on that circuit. If the generation from DPV exceeds the underlying load, the circuit will be in reverse flows.

The proportion of load on UFLS at frequency stages above 48 Hz is also shown in Table 9; loads at frequency stages above 48 Hz assist with arresting frequency decline earlier, before frequency reaches very low levels. Stabilisation of the frequency at higher levels increases the probability of forming a stable island.

UFLS is the only available control mechanism to arrest a frequency decline in the event of a double-circuit loss of the Heywood interconnector, when the interconnector is importing into South Australia. In high PV periods where the network measured load on UFLS feeders is lowest, the interconnector is more likely to be exporting or only importing at low levels, which has reduced the incidence of high-risk periods to date. However, risks associated with increasing DPV are likely to escalate in future periods (see Section A1.2.4).

Determining the operational envelope

Figure 28 summarises the findings from SMM studies conducted, across the range of cases explored. The contingency event modelled in all cases was a double-circuit loss of the Heywood interconnector (a 'clean' separation event). Other multiple contingency events could also require UFLS response to prevent cascading failure, but have not been examined in these studies.

The studies explored UFLS outcomes in different zones of operation, across a wide range of feasible dispatch scenarios. Selected historical and projected future scenarios, and the incidence with which various risks may occur in practice are discussed in more depth in the following sections.

A SMM simulation was conducted for each dispatch interval, represented by a point on Figure 28, with:

- Red indicating 'Fail' cases where RoCoF exceeds 3 Hz/s or frequency falls below 47.6 Hz. These cases are considered likely to lead to cascading failure.
- Orange indicating 'Risk' cases where RoCoF exceeds 2 Hz/s or frequency falls below 48 Hz. These cases have some risk of cascading failure, given modelling uncertainties and power system complexities that may not be captured in those models, particularly as frequency falls below 48 Hz and far outside of normal ranges.
- Blue indicating 'Pass' cases where RoCoF is maintained below 2 Hz/s and frequency is maintained above 48 Hz. These cases are considered unlikely to lead to cascading failure, allowing for a margin that gives reasonable confidence that frequency can be contained above 47 Hz.

As shown in Figure 28, the most significant factors that influence these acceptance criteria were found to be:

- The level of Heywood imports (represented on the vertical axis).
- The total amount of net load on the UFLS scheme (represented on the horizontal axis).
- The power system inertia (the top and bottom figures compare high and low inertia levels).
- The quantity of DPV operating (the left and right figures compare high and low PV generation periods).

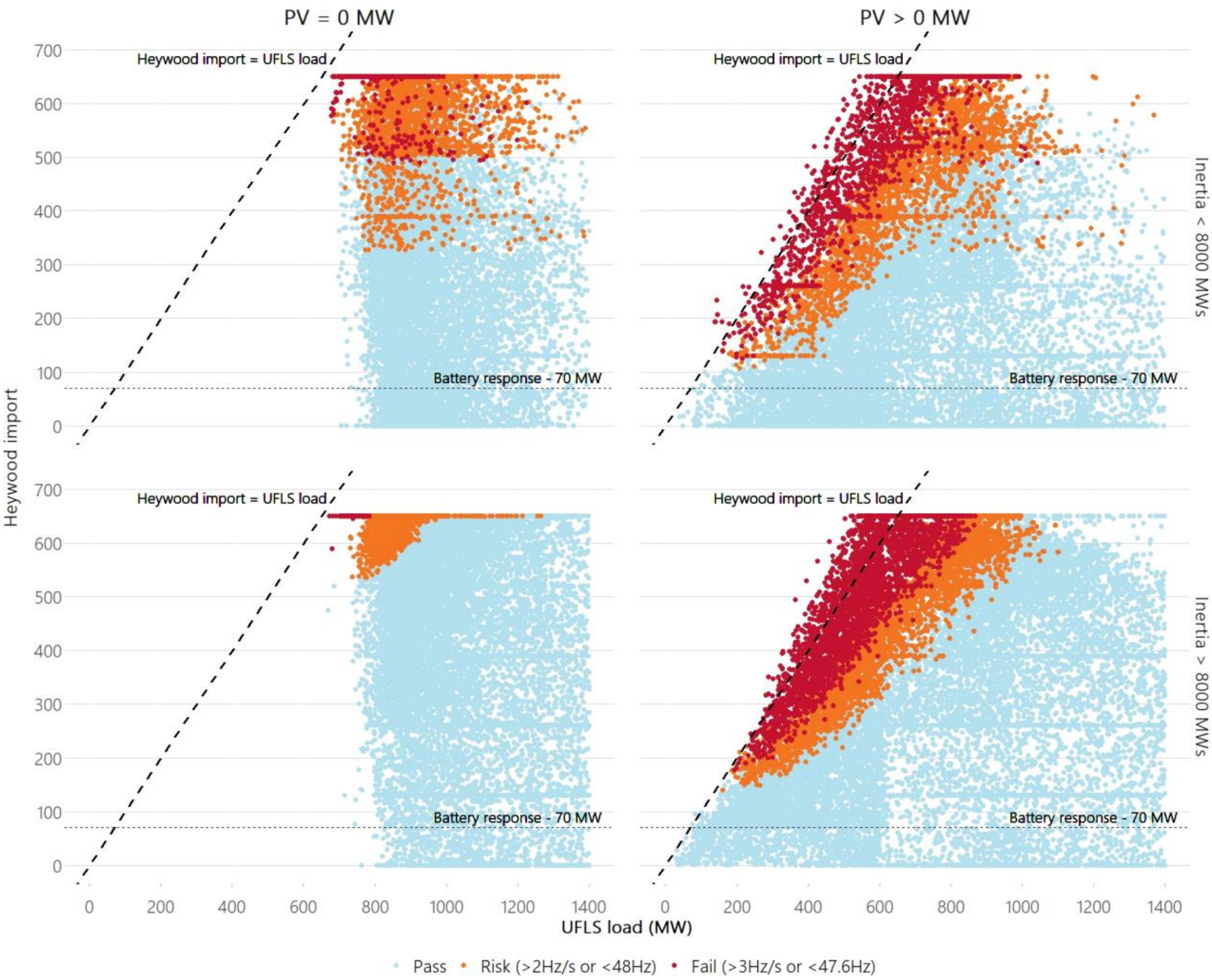
Figure 28 illustrates the zones of operation where UFLS failure is likely or possible based on these four criteria, and the following trends:

- **Heywood imports equal to UFLS load** – the dashed line represents where the total amount of UFLS net load is equal to Heywood imports. Cases above this line are likely to fail in most instances due to inadequate aggregate load available for shedding with existing UFLS schemes. This has been confirmed by the SMM studies.
- **FAPR** – the 70 MW of FAPR assumed from the Hornsdale BESS means all cases with Heywood imports below 70 MW pass all acceptance criteria. This suggests that FAPR is an effective replacement for UFLS (although it would be impractical to configure FAPR as a sole solution for a range of non-credible events). This is explored further below.
- **Periods with low DPV generation** – with low levels of DPV generation, as shown in Figure 28 on the left, total UFLS load rarely falls below ~700 MW. Some risk and fail conditions are identified even under low PV conditions.

- When inertia exceeds 8,000 MWs (Figure 28 in the bottom left), risk periods only occur when Heywood imports exceed 500 MW, in periods with low load. These periods are indicative of frequency falling below 48 Hz (but not below 47.6 Hz). It may be possible to reduce the incidence of these risk periods via rebalancing of UFLS stages.
- When inertia is less than 8,000 MWs (Figure 28 in the top left,) risk periods may occur with Heywood imports as low as 300 MW, and some possible fail conditions are identified with Heywood imports as low as 500 MW. These are primarily related to the higher RoCoF under low inertia conditions. Some of the risk periods may be mitigated by rebalancing of UFLS stages, but the appearance of fail scenarios indicates that constraints are required even in periods with low levels of DPV, to maintain Heywood imports within levels that prevent cascading failure. These constraints would primarily bind when inertia levels are low.

- **Periods with high DPV generation** – with high levels of DPV generation (Figure 28 on the right), total net UFLS load can become very low, falling to zero or becoming negative. This means risk and fail conditions appear even at very low levels of Heywood imports. Risk and then fail conditions are progressively identified as Heywood imports approach the net UFLS load available. The failure of many cases below the dashed line is related to the behaviour of DPV. The disconnection of DPV as frequency falls below 49 Hz exacerbates the under-frequency disturbance, as discussed further below. This is particularly problematic at low levels of inertia.

Figure 28 Range of SMM outcomes



* SMM study outcomes show the risk associated with non-credible clean loss of the Heywood interconnector.
* All studies shown in this Figure include the addition of ~100 MW load to the UFLS 47.5 Hz and 47.6Hz stages, due for completion in late July 2020, but do not take into account possible rebalancing of UFLS stages as part of AEMO's re-optimisation of the scheme.

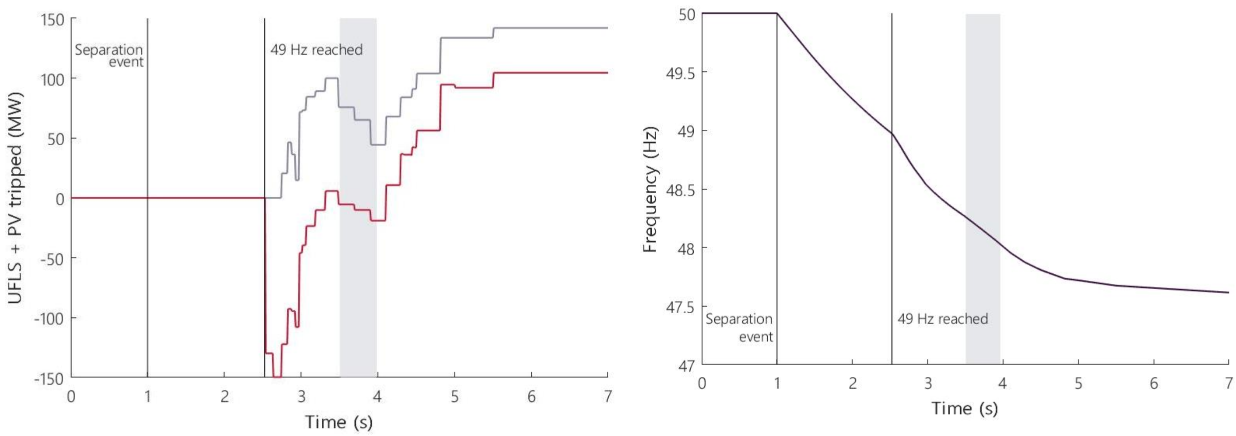
The outcomes depicted in Figure 28 illustrate the zones of operation where the UFLS scheme can be expected to arrest a frequency decline in the event of a clean separation, and the zones where it is unlikely to prevent cascading failure. This provides a basis for the development of a constraint to maintain Heywood imports at a level where UFLS functionality is robust, as discussed further in the recommendations below.

Distributed PV tripping

AEMO's survey of manufacturer settings[132] indicates that around 12% of DPV installed prior to October 2015 will disconnect within 60 ms of frequency falling below 49 Hz. This acts to exacerbate the under-frequency disturbance in scenarios with high levels of DPV generation.

As an example, Figure 29 illustrates the impact of PV tripping in a SMM study, based on an ISP forecast case in January 2023, with 1.6 GW of DPV generation and 200 MW of Heywood import. A future case has been selected to emphasise the impacts of DPV, for illustration purposes. The left panel of Figure 29 shows the total aggregate load shed by the action of UFLS relays as a function of time from the separation event, with and without the DPV that disconnects due to under-frequency trip settings. The red line provides the actual quantity of net load tripped (as seen by the power system), while the grey line provides a hypothetical quantity of net load that would have been tripped, if DPV did not disconnect on under-frequency. The right panel shows the South Australian system frequency. The separation event occurs at one second. Frequency declines and reaches 49 Hz at around 2.5 seconds. Almost immediately, approximately 150 MW of DPV generation trips off in response to the frequency decline, before UFLS relays start to activate shortly after[133]. The corresponding accelerated drop in frequency can be seen at 2.5 seconds in the right panel, exacerbated by the loss of DPV.

Figure 29 Example of UFLS operation during a period with high distributed PV generation



Assumptions: Heywood imports = 200 MW, DPV generation = 1.6 GW, inertia = 6280 MWs, UFLS load = 345 MW

The detrimental impact of DPV tripping behaviour on functionality of the UFLS highlights the importance of improving compliance of distributed resources with the 2015 standard (which requires that inverters do not disconnect until frequency reaches 47 Hz). AEMO has a program of work underway with stakeholders to develop methods for improving compliance.

UFLS stages in reverse flows

By spring 2020, with continuing growth of DPV at forecast rates, it is anticipated that more than 50% of UFLS load blocks in South Australia will be in reverse flows at certain times. This means that the action of UFLS relays to trip load blocks will act to exacerbate an under-frequency event, rather than helping to correct the disturbance. UFLS relays in South Australia do not currently have the ability to disarm when circuits are in

132 AEMO, Response of existing PV inverters to frequency disturbances, April 2016, at https://aemo.com.au/-/media/Files/PDF/Response-of-Existing-PV-Inverters-to-Frequency-Disturbances-V20.pdf.

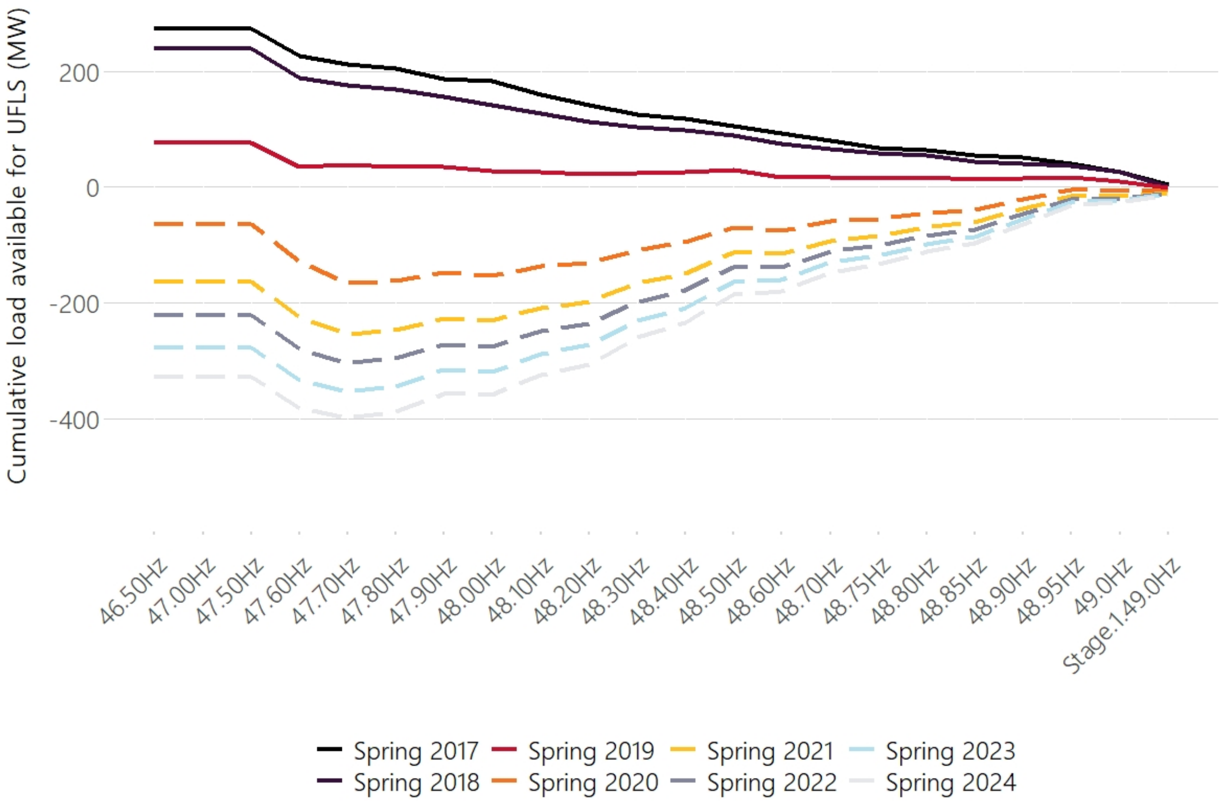
133 UFLS relays in South Australia have a trip delay time in the range 150-300 ms.

reverse flows. The operation of relays to trip UFLS stages that are in reverse flows (feeding DPV generation into the network) will act to exacerbate an under-frequency disturbance. This means that in some circumstances the UFLS will act to actively escalate a frequency disturbance, rather than helping to correct it.

The SMM study shown in Figure 29 above provides an illustration of the impacts of feeders in reverse flows. In the shaded period shown between 3.5 seconds and 4 seconds, the cumulative amount of load tripped on UFLS circuits (shown in grey) *declines* as UFLS stages in reverse flows are tripped. This, in combination with the frequency-based tripping of DPV described above, acts to further accelerate frequency decline, as seen in the right panel of Figure 29.

The aggregate load shedding profile in the lowest UFLS load period is shown in Figure 30. Load shedding profiles for 2017, 2018, and 2019 are based on historical measurements of total load in SAPN's network. Load on all UFLS frequency stages in the minimum period has reduced each year since 2017. The minimum period in 2017 was relatively severe, because a sunny day with mild temperatures occurred on Christmas Day. Conditions were milder in 2018. In spring 2019, during the minimum load period, almost half of the UFLS stages had negative net load.

Figure 30 SAPN UFLS load shedding profile in lowest period



* This load shedding profile is based only on SAPN load data, and does not include transmission connected loads. This adds an additional 20-60 MW. Forecast values include the addition of ~100 MW of new load to the UFLS 47.6Hz and 47.5Hz stages, due for completion in late July 2020.
** Historical minimum load periods illustrated occurred on 25 December 2017, 21 October 2018 and 10 November 2019.
*** Forecasts are based upon the PV growth in the 2020 ISP High DER scenario.

Based on the Draft 2020 ISP High DER forecast, by spring 2020 almost the whole UFLS profile is in reverse flows (the line trends downwards from right to left as frequency falls). Negative values in Figure 30 mean the total net load on the UFLS is negative, indicative of reverse flows on UFLS circuits. Reverse flows are projected to increase over time, as more DPV is progressively installed.

Although Figure 30 illustrates the period with the lowest net load on the UFLS, this may not represent the highest risk period with regards to separation events. The risk associated with a separation event also depends on imports on the Heywood interconnector, which may be reduced at times of very low load in

South Australia. This means the highest risk periods may occur when UFLS load is higher, and Heywood imports are also higher. The likely incidence of risk based on SMM studies of forecast dispatch scenarios is explored further in Section A1.2.4.

The effect of reverse flows can be mitigated by implementation of 'dynamic arming'. In its simplest form, dynamic arming of UFLS blocks would act to disarm frequency relays at feeders in periods where they are operating in reverse flows. This is discussed further below in the recommended actions.

Fast Active Power Response (FAPR)

Analysis shows that all cases with Heywood imports below 70 MW meet the pass criteria, regardless of the level of net load on the UFLS. This is due to the action of the Hornsdale BESS, which successfully delivers FAPR and prevents frequency from falling to the level where UFLS load blocks start to be activated (49 Hz).

The Lake Bonney BESS, the Hornsdale expansion, and any future new entrant BESS are anticipated to be capable of providing similar value. Large-scale solar farms can also provide a similar FAPR response.

However, these units need to be dispatched well below the output level determined by energy source availability in order to provide material FAPR response, and BESS must retain a suitable state of charge. This response may not therefore be available in all dispatch intervals where UFLS risks have been identified.

Furthermore, relying on BESS for FAPR may mean that BESS have limited dynamic range subsequent to a separation event, and therefore have reduced ability to deliver frequency control services and assist with frequency recovery. Contracting with market participants to dispatch appropriately to deliver minimum quantities of FAPR when required may be possible; AEMO is collaborating with ElectraNet and the South Australian Government to explore various regulatory pathways.

Further sensitivity studies will be conducted to quantify the value of FAPR and accurately take this into account in the design of mitigation strategies, as discussed in Section A1.2.5.

A1.2.4 Incidence of risk

Historical periods

As shown in Table 10, only a very small number of risk periods have occurred to date, due to the historically low probability of significant imports on the Heywood interconnector coinciding with low demand in South Australia.

Table 10 Number of historical half-hour dispatch periods showing risk

	Incidence of 'Fail' scenarios (RoCoF >3 Hz/s or f< 47.6 Hz)		Incidence of 'Risk' scenarios (RoCoF >2 Hz/s or f< 48 Hz)	
	DPV = 0 MW	DPV > 0 MW	DPV = 0 MW	DPV > 0 MW
2018	11	3	236	169
2019	13	7	95	44

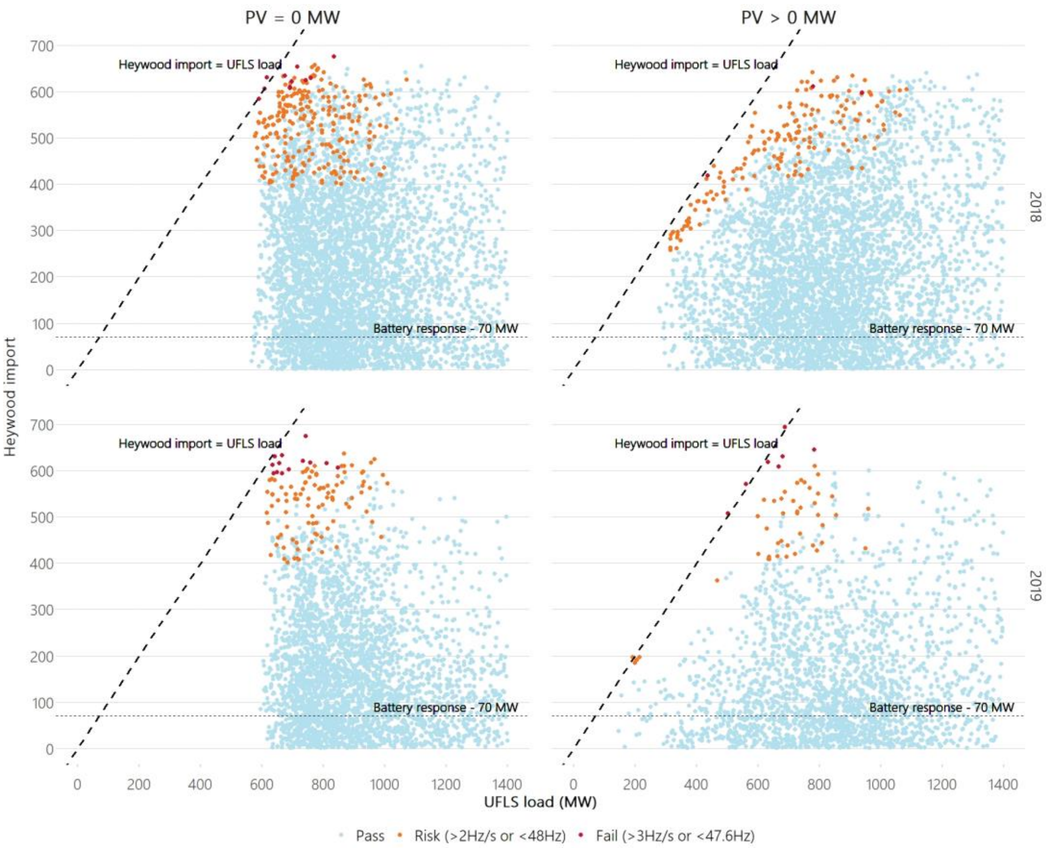
Figure 31 shows the spread of outcomes in 2018 (top) and 2019 (bottom), for low DPV periods (left) and high DPV periods (right). This reveals the following trends:

- In low PV periods (left), net UFLS load never falls below ~600 MW. Risk periods only occur at higher levels of Heywood imports (>400 MW), and 'fail' scenarios only occur at the very highest levels of Heywood imports (>600 MW). The nominal limit on Heywood in these historical periods was 600 MW, and the dispatch conditions observed in these cases represent periods where Heywood imports 'drifted' beyond this nominal limit, due to power system variables shifting within a dispatch interval[134]. In many of these periods, the Heywood interconnector is operating close to or beyond the existing 3 Hz/s constraint. High Heywood imports occur very rarely under low load conditions, minimising the incidence of risk, but have occurred in these few historical dispatch intervals.

- In high PV periods (right), net UFLS load has fallen as low as 100 MW (in 2019). Risk periods are observed with Heywood flows as low as 300 MW, but mostly occur in higher import periods. Several historical 'fail' cases are identified, in one case with Heywood imports as low as 200 MW. In this these 'fail' scenarios, total DPV generation is very high (above 880 MW). DPV is contributing to the fail outcome by reducing net UFLS load (such that the total net UFLS load is only slightly higher than Heywood imports), and also through DPV frequency-based tripping behaviour.

In all cases, the incidence of high Heywood imports is low in periods with low load and high DPV generation, which limits the incidence of risk associated with separation events.

Figure 31 UFLS outcomes in historical dispatch scenarios



* SMM study outcomes are shown for historical periods where the Heywood interconnector was importing, and show the risk associated with non-credible clean loss of the Heywood interconnector.

Risk in low PV periods

This analysis has identified that there is some risk of UFLS inadequacy to manage a separation event even in some periods with low DPV generation. In some low load periods, depending on the distribution of load on UFLS stages, frequency may fall below 48 Hz, entering the 'risk' zone, before the UFLS can arrest the frequency decline.

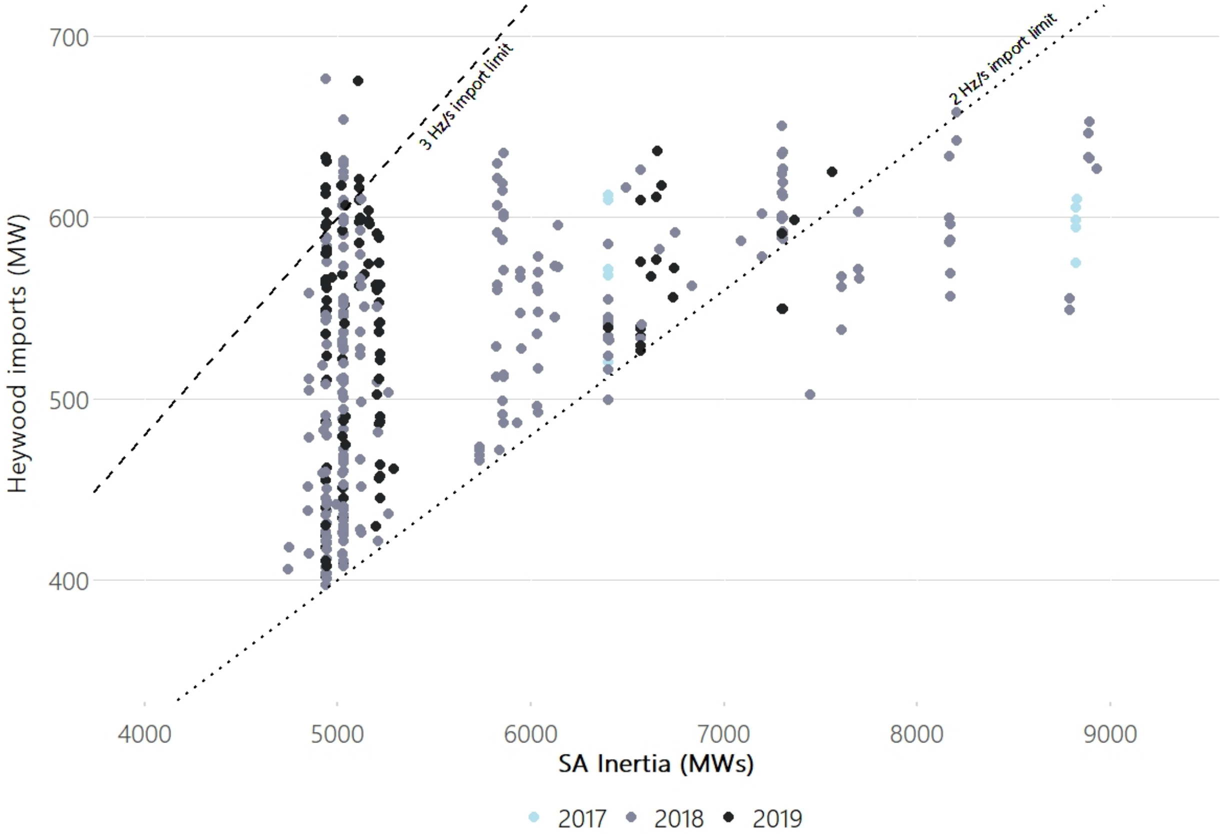
Figure 32 shows the incidence of historical risk periods with low DPV generation in 2017 (blue), 2018 (grey), and 2019 (black), as a function of Heywood imports and power system inertia. All identified risk or fail scenarios are low load periods (with total UFLS load below ~1.1 GW). When inertia was above 5,500 MWs, risk

[134] The dataset used for Heywood flows provides a 30-minute interval snapshot, rather than an average over the 30-minute period.

periods only arose when Heywood imports were high (>500 MW), and this has occurred on very few occasions historically in combination with low UFLS load. When inertia was below 5,500 MWs, risks emerged in some periods with Heywood imports as low as 400 MW.

Figure 32 includes dotted lines that indicate the zones where instantaneous RoCoF upon separation would exceed 2 Hz/s or 3 Hz/s respectively. Most of the risk or fail cases identified are associated with high RoCoF, related to low inertia and high Heywood imports. A small number of periods are identified where instantaneous RoCoF exceeds 3 Hz/s; in these periods, flows on the Heywood interconnector varied temporarily as a result of power system variables 'drifting' during a dispatch interval.

Figure 32 Historical periods with low distributed PV generation which show risk or fail outcomes in SMM studies



Incidence of risk in future periods

Table 11 shows the incidence of dispatch intervals for the Draft 2020 ISP High DER forecast which are projected to show 'risk' or 'fail' outcomes in the SMM (based on the defined acceptance criteria), for a clean separation event. Comparing with the historical periods, the following observations can be made:

- The incidence of 'fail' scenarios is projected to increase considerably from only a handful of intervals to around 1% of the time from 2021, occurring almost entirely in high PV conditions.
- The incidence of 'risk' scenarios is projected to increase from around 1-2% of the time in historical years to around 9% of the time from 2021. Risk scenarios are observed in both low PV and high PV conditions.

Table 11 Number of half-hour dispatch periods showing risk (draft 2020 ISP High DER scenario)

		Incidence of 'Fail' scenarios (RoCoF >3Hz/s or f< 47.6 Hz)		Incidence of 'Risk' scenarios (RoCoF >2Hz/s or f< 48 Hz)		Total percentage of time	
		DPV = 0 MW	DPV > 0 MW	DPV = 0 MW	DPV > 0 MW	Fail scenarios	Risk scenarios
Historical	2018	11	3	236	169	0.1%	2%
	2019	13	7	95	44	0.1%	1%
Forecast (2020 ISP High DER scenario)	2020	0	2	355	145	0.01%	3%
	2021	51	171	969	590	1%	9%
	2022	0	194	820	672	1%	9%

AEMO's draft 2020 ISP forecasts an increase in the number of periods where Heywood is importing into South Australia. The Heywood interconnector was importing 55% of the time in 2018 and 33% of the time in 2019, and this is projected to increase to 60% of the time in 2020, and 68% of the time in 2021. The incidence of periods where imports coincide with high DPV generation (>500 MW) is also projected to increase, from 4% of the time in 2018 and 2019, to around 10-14% of the time in 2020-22.

The forecast increase in the number of periods with Heywood imports is related to:

- The commissioning of synchronous condensers in South Australia, which allows fewer synchronous units to operate in South Australia in low load periods. In the ISP scenarios, the synchronous condensers are assumed to be commissioned by April 2021. Beyond this date, it is assumed that as few as two synchronous units may be operating in South Australia.
- A large number of committed wind and solar projects commissioning in Victoria (1.8 GW of new generation in Victoria by December 2021, compared to approximately 100 MW of new generation in South Australia over the same period[135]).

Many of these Heywood import periods will not be associated with a high risk of UFLS inadequacy in the event of a separation, especially if South Australian load is high, which will often coincide with Heywood imports. However, the general trend towards increasing incidence of imports does increase the incidence of risk periods.

Figure 33 shows the SMM study outcomes for future periods projected for 2020-22, illustrating the conditions under which risk conditions are anticipated to arise. In periods with low PV generation, risk arises when load is low and Heywood imports are high. In high PV periods, risks can arise even when Heywood imports are low, if Heywood imports are approaching the level of net UFLS load available.

In periods with high DPV generation, most scenarios with Heywood imports approaching the level of net UFLS load fail the acceptance criteria, even where total net UFLS load may exceed Heywood imports by 100-200 MW. This is due to the detrimental impact of DPV tripping behaviour, which significantly reduces UFLS functionality under high PV conditions.

Figure 33 only shows periods where the Heywood interconnector was importing. There are very few periods illustrated where UFLS load falls below ~200 MW. This is because the Heywood interconnector was not forecast to be importing in periods with extremely low load in South Australia. In extremely low load periods, a separation event would typically lead to an over-frequency event (rather than an under-frequency event). The operation of EFCS in periods of this type has not been studied in this analysis, but will be investigated in

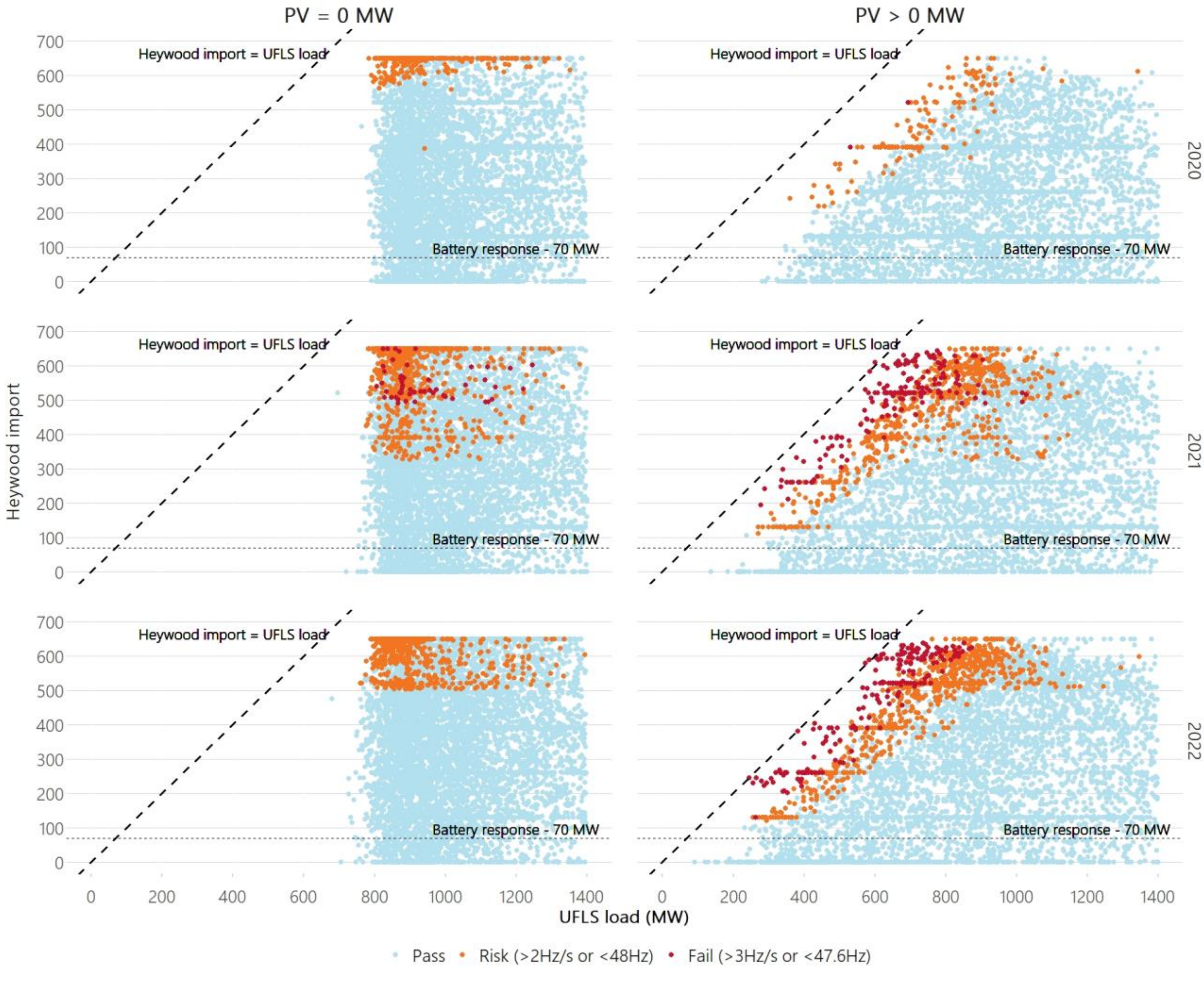
[135] AEMO, Generation Information, April 2020 update, at https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/generation_information/nem-generation-information-april-2020.xlsx?la=en.

Stage 2 of the PSFRR. Different risks may emerge in these periods related to the reduced functionality of the UFLS, and have not been captured here.

A range of forecasts are presented in the 2020 ISP. To account for possible variation in forecasts for minimum demand and DPV, AEMO compared several demand and DPV forecasts to identify their impact on Heywood import risks, as summarised in Table 12.

These sensitivities demonstrate that when demand is lower, there is a lower occurrence of periods where the Heywood interconnector is importing into South Australia. This minimises the impact of differences between sensitivities, such that the incidence of risk is similar across the various cases considered. This indicates that these findings are relatively robust to differences in forecast demand and DPV installation rates.

Figure 33 SMM outcomes for forecast periods under the 2020 ISP High DER scenario



* SMM study outcomes are shown for forecast periods where the Heywood interconnector was importing, and show the risk associated with non-credible clean loss of the Heywood interconnector.

* All studies shown in this Figure include the addition of ~100 MW load to the UFLS at the 47.5 Hz and 47.6Hz stages, due for completion in late July 2020, but do not take into account possible rebalancing of UFLS stages as part of AEMO's re-optimisation of the scheme.

Table 12 Comparison of outcomes in various demand and PV sensitivities

	Minimum demand forecast	DPV forecast	Percentage of time Heywood is importing to SA (%)	Incidence of risk and fail periods (%)
Sensitivity 1	High DER, 50% probability of exceedance (Minimum demand is moderate)	High DER	68%	10%
Sensitivity 2	High DER, 90% probability of exceedance (Minimum demand is low)	High DER	54%	8%
Sensitivity 3	Central, 90% probability of exceedance (Minimum demand is low)	Central	59%	7%

The importance of EFCSs beyond managing separation events

In addition to managing separation events, it is prudent to maintain sufficient emergency frequency response in all periods, even if the Heywood interconnector is exporting. As the South Australian power system increasingly operates in new and untested territory, the importance of effective EFCSs as the last line of defence becomes increasingly important. In the design of a new power system based on new technologies, unforeseen events should be anticipated, and plans in place for their management. This is the role of EFCSs. This means it is important to address the security risks identified, even if the security risks associated with separation events are mitigated.

Summary

AEMO's studies have identified an emerging risk that the South Australian UFLS will not be capable of arresting a frequency decline and preventing cascading failure in the event of a clean separation at the Heywood interconnector in a growing number of future periods. This is related to a number of factors, including ongoing growth in DPV (which reduces the robustness of the UFLS by reducing the net load available, and through under-frequency tripping), and the anticipated increase in imports into South Australia on the Heywood interconnector. AEMO has identified a series of remedial actions to address the identified risks. These will be further assessed as part of AEMO's submission to the Reliability Panel and development of the PSFRR stage 2 report.

Analysis has focused on South Australia to date. Similar issues are anticipated to emerge in other regions, and AEMO is working with NSPs to compile the necessary datasets and investigate these issues in other regions.

A1.2.5 Recommendations

To mitigate the identified risks, AEMO recommends the measures listed in Table 13. Many of these are underway, and were noted in AEMO's RIS Stage 1 report[136]. These are complementary measures; all will assist, but none are sufficient in isolation. Further discussion is provided below.

[136] See Appendix A – Distributed Solar PV, April 2020, at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

Table 13 Recommended measures – Improving and managing UFLS functionality in high PV periods

	Description	Implementation	Indicative completion timeline
Heywood interconnector constraint	AEMO recommends that flows on the Heywood interconnector are limited to the level where there is confidence in UFLS functionality to prevent cascading failure following a separation event. Since this relates to managing a non-credible event, AEMO cannot implement ex ante measures to manage the consequences unless it is declared as a protected event[A]. However, AEMO also needs to meet the requirements of South Australian Government Regulation 88A[B]. AEMO will implement the constraint to meet the requirements of this Regulation in the interim, and in parallel pursue a protected event declaration to formalise this under the NER. This is discussed further in the section below.	• AEMO will develop and submit to the Reliability Panel a request for declaration of this non-credible contingency event as a protected event by the end of 2020. • SAPN and ElectraNet are establishing a SCADA feed of the aggregate measured load on UFLS feeders, so that AEMO has real-time visibility of total net UFLS load. This may require improvements to SAPN's measurements in some cases, so that reverse flows are correctly included.	By late 2020
Increasing load in UFLS	Increase load in the UFLS by: • Adding loads that are not in the UFLS at present to the UFLS (maintaining appropriate balance between NEM regions) • Exploring potential to move more loads to daytime	• SAPN and the South Australia Government have identified ~100 MW load to be added to the UFLS at the 47.5 Hz and 47.6Hz stages. SAPN is implementing this at present, due for completion in late July 2020. • ElectraNet and SAPN are identifying any further loads that could be added to the UFLS via conventional technologies. SAPN has advised that even if all additional distribution connected load were added, in light load periods this would add only ~25MW to the UFLS. • AEMO is conducting studies to re-optimise the UFLS profile and settings, for implementation by SAPN and ElectraNet. • ElectraNet and SAPN will explore non-conventional options for further load to be added to UFLS. This could include considering novel options such as more granular trip devices at the customer level.	Late 2020
Dynamic arming	Progressive implementation of dynamic arming at circuits in reverse flows will slow deterioration of the UFLS and mitigate risks of UFLS acting to exacerbate a frequency disturbance. This is discussed further in the section below.	• AEMO and SAPN will determine suitable thresholds for the duration and magnitude of reverse flows before a UFLS relay will be addressed. • SAPN will monitor UFLS circuits and progressively implement dynamic arming as required. • SAPN should explore including remote communication capability to allow implementation of 'smart' dynamic arming in future (adapting load block trip frequencies in real time).	Specifications determined by late 2020

	Description	Implementation	Indicative completion timeline
Enduring frameworks	The regulatory frameworks in the NER never envisioned a power system supplied primarily by distributed generation at individual customer sites, and do not provide a clear or adequate basis for investment in the optimal solutions for the long term. Review is required. AEMO is developing concepts for a rule change proposal.	• AEMO is collaborating with network service providers to investigate possible technical options to provide effective and efficient EFCS capabilities in high DER conditions, as well as exploring development of suitable regulatory frameworks.	2020-2022

A. A protected event is a non-credible contingency that, following a declaration by the Reliability Panel, must be managed in a similar manner to credible contingencies. Protected Event declaration is intended to allow a non-credible contingency event to be managed using ex-ante operational measures, where it is economically efficient to do so, compared to leaving the event unmanaged or managed with new or modified schemes or assets. For an event to be declared a protected event, AEMO must submit a request to the Reliability Panel for review. The Reliability Panel makes the protected event declaration if it is satisfied that the benefits outweigh the costs.
B. Regulation 88A requires that Heywood flows are limited to the level that maintains Rate of Change of Frequency (RoCoF) below 3Hz/s. In the event of a cascading failure, when frequency falls below 47Hz, RoCoF will exceed 3Hz/s as the system collapses. This Regulation therefore requires that Heywood flows are maintained to the level where there is confidence that cascading failure will be avoided in the event of a non-credible coincident trip of both circuits of the Heywood interconnector.

A number of other work streams underway will also assist with addressing the identified challenges, including improving compliance with DER performance standards (reducing DPV under-frequency tripping behaviour), pursuit of increased FAPR to complement the UFLS response, and Project EnergyConnect (reducing the likelihood of separation events).

Proposed protected event

The NER power system security principles and responsibilities assume that EFCSs such as the UFLS scheme will be in place and adequate to significantly reduce the risk of cascading failure in the event of significant multiple contingency events. This is no longer the case in many periods in South Australia.

Since market start in 1998, South Australia has separated from the rest of the NEM 16 times, with six of these occurring in the past four years. Of these 16 separation events, three were 'clean' separation events[137]. This indicates that the clean double-circuit loss of the Heywood interconnector is a plausible non-credible event which has occurred on multiple occasions in the past. It would therefore be prudent and consistent with the NER for EFCSs to be sufficient to address this plausible event, and otherwise for AEMO to operate the power system with reasonable confidence that it will not lead to cascading failure and a black system.

As an interim measure while longer-term solutions are implemented to restore the capability of the UFLS scheme and other EFCSs in South Australia to adequately perform the risk mitigation role envisaged by the NER for multiple contingencies, AEMO recommends that Heywood imports are limited to the level where there is confidence that the UFLS scheme will be adequate to prevent cascading failure in the event of a non-credible separation from the rest of the NEM. Since this relates to a non-credible contingency, AEMO will apply this initially to meet the limits advice provided under South Australian regulations, and then seek to formalise this under the NER frameworks via a protected event declaration.

A constraint can be implemented rapidly[138]. From October 2020, net UFLS load in South Australia is projected to become zero or negative in some periods. With commissioning of the first two ElectraNet synchronous condensers in late 2020, and the second two in mid-2021, interconnector flows are anticipated to shift increasingly towards imports into South Australia, including sometimes in low load periods. This is projected to significantly escalate the risks associated with separation events in low load, high PV periods.

[137] A 'clean' separation is defined here as simultaneous loss of both Heywood-South East circuits, or the circuits exiting the Heywood Terminal Station.

[138] Typical implementation time for a constraint is approximately six weeks from receipt of limit advice, if the underlying limit equation is clearly defined, the necessary SCADA inputs are available, and the necessary terms in the constraint formulation are available in EMS.

SAPN and ElectraNet are establishing a SCADA feed that will provide AEMO with real-time data on the total net UFLS load available. This can be used in combination with AEMO's real-time estimates of DPV generation, power system inertia, availability of FAPR, and other relevant parameters to inform a constraint that calculates suitable Heywood limits in real time. AEMO is in the process of designing this constraint based on thousands of power system studies, seeking to maximise accuracy and minimise market impacts.

The constraint will be applied as an interim measure while longer term solutions are implemented. The incidence and extent of the constraint binding (and therefore market costs and impacts) would naturally grow over time in the absence of Project EnergyConnect, as DPV penetration increases and as Heywood starts importing more often. However, AEMO anticipates that these impacts will be reduced with the progressive implementation of the recommended complementary actions, summarised above. As described, the formulation of the constraint will account for relevant power system conditions and will be minimised through implementation of the recommended complementary actions.

If AEMO's forecasts do not eventuate, and Heywood interconnector flows do not shift towards greater imports into South Australia, then the constraint will bind very rarely, and the market costs of implementing the constraint will be very low. However, if AEMO's forecasts are accurate and Heywood flows do shift towards more imports, the constraint may bind more frequently. In this case, although the market impacts will be higher, the implementation of the constraint will be much more important, to protect against the significantly escalated risk of cascading failure in the event of a separation.

As part of the process of developing the submission to the Reliability Panel on declaration of the protected event, AEMO will also consider whether additional measures may be required to meet the FOS for a protected event in island conditions. This may involve the need for additional frequency services in South Australia to provide suitable restoration of frequency, following separation.

This protected event declaration can be reconsidered upon possible commissioning of other interconnectors such as EnergyConnect, which would considerably reduce the likelihood of separation events.

AEMO will prepare a submission to the Reliability Panel proposing that a protected event be declared, outlining options and a cost/benefit analysis. AEMO is liaising with the Reliability Panel at present, and intends to provide a formal submission by the end of 2020.

Stage 2 of the PSFRR will consider South Australian separation events in further detail, and may provide further recommendations.

Dynamic arming of UFLS feeders

Dynamic arming of UFLS blocks would act to disarm frequency relays at feeders that are operating in reverse flows. This will fully mitigate the risk of the UFLS relays acting to exacerbate a frequency disturbance[139], although it will not restore the capability of the UFLS. Even with full implementation of dynamic arming, in the long term the UFLS will not have any ability to reduce load at times of high DPV generation.

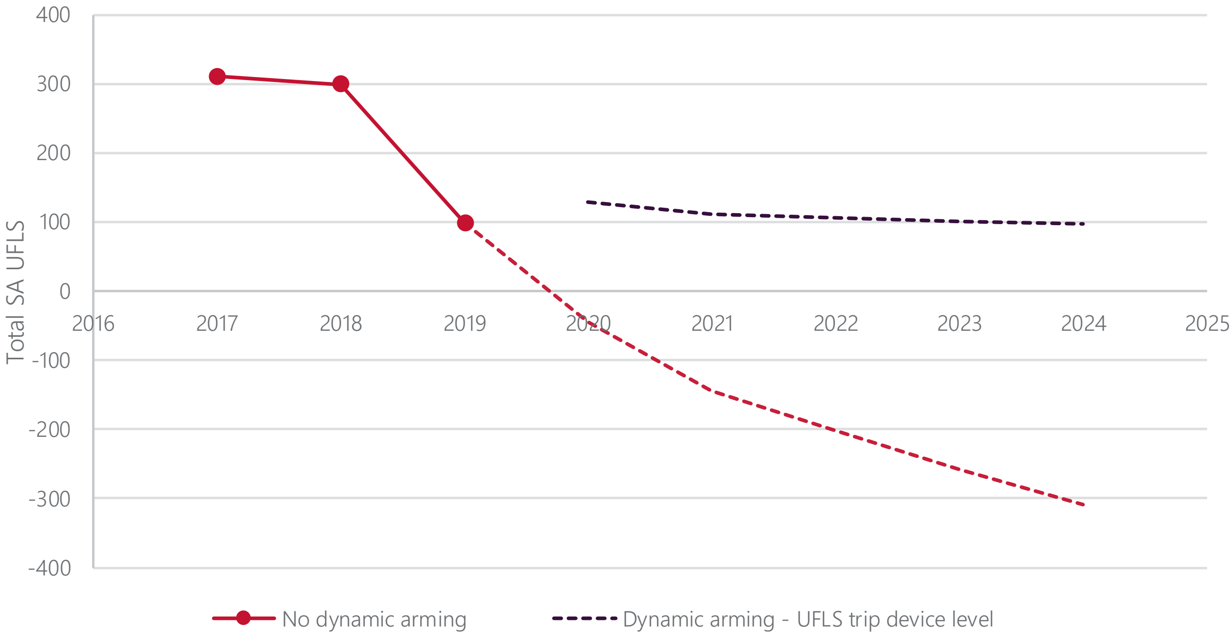
Figure 34 illustrates the benefit of dynamic arming in slowing the decline in net UFLS load. The red line illustrates the minimum level of net UFLS load reached in each year with continuing growth in DPV, without dynamic arming. The black line illustrates the same level of DPV growth, but with dynamic arming implemented on UFLS circuits that move into reverse flows (at the existing trip device level). As much as 200 MW of load could be recovered as soon as this is implemented, with the benefits increasing progressively over time. By 2024, dynamic arming is projected increase UFLS load by around 400 MW (in the lowest load period).

Extreme low load periods (such as those shown in Figure 34) are unlikely to be associated with Heywood imports, and therefore negative load on the UFLS presents a lower risk when considering only the management of separation events. However, it would be highly imprudent to allow South Australia's UFLS to approach periods with as much as 200-300 MW of reverse flows in the next few years. Under these

[139] PV tripping related to device protection settings needs to be considered in the implementation of dynamic arming. AEMO's analysis indicates that approximately 15% of DPV may trip during UFLS frequency ranges and timeframes, and can increase the generation loss following the double-circuit trip of Heywood.

conditions, any multiple contingency event that causes frequency to fall below 49 Hz could be actively escalated into a cascading failure. This poses a risk not only to South Australia, but potentially to the rest of the NEM through impacts on the NEM-wide UFLS. Introducing dynamic arming capability to South Australia's UFLS is therefore considered a 'no-regrets' action.

Figure 34 Trading Interval of lowest South Australian UFLS load, with and without dynamic arming



* DPV growth and underlying demand growth assumptions are based upon the draft 2020 ISP High DER scenario.
** Includes SAPN and ElectraNet load circuits in the UFLS

SAPN has advised that the majority of its UFLS relays cannot be reprogrammed to implement dynamic arming, and will need to be replaced if they reach reverse flows and dynamic arming is required.

Sophisticated dynamic arming that re-orders UFLS blocks in real time depending on system conditions may be beneficial to optimise UFLS functionality. In the replacement of relays, selection of a 'smart' technology should be considered, to lay the foundation for implementation of much more sophisticated algorithms. This is likely to become increasingly beneficial as load on UFLS blocks changes considerably over the course of days and seasons, and the UFLS settings for the load available can be optimised for improved functionality in real time, while minimising customer impacts. AEMO will collaborate with SAPN to determine suitable specifications.

Dynamic arming can be implemented in a staged manner, targeting locations that are measured to be in reverse flows beyond pre-defined duration and magnitude thresholds. Delaying relay replacement until it is required at each specific location will minimise costs to consumers. It will also be responsive to the actual quantity and location of customer PV installations that eventuates (independent of forecasts). AEMO will collaborate with SAPN and ElectraNet to determine suitable thresholds for the duration and magnitude of reverse flows that would trigger relay replacement. This analysis will take into account PV under-frequency tripping behaviour.

SAPN has proposed work to improve the robustness of the power system in responding to DER-related changes, including dynamic arming, in its 2020-25 regulatory proposal, as part of a contingent project[140],

[140] SA Power Networks (31 January 2019), Attachment 5, Capital Expenditure, 2020-25 Regulatory Proposal, at https://www.aer.gov.au/system/files/SAPN%20-%20Attachment%205%20-%20Capital%20expenditure%20-%20January%202019.pdf.

which has been approved by the AER[141]. AEMO will collaborate with SAPN to develop the specifications for delivery of this work, and the other work in that contingent project.

A1.3 Low load periods

In addition to analysis on the functionality of the UFLS, AEMO has conducted a preliminary investigation of the broader suite of operational challenges that may emerge under low load, high DPV generation periods[142]. These are summarised briefly in this section for completeness, and were also elaborated in AEMO's RIS Stage 1 report[143].

A1.3.1 Emerging frequency risks identified

Two areas of emerging frequency risks have been identified, as summarised below.

Disconnection of distributed PV

AEMO now has considerable evidence that many DPV inverters disconnect in response to voltage disturbances. This is demonstrated by laboratory testing[144], field measurements from DPV inverters during historical voltage disturbances occurring during 2016 to 2020[145], and high speed monitoring at selected load feeders in the distribution network[146].

AEMO used these observations to develop and calibrate dynamic power system models of DPV and load behaviour in PSS®E.

AEMO's analysis demonstrates that a severe but credible fault near the Adelaide metropolitan area could cause disconnection of up to half the DPV in the South Australian region. This could occur coincident with the sudden loss of a large generating unit, such that the disconnection of DPV increases the size of the largest credible contingency.

This has the following implications for frequency risks:

- **System normal periods** – if the Heywood interconnector is importing into South Australia, a sufficiently large generation contingency in South Australia (caused by a severe fault in the Adelaide metropolitan area under high PV conditions, co-incident with a unit trip) could lead to activation of the SIPS, and possible separation from the rest of the NEM. As discussed in Section A1.2, the UFLS has reduced robustness at times of high PV generation, and may not be sufficient to prevent cascading failure if separation occurs under these conditions. To maintain power system security and reduce the risk of separation related to a large credible loss of DPV, imports on the Heywood interconnector need to be limited in some periods. Since this represents a credible event, a preliminary constraint has been implemented, and ElectraNet is completing analysis to refine the network limit advice.
- **Operation as an island** – when South Australia is operating as an island, AEMO's studies indicate it is now almost impossible to maintain the FOS for certain credible fault events if they cause DPV disconnections. This means AEMO may no longer have the means to operate a South Australian island securely at times of

[141] AER Final Decision, SA Power Networks, Distribution Determination 2020 to 2025, June 2020, Attachment 5, Capital Expenditure, at https://www.aer.gov.au/system/files/Final%20decision%20-%20SA%20Power%20Networks%20distribution%20determination%202020-25%20-%20Attachment%205%20-%20Capital%20expenditure%20-%20June%202020.pdf.

[142] AEMO, Minimum operational demand thresholds in South Australia – Technical Report, May 2020, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2020/Minimum-Operational-Demand-Thresholds-in-South-Australia-Review.

[143] Appendix A, at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.

[144] Bench testing of individual PV inverters was conducted by UNSW Sydney as part of an ARENA funded collaboration with AEMO. Testing demonstrated that 14 out of 25 inverters tested (including a mix across both the 2005 and 2015 standards) disconnected or significantly curtailed when exposed to a 100 ms voltage sag to 50 V.

[145] For each disturbance, data from a sample of hundreds of individual DPV inverters was provided by Solar Analytics, under a joint ARENA funded project. Data was anonymised to ensure that system owner and address could not be identified. In some cases, up to 40% of inverters in a region were observed to reduce power to zero (indicative of disconnection) immediately following a voltage disturbance. PV disconnection behaviour was confirmed to be related to the severity of the voltage disturbance, and proximity to PV sites.

[146] Energy Queensland provided AEMO with high speed measurements at various load feeders. The data demonstrated apparent increases in load following significant voltage disturbances in high PV generation periods, consistent with PV disconnection behaviour.

high DPV generation. Security risks will grow rapidly as more DPV is installed, if the mitigating actions discussed below are not implemented.

Minimum load required to operate under islanded conditions

When South Australia is operating as an island, there is a need for sufficient demand to match the minimum output of the synchronous generating units needed to provide required levels of frequency control, inertia, system strength, and voltage management.

AEMO estimates that, under some conditions, the threshold level of operational demand required will be around 550 MW in late 2020 (with two synchronous condensers installed), reducing to around 450 MW from late 2021 (with four synchronous condensers installed). This level of demand allows for island operation with a subset of possible generating unit combinations, allowing for a range of operating conditions.

If South Australia needs to operate as an island under low load conditions, and cannot meet these minimum load thresholds, it may be necessary to operate without the amount of frequency control services required for secure operation.

South Australia has already experienced operational demand as low as 458 MW[147], and this is expected to reduce further by spring 2020. That means there is an urgent need to establish a back-stop that allows AEMO to shed DPV when extreme and unusual operational circumstances arise, such as the need to operate a South Australian island for an extended duration under low load conditions.

The need for generation shedding capability should be considered analogous to load shedding capability – it is a last resort mechanism used to maintain system security in exceptional circumstances. All large-scale generation output is controllable when necessary. This is now an essential capability for distributed resources, given they supply a large proportion of generation in South Australia at some times.

Generation shedding capabilities will only be required when South Australia is operating as an island, when there are unusual power system outages or other abnormal conditions, or if unexpected major load reduction occurs. If the other mitigating actions recommended are implemented, they should not need to be activated on a regular basis.

AEMO estimates that around 200-500 MW of generation shedding capability is required as a back-stop in South Australia by spring 2020, and up to 1 GW may be required as a back-stop by spring 2024 if DPV growth continues at current rates.

A1.3.2 Actions to be taken

Several of the recommended actions noted in the previous section will also assist with managing the challenges outlined here, notably:

- Improving compliance with DER performance standards.
- Commissioning of EnergyConnect to reduce the likelihood of separation.
- Increasing FAPR.

AEMO has also introduced a constraint on the Heywood interconnector, accounting for the increased maximum contingency size associated with DPV disconnection behaviour.

Two additional actions are recommended:

- **Improving DER performance standards** – improving DER performance standards limits the growth in contingency sizes associated with voltage disturbances as more DPV is installed. AEMO has initiated a review of AS/NZS4777.2 to collaboratively develop the new standards required. AEMO is also working with SAPN to introduce an accelerated requirement for voltage ride-through capabilities, to be required as a condition of connection for all new DPV in South Australia.

[147] Occurring on 10 November 2019.

- **DPV shedding capabilities** – enabling PV shedding capabilities for as much DPV as possible in South Australia will provide AEMO with essential 'back-stop' tools to manage network outages and other unusual conditions during very low load periods, and maintain sufficient units online for system security. It is anticipated that PV shedding will be enabled very rarely, and only under network outages or other abnormal conditions. SAPN is proceeding with introduction of flexible export capability as part of its regulatory determination for 2020-25, and AEMO strongly supports this program. SAPN has advised that the earliest date when these capabilities could come to fruition is 2023; stop-gap measures will be required before this time. A range of options are being explored. AEMO recommends that the following two options are pursued as a priority for implementation as soon as possible:
  - **Smart meters** – with some minor changes to specifications, smart meter functionality may provide PV shedding capabilities with minimal additional cost. AEMO is pursuing this in collaboration with Metering Coordinators and the South Australian Government.
  - **Enhanced voltage management** – SAPN has identified that introducing dynamic fine-grained voltage control capability would improve distribution voltage management and reduce customer impacts related to high voltages. As a side benefit, this also introduces the capability to improve system security via the ability to induce a temporary slight increase in voltages to cause a controlled shedding of DPV. SAPN's initial trials of this capability indicate that it is effective, safe, and has minimal customer impact. AEMO recommends that this is pursued for rollout across SAPN's network as extensively as possible, contingent on SAPN trial outcomes.

This work is already underway, and these actions were presented as part of a holistic plan for DER integration in AEMO's RIS Stage 1 report[148].

[148] See Appendix A, at https://aemo.com.au/-/media/files/major-publications/ris/2020/ris-stage-1-appendix-a.pdf?la=en.